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U.S. Army Medical Command's Medical Treatment Facilities' Response to SARS-CoV-2 (COVID-19)

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U.S. ARMY MEDICAL COMMAND'S MEDICAL TREATMENT FACILITIES' RESPONSE TO SARS-COV-2 (COVID-19)

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by
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ABSTRACT

Starting in December 2019 to the current time in May 2022, COVID-19 was a devastating pandemic with approximately 440 million cases and 6 million deaths worldwide (Centers for Disease Control and Prevention [CDC], 2021). The United States (US) with roughly 90 million cases and 1 million deaths (CDC, 2021) was one of the epicenters of the outbreak since the beginning. The pandemic has significantly impacted the health systems across the US with unpredictable surges of highly infectious patients with uncertain symptomology and acuity levels, requiring isolation and critical level of care (Brambilla et al., 2021).

Based on the findings from the available literature and case reports of the pandemic impacts and responses, it is clear that the pandemic has put unprecedented pressure on US healthcare facilities, which are not intentionally designed to respond to a pandemic of this scale. Hospitals have struggled to adapt to the increased care complexity, infection control requirements, and the sheer volume of patients (Cohen et al., 2021). The need for such adaptability in the healthcare system's has never been clearer as we have observed major deficiencies in how facilities have responded to the pandemic and how the buildings have failed to facilitate and support the required changes in spaces and operations.

In the first phase of this study, through a comprehensive literature review, a framework was developed to explore the COVID-19 pandemic from the impact and response perspectives. The effective factors and themes of the pandemic impact on patient populations and the adaptation response strategies of healthcare facilities were

analyzed to explain the role of hospital's built environment features in support of these adaptations. Themes of operational and structural challenges, the associated response strategies, and effective built environment features were identified and used as the basis for understanding the strategies addressing various pandemic challenges and requirements.

In the second phase of this study, based on the developed framework, a coding structure was developed to analyze the interview section of nine comprehensive reports of pandemic responses from military medical facilities. The reports were conducted and generously provided by the HKS (Harwood K. Smith) / WSP (Williams Sale Partnership) joint venture. The goal was to provide evidence of the challenges, adaptations, and recommendations experienced by the US Army Medical Command Medical Treatment Facilities in response to the pandemic. The themes of pandemic challenges and response strategies were extracted through a comprehensive coding procedure and the emerging concepts were compared to the framework to identify the similarities, differences, and understand the potential role of the built environment features.

Major similarities between the literature review findings and the outcome of the reports were evident after the thematic coding and analysis of the reports and the interview responses contained clear evidence of similar themes of operational and built environment concepts. The content of the participant's responses was found to be focused on three main concepts of infection control, surge capacity, and preparedness, each consisting of relevant subthemes providing more details and indicating the area of application within the hospitals' built environment.

ACKNOWLEDGMENTS

I would like to express my gratitude to my advisor Dr. Anjali Joseph. Her great insights, patience, and understanding made it possible for me to learn a great deal and come a long way from where I started at Clemson.

I would also like to appreciate David Allison's guidance and support. He generously shared his vast experience and knowledge on this topic and guided me to the most relevant sources of information along the way.

I am also grateful to have Dr. Deborah Wingler as my third committee member and Brenda McDermott as the honorary member of the committee, who generously provided the source data for this study and helped to improve the outcome by sharing their insightful feedback and guidance.

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CHAPTER ONE

INTRODUCTION

Introduction

In response to large-scale and unpredictable events with a massive number of patients and potential casualties, existing healthcare facilities' space programs, operational workflow structure, and emergency preparedness plans have been historically focused on out-of-date and unlikely measures regarding the type, prevalence, and the scale of the disasters. Previously (until the early 2000s), the discussion of sudden-onset disasters was mainly focused on natural disasters, and the preparedness measures of the facilities for contagious diseases (for instance, the isolation capability) were limited to diseases such as Tuberculosis which are not the primary concern in current times.

Recent respiratory pandemics such as severe acute respiratory syndrome (SARS) in 2002- 2004 and the ongoing COVID-19 pandemic has shifted the discussion towards the sudden onset of patients with novel (and potentially infectious) diseases (Paganini et al., 2020, Bowden et al., 2020). However, compared to the recent pandemics such as SARS, Middle East Respiratory Syndrome (MERS), and EBOLA, COVID-19 has changed the patient population more significantly in terms of its volume, contagiousness, and acuity levels. COVID-19 has far exceeded previous experiences in terms of the overall impact, and despite having relatively lower death rates, is proved to be much more contagious, involving larger populations and resulting in massive surges of infectious patients presenting in the healthcare system (CDC, 2021).

Problem statement

Compared to similar pandemic diseases, COVID-19 introduced new levels of uncertainty in terms of symptomology, acuity levels, and patient volumes, and left a long-term impact on healthcare systems, demanding reorganization of the hospitals operations and built environment (Brambilla et al., 2021).

Across the US, COVID-19 has put unprecedented pressure on the healthcare system through increased care complexity of cases, infection control challenges, and the sporadic surges of patients. This massive change in the patient populations; and accordingly, their care requirements; has emphasized the need for flexibility and capacity headroom in terms of resources, space, and staff (Cohen et al., 2021). Consequently, due to the existing rigidity of space and operations and the lack of ability to overcome various resource shortages, many hospitals across the US have struggled to appropriately respond to the pandemic (Fracas et al., 2021, Wallace et al., 2020).

Goals

The purpose of this study is to understand impact of the COVID-19 pandemic on the healthcare-built environment and identify the specific challenges, responses and adaptations made by health systems in response to the pandemic. Through further analysis of the findings, the goal is to understand the role of built environment features as potential facilitators or barriers for the employed adaptations by healthcare facilities in response to the pandemic. Understanding the role of the effective features, enabled us to develop specific design guidelines and recommendations to address the challenges that are expected to rise from similar pandemic events in the future.

The main themes of the impact, built environment responses, and the implemented adaptations are explored through an in-depth review of the literature and a secondary analysis of nine case reports of pandemic responses by US Army Medical Command Medical Treatment Facilities.

Scope of the study

The impact of the COVID-19 pandemic on various departments within the hospital is widely different. The COVID-19 pandemic has created a large population of critically ill patients who require greater testing resources, more critical levels of care, and an overall extra capacity compared to the normal patient population (Wallace et al., 2021, Uppal et al., 2020, Gopinathan et al., 2021).

During previous similar pandemics (Flu, SARS, MERS, COVID-19), due to patients' special requirements, certain departments within the hospitals required more significant changes and adaptations and tended to draw the resources and workforce from across the facility to respond to the needs of the pandemic patients. As it is evident through numerous reports from the available literature, the majority of the patients with COVID-19 (suspected or confirmed), are also expected to pass through certain departments more frequently, including the emergency department (ED), inpatient wards, Intensive Care Units (ICU), and imaging departments (Wallace et al., 2020, Martin, 2020, Uppal et al., 2020, Zhu et al., 2020). Also, depending on the physical status of the facility, in many cases, new infrastructure for testing, screening, and vaccination was implemented to provide the required capability of response.

As a result, these existing components of the hospital along with the added functions along with their surrounding spaces and their circulation paths are expected to accommodate higher degrees of change and adaptation to cope with the changes in their patient populations. Therefore, this study is primarily focused on the impacts and adaptations resulting from the pandemic within the emergency department (ED), inpatient wards, Intensive Care units, imaging departments, and the temporary add-ons and expansions that are closely connected to the main facility (such as central screening centers, pre-triage tents, testing, and vaccination).

Research questions

The key research questions that will be addressed by this study include:

- What is the impact of the pandemic in terms of changes in patient volume and characteristics in the key departments of ED, inpatient, ICU, and imaging? What are the functional facility requirements in response to these changes?
- How have the key hospital departments responded to these changes in terms of operational and built environment adaptations? What are the main themes of adaptation within each category?
- What is the role of the mechanical, electrical, and plumbing system (MEP) and architectural features of the built environment in support of these adaptations? What is the relationship between various built environment features and adaptation approaches?

Chapter guide

In chapter 2, a comprehensive literature review was conducted to understand the impact of the pandemic on the patient population, the implemented response strategies within key departments, and the role of the built environment in support of these adaptations. The peer-reviewed articles and case reports reflecting the actual pandemic experiences and case studies were used as the primary sources of the literature review. By understanding the relationship between the pandemic impact and adaptation strategies, we can define the main themes of adaptation, their drivers, their potential role in response strategies, and the application areas within the facility.

In Chapter 3, the findings of the literature review and the final framework were utilized to create the methodology of the study for analyzing healthcare facility responses to COVID-19 from the operational and built environment standpoints. The framework was used to develop various versions of coding structures to be applied and tested on three out of nine COVID-19 response evaluation reports of military medical facilities through three experimental rounds of coding to develop the final thematic coding structure compatible with the report contents.

In the initial section of Chapter 4, descriptive contextual information about the included case studies and the distribution of interview comments across the departments and cases are presented. Also, some of the military facilities' distinguishing attributes are explained to highlight the potential differences from the civilian hospitals.

In the main section, based on the final coding structure, the thematic analysis of the results of the secondary qualitative analysis of nine COVID-19 response evaluation reports of military medical facilities is included. Through the application of the coding structure in the interview section of the reports, the main themes of pandemic challenges, staff recommendations, and response strategies were redefined and described in detail.

In Chapter 5, the outcome of the qualitative analysis of the reports and framework of the main themes of response strategies from the literature review are compared to highlight the similarities and differences and generate a comprehensive and generalizable list of key themes and features. This comparison provided the context for understanding the role of the built environment features as the facilitators or barriers of the implemented and recommended adaptations from both departmental and conceptual standpoints.

The outcome of the comparative analysis is used to create a set of design guidelines, addressing the effective features to accommodate the pandemic response adaptations within the hospital buildings. These architectural and MEP design guidelines are applicable for COVID-19 and similar pandemics within the healthcare settings.

In Chapter 6, through the initial section, major points and the most prominent findings of the study are highlighted and summarized. The limitations of the study (case study analysis), the potential contributions, and future research are also presented to provide a comprehensive conclusion for the study.

CHAPTER TWO

PHASE 1: LITERATURE REVIEW

Methodology

This literature review is the final result of a comprehensive search, review, and analysis process of 75 articles and 5 white papers. The first phase of the study was based on the general idea of the COVID-19 impact and the employed response strategies in the hospitals, with a deeper focus on the implications and adaptations within the emergency department as the front line of pandemic response. After identifying the most involved components of the hospital through a preliminary analysis of the findings, in the second phase of the review, further articles addressing inpatient, ICU, and imaging departments were also added and reviewed.

Through the third phase of the literature review study, the findings were analyzed and thematically coded to define the main themes of pandemic impact and response strategies and understand the role of the built environment as a potential facilitator or barrier of the response strategies. Several case studies across the reviewed articles and case reports were identified and analyzed. In each section, the most relevant case studies are presented to provide a realistic context for the challenges, response adaptation, and the features of the built environment.

Based on the findings from the peer-reviewed articles, and the identified case studies of COVID (and other similar pandemics) responses, the framework of the study was developed. This framework, presents the main themes considering pandemic impact (patient volume and characteristics), pandemic adaptations (operational and built environment), and the associated supportive built environment features.

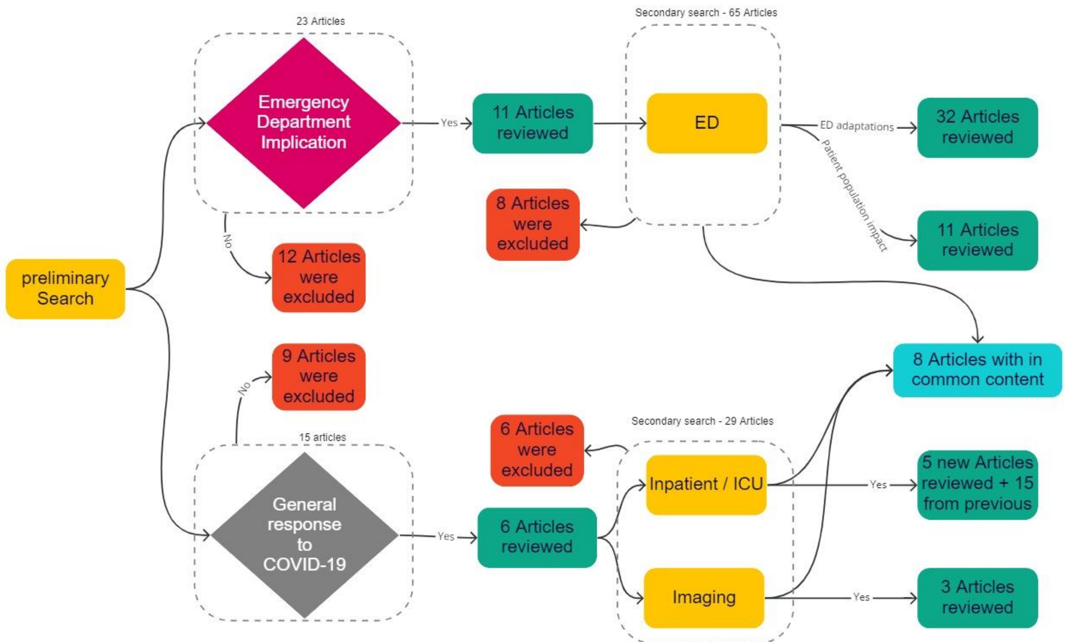


Figure 2.1. The progress of literature review search and analysis process.

Pandemic impact structure

The observed impacts of the pandemic across healthcare systems and facilities appeared significant and complex. It is rather difficult or even impossible to isolate and quantify different types of impacts in terms of their potential effects on the healthcare delivery environment, workflow, and the associated response strategies. However, considering the pandemic as the factor that brings change into the existing patient population initially, we may argue that this impact is the starting point and the source of the consequent effects, changes, and consequent adaptations in healthcare systems.

Through the course of the pandemic, a wide range of factors was found to be potentially effective in changing the patient population from various standpoints. The effective factors during the pandemic were either passive and external or active and internal (intentional strategies) concepts. Based on the preliminary analysis of the findings, we were able to differentiate between the disease characteristics, context-related, and healthcare system capacity (interventions) factors as the three sources of the impact that changed the patient population.

Disease characteristics

The COVID_19 pandemic has had a complex and variable impact on patient characteristics regarding the involved patient's demographics (age group), contagiousness, symptomology, and acuity levels. The pandemic has impacted different age groups disproportionately, with most of the patients within the 65+ age group (also being more vulnerable) and rare cases of pediatric patients with mild symptoms or being asymptomatic (Parri et al., 2020, Tan et al., 2020, Dann et al., 2020, and others).

Compared to the previous pandemics (SARS, MERS, H1N1, etc.), evidently COVID-19 virus is highly contagious and can travel long distances by air through droplets and aerosols (Nissen et al., 2020) or spread by fomites. Therefore, the infection control was particularly challenging and exacerbated by the increased patient volumes, use of shared and crowded spaces, lack of necessary protocols and resources (PPE), and most importantly, lack of appropriate isolation capabilities.

The surge of highly infectious patients in such an environment increased the chances of transmission, especially among healthcare providers (Wang et al., 2019, Burrer et al., 2020) and further strained the available capacity of the hospitals. COVID-19 also changed the expected acuity levels of the patient population rather significantly, with 25% of the cases requiring a critical level of care (Livingston, 2019, Arentz, 2020) with high possibilities of fast deterioration. A significant portion of the cases required ICU care, and therefore, more resources, staff, and equipment per case.

Compared to the baseline situation, during a disaster, the care is focused on a surge of a certain population of patients (Valipoor et al., 2020), and as mentioned, the COVID-19 pandemic has resulted in a surge of highly infectious and critically ill patients presenting to the hospitals in sporadic surges. During the pandemic, the patient volume and flow have been reportedly inconsistent across different facilities. For instance, at certain points, the overall ED volumes for non-COVID patients decreased as regular ED patients avoided presenting for fear of the disease (Cohen et al., 2021, Liu et al., 2020, Noble et al., 2020, and others), while in other cases at the same time, the ED, critical care, and inpatient capacity were significantly overwhelmed as a result of pandemic patient surges (Uppal et al., 2020).

Besides the inconsistent overall rates of patient volume across the facilities at different locations, the pandemic has shown a complex and dynamic pattern of patient surges throughout its timeline in each environment (CDC. 2021) with different patterns of increase and decrease in rates of new cases. Compared to previous respiratory outbreaks (2009 H1N1 pandemic), COVID-19 has caused a more varied flow of patients across different locations as they have experienced different “waves” of surges through the pandemic timeline, showing the potential connection between patient flow, the context environment, type of the facility, and patient allocation strategies (Rubinson et al., 2013).

Context factors

As argues in the previous paragraph, the context is potentially effective in pandemic patient volumes. The context-related factors are the attributes of the context environment that determines the impact of the pandemic on each facility through certain characteristics such as the location, local population volume and demographics, local policies, and the presence of other facilities and healthcare systems.

Generally, higher pandemic patient loads are experienced in highly populated and urban environments in which the population was confined and exposed (Uppal et al., 2020, Gopinathan et al. 2021, Cohen et al., 2021). Healthcare facilities serving vulnerable populations including those in confined like army camps, prisons, detention, or refugees camps were prone to more dramatic changes in patient flow (Liu et al., 2020, Manauis et al., 2021). New York City was a clear example of this phenomenon and was disproportionately impacted by the pandemic with a massive influx of critical cases (Uppal et al., 2020).

Besides the impact of the area population characteristics, the patient volume of the facilities is affected by the presence of neighboring facilities, local policies, and patient allocation strategies. Depending on the defined role of the hospital during the pandemic (some might be completely dedicated to COVID-19 to relieve the pressure from other neighboring facilities), the inflow of the patients, including ambulance arrivals, other facility referrals, and walk-in cases can be significantly different (Liu et al., 2020, Huddy 2020).

The patient allocation strategies, depending on the area of application (specifically the ED), may cause a continuing impact on patient volume in the response departments (as the patient passes through different steps) including the emergency care, diagnostic services, inpatient wards, and critical care units.

Healthcare system capacity

The healthcare system capacity factors includes the changes that are intentional and meant to control and balance the patient volume impact across the local network of hospitals. These changes are made by the decision-makers as active responses to the pandemic surges, having their own impact on each facility's patient load. External changes in the role of the facility, local policies, regulations, and patient distribution strategies are among the examples that were found to be effective across the literature.

For instance, the infection control regulations and protocols, and the capacity of the facility were closely interconnected. Jee et al., (2020) argue that contagious pandemics pose an extra burden on the available care capacity by adding infection control requirements to care for a surging number of infectious patients. To improve the infection control capability, conversion of most patient wards and spaces (especially for suspected and non-COVID cases inside the ED) into single bed configurations and adding regulations such as safe distancing limited the available space and bed capacity (Hu et al. 2020, Liu et al. 2020).

Besides, previously safe medical procedures were identified as aerosol inducing and required extra protective measures and dedicated spaces and equipment. This impact combined with the further shortage of staff due to nosocomial infections and the added workflow difficulty strained the available manpower and results in prolonged stays for the patients, potentially increasing the chance of infection.

The decisions that are directed toward balancing the patient load also have implications in the interdepartmental scale. Lack of enough capacity and capability at any point throughout the facility to care for the surge of critically ill and infectious patients increases the pressure on other departments. For instance, the lack of ICU units and inpatient capacity results in a backlog of patients in the ED and reception areas (which by itself increases the risk of transmission). Therefore, the capability and capacity of the facility to respond to the patients should be homogeneous among the involved departments to allow the patient population to move effectively and avoid bottlenecks.

Through these and more similar examples and experiences, we can clearly see the impact of intentional large and small scale infection control and patient allocation strategies on the final load of individual hospitals. These efforts are ideally aimed to balance the load of the patients and optimize the use of manpower and resources across the neighboring networks of facilities.

Impact and response in the involved departments

Facility adaptations for the pandemic response are primarily shaped around the path of movement of the majority of the pandemic patients through the different parts of the hospital. Depending on the arrival methods (ambulance, walk-in, other facility referrals, scheduled procedures, etc.) and acuity levels, COVID-19 patients may go through various spaces inside the building to receive different screening, diagnostic, and treatment services. The significance of the changes in patient volume and characteristics through various departments is an indication of the pandemic impact footprint within the hospital, and the identified impacts are responded accordingly through adaptation strategies to cope with the changing patient population. These adaptations are happening at various scales, from a single unit or department to interdepartmental or facility-wide strategies.

Evidently, in highly impacted areas, a significant decrease in normal outpatient visits, ED presentations (non-COVID), general inpatient admissions, and elective procedures are reported across the literature (Cohen et al., 2021, Uppal et al., 2020). This overall decline in the non-COVID patient population was simultaneous with the surge of pandemic patients (suspected or confirmed cases) that mainly required screening, testing, and treatment from the ED, inpatient, ICU (Wallace et al., 2020, Paggiani et al. 2020, Martin, 2020) and imaging (Uppal et al., 2020, Tsou et al., 2020, Zhu et al., 2020) departments. Therefore, the majority of the adaptations have been implemented in these departments in an attempt to provide the necessary care capacity and ensure safety for the majority of pandemic patients, visitors, and staff.

This section specifically aims to explore and identify the specific challenges and the associated adaptation responses within the selected departments. However, the responses to the changes in patient volume and characteristics appeared to be extremely complex and intertwined. To be able to assess these strategies clearly, we can categorize these adaptations in the different departments primarily from the operational and built environment standpoints.

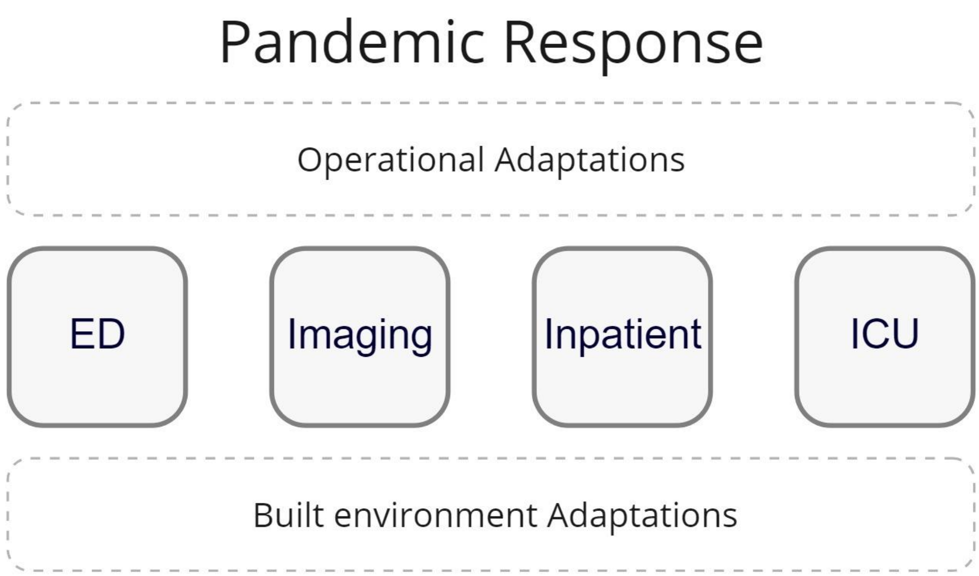


Figure 2.2. Pandemic response adaptations (operational and built environment)

In the following sections, based on the findings from the literature review, the evidence of challenges and adaptation strategies in each of the most involved departments are presented. The identified response strategies and approaches are further explored to understand the potential role of the built environment features as facilitators or barriers. At the end of each section, a summary of the findings along with the framework of themes of impact, responses, and effective built environment features are included.

Emergency Department (ED)

During large-scale pandemics, the emergency department (ED) is the main entry point and the first point of contact working as the front line of response for the care of highly infectious patients (Fracas et a., 2021, Bressan et al., 2020). Considering the vast impact of the pandemic on the ED, it is vital to provide a safe workspace and workflow to manage the flow of infectious patients from triage to discharge (Gopinathan et al., 2021). The ED is also the pivotal response space in any incident command system (Fracas et al., 2021) or contingency plans; however, during the initial phases of the COVID-19 pandemic, most EDs did not have any preparedness plans for a large-scale respiratory outbreak and struggled to extend and adapt their pre-stressed capacities (Jee et al., 2020) to match the demand. Through the reviewed literature, the following themes of challenges and response strategies were identified in the ED.

Creating surge capacity: To respond to the surge of infectious patients and overcome challenges such as the need for extra space (mainly the result of new safety measures), adding additional space to existing EDs was among the primary physical changes undertaken by various organization's decision-makers (Liu et al., 2020, Noble et al., 2020). Beside the expansion beyond the building outline, the expansions through the existing building footprint can utilize the adjacent "soft spaces" such as nearby hallways, family conference rooms, and ED offices as flex areas, which are often easily emptied and reconfigured (Paganini et al., 2020). These flex areas inside the hospital or other planned spaces need to be tested (by simulations) for their supportiveness of the required space and infrastructure (outlets, MEP support) for effective isolation, life support equipment, portable imaging, bed movements, and other procedures and equipment necessary for COVID-19 pandemic (Jee et al., 2020, Paganini et al., 2020). Lack of availability of such spaces near the ED has resulted in crowding inside the ED or utilization of distant spaces (Liu et al., 2020) which is not preferable due to higher chances of exposure (through circulation paths) and more intensive use of manpower.

Based on the findings, the ideal expansion space needs to be in close proximity, have a similar layout, and separate enter/exit doors (Paganini et al., 2020, Liu et al., 2020, Noble et al., 2020), along with the necessary MEP support outlets. Evidently, the expansions are easier to achieve in smaller EDs with orthogonal design, since achieving appropriate supervision in bigger EDs with multiple care areas is potentially more challenging (Huddy, 2016). This layout provides more flexible patient care pods within the ED (Huddy, 2016), and the possibility to create bypass paths and temporary separations of pod groups.

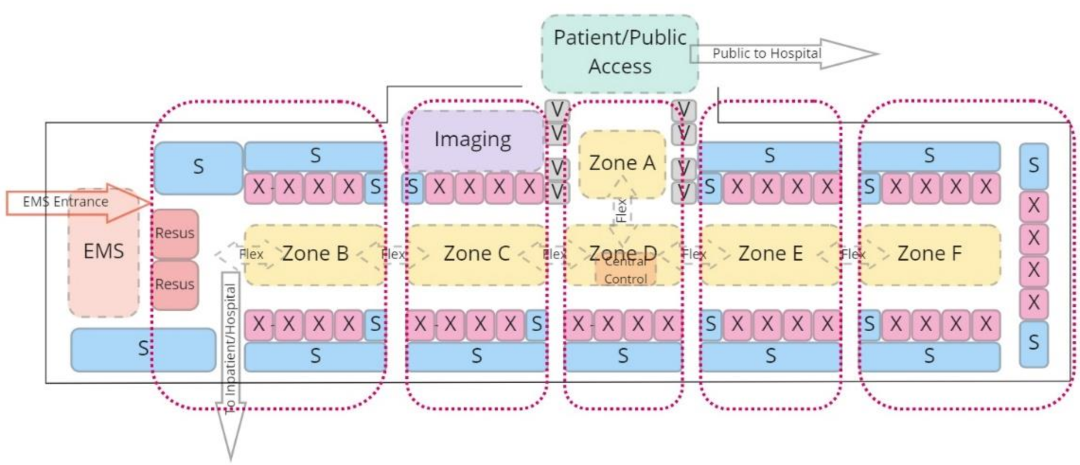


Figure 2.3. Orthogonal layout for the ED provides more flexibility with potentially segregated pods and double access paths and is preferable for expansion. (Huddy, 2016). (X: exam rooms, V: vertical care, S: support)

Infection control and isolation: EDs are traditionally open spaces, making it challenging to segregate and isolate different patient populations inside the existing space (Garcia-Castrillo et al. 2020). In previous similar outbreaks, there were experiences of super spreader events inside the ED (MERS-2015 in Korea) as a result of using shared open spaces (Chung et al. 2020). In the reviewed case study reports, certain strategies were found to improve infection control inside the ED.

Depending on the patient arrival method, to effectively control the cross-contamination, the segregation of different patient populations (and their dedicated staff teams) inside the ED was vital and needed to be supported by the structure of the ED. Therefore, the ED treatment spaces and the path of movement of patients and staff to other areas of the hospital were identified and segregated in many cases through markings on the floor, signage, partitions, or other types of barriers (Turcato et al., 2020, Zu et al. 2020, Garcia-Castrillo et al. 2020, Paganini et al. 2020).

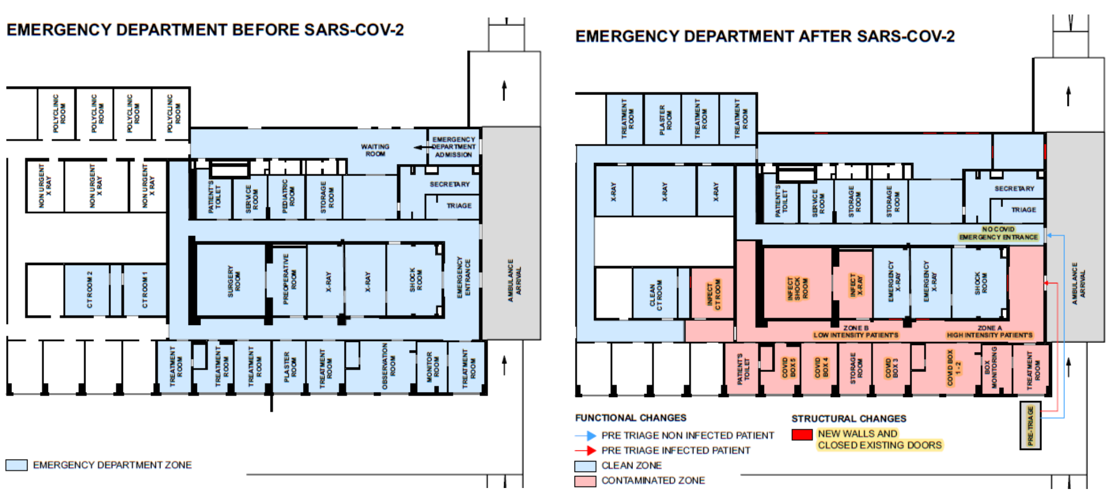


Figure 2.4. Example of segregated ED space and flow for patients and staff teams (Turcato et al., 2020).

Considering the large population of suspected patients with mild symptoms or no symptoms and the rather long testing procedures (especially during the early stages of the pandemic), traditional test-driven separation of patients into confirmed and negative populations was not feasible. Several studies have recommended the physical separation of the patient populations into confirmed, suspected, and non-COVID (clean) patients (Hu et al. 2020, Zu et al. 2020). However, providing various services for these excessively separated and isolated populations inside the ED is challenging. For instance, considering the imaging equipment, features such as mobile equipment, decentralized workstations, and separate access points provided the ability to segregate the patients effectively while having access to the necessary equipment and spaces (Tsou et al. 2020).

Therefore, depending on the pre-defined role of the ED (some might be dedicated to COVID) and its ongoing segregation strategy, providing separate access points and controlling the paths to other parts of the facility is vital. To support the flow segregation of the patients and their associated medical teams and logistics, the ED and the rest of the hospital needed to support spatial and operational segregation, enabling the staff to maintain full service.

A great example of such capability was evident in H-shaped EDs which are supposedly more suitable for the isolation of different patient populations regarding the capability of the wings to work independently from each other (figure 2.5).

Besides the overall space and flow segregation, Airborne Infection Isolation rooms (AIIR) and negative pressure isolation rooms (NPIR) have been widely desired across hospital EDs to contain individual confirmed or suspected cases. In the US, there are different regulatory requirements regarding the number of isolated rooms, their dedicated toilets, and the availability of anterooms (Huddy 2016). The Facility Guidelines Institute (FGI) requires at least 1 NPIR in the ED, which is obviously not enough during an airborne pandemic. It is generally known that the healthcare system in the United States does not have adequate isolation capacity to meet the increased needs during a major outbreak of airborne infectious disease (Johnson et al., 2009).

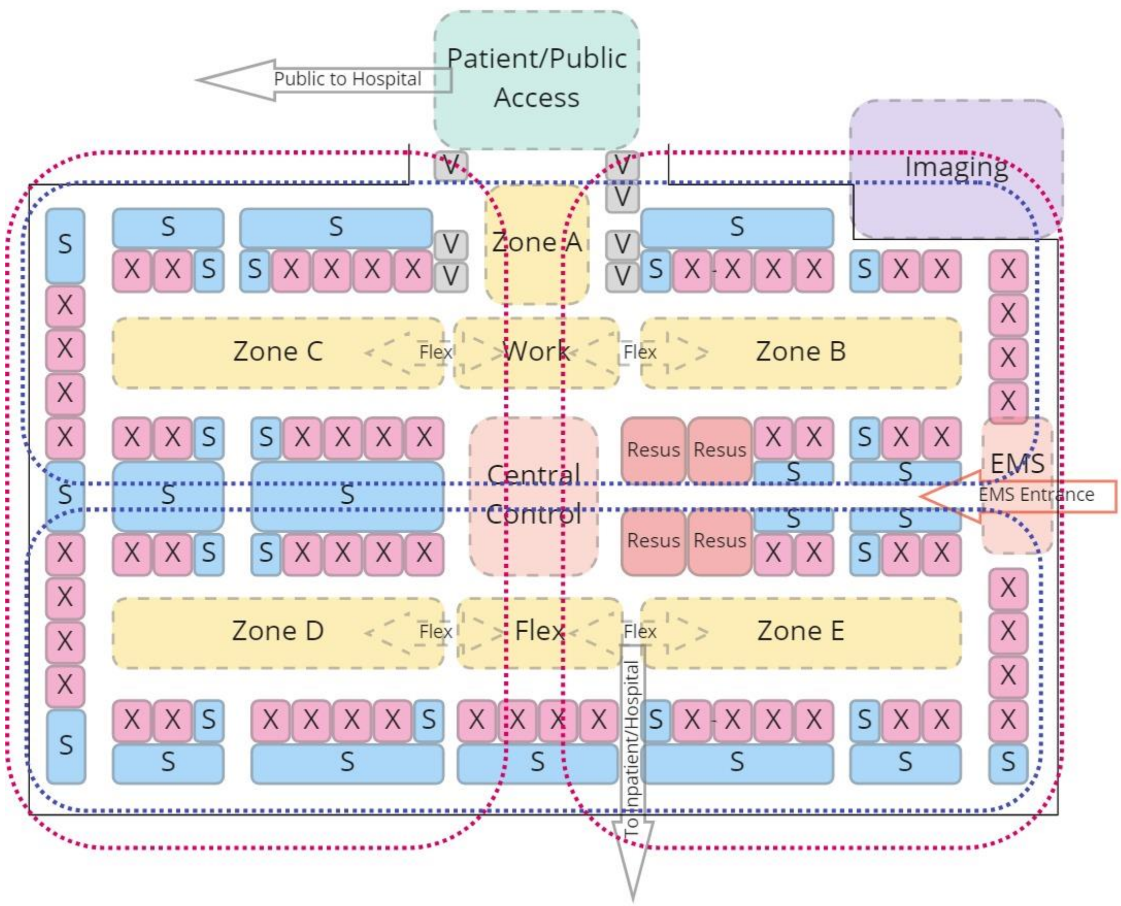


Figure 2.5. The H-shaped EDs perform better for different scenarios of spatial and operational separation (Huddy, 2016). (X: exam rooms, V: vertical care, S: support)

Triage strategies: Considering the necessity of separation and isolation of the patients, triage is the first contact point between potentially contaminated patients, the ED, and the rest of the hospital. Therefore, it is vital to segregate and isolate the suspected or confirmed COVID patients from the rest of the ED patients as soon as possible (Lim et al. 2013, Cao et al. 2020, Zhang et al. 2020, Fistera et al. 2020). During the pandemic, triage served to screen, isolate, and cohort patients as the key operational strategy to control the spread in the hospital from the outset (Turcato et al. 2020, Manauis et al. 2021, Garcia-Castrillo et al. 2020).

This early infection control measure is defined as "pre-triage" (Cho et al. 2021, Paggiani et al. 2020), segregating the patients based on the infection risk measures (Turcato et al. 2020) for different isolation spaces (Casalino et al. 2020) and criticality levels for patients requiring ambulatory, non-ambulatory, or resuscitation level of care (Liu et al. 2020).

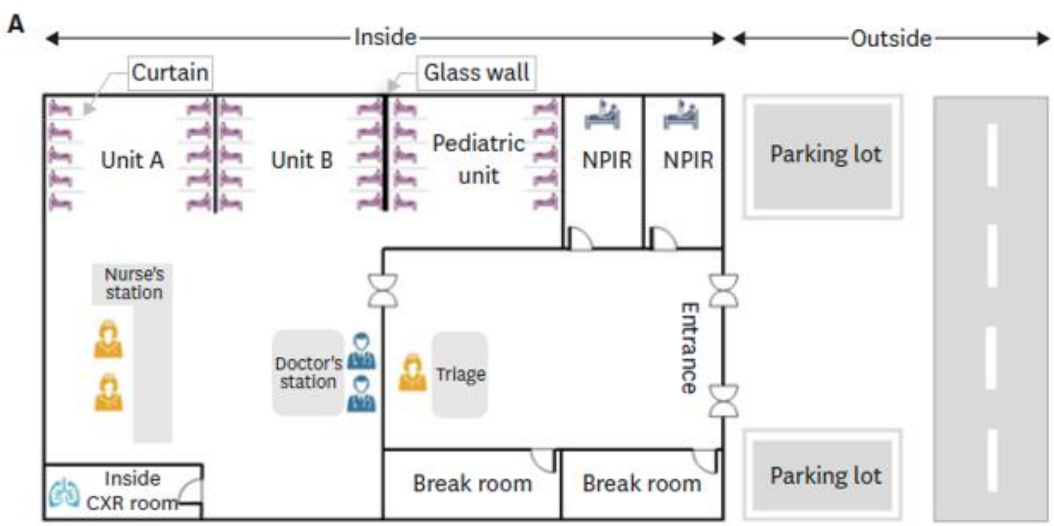


Figure 2.6. An example of pre-triage implementation outside of the main ED - pre-COVID, layout of the ED (Chung et al., 2020)

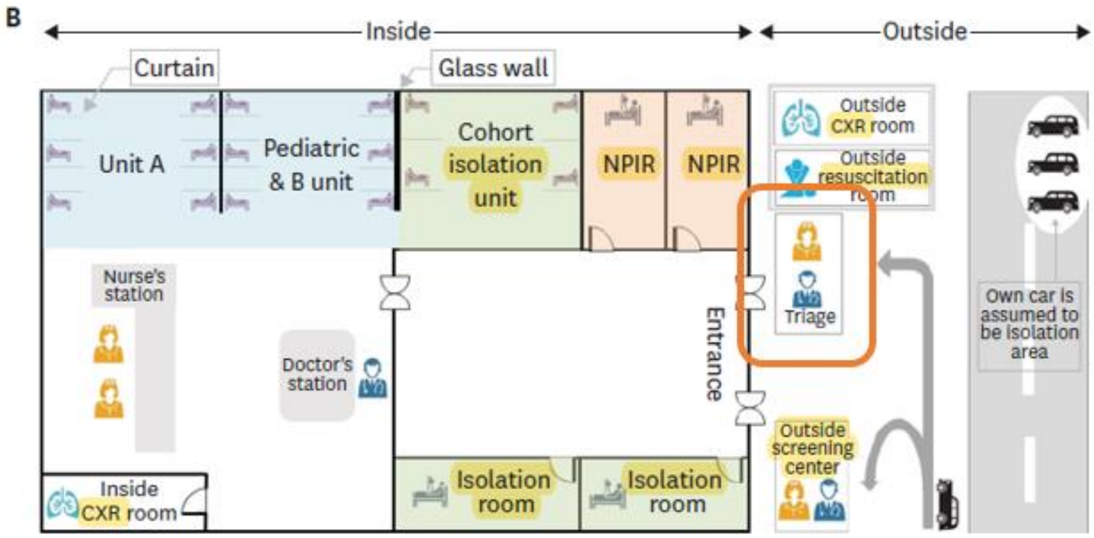


Figure 2.7. An example of pre-triage implementation outside of the main ED - Post-COVID layout of the ED (Chung et al., 2020)

This strategy along with structural adaptations can effectively limit the spread within the ED, provide a safer environment, and optimize the use of resources (Turcato et al., 2020). To be able to effectively apply the segregation from the beginning and support the pre-triage, built environment adaptations such as exterior temporary structures and reconfiguration of interior spaces were widely used among the facilities. The exterior tents and annexes were utilized in most of the cases due to the inability of the existing EDs to provide separate (or enough space) zones for COVID and non-COVID patients (Jee et el., 2020). In order to preserve the ED for higher acuity cases, generally, the exterior tents were placed right outside of the ED entrance for screening of the low acuity patients who require testing but not hospitalization (Fracas et al. 2021, Uppal et al., 2020).

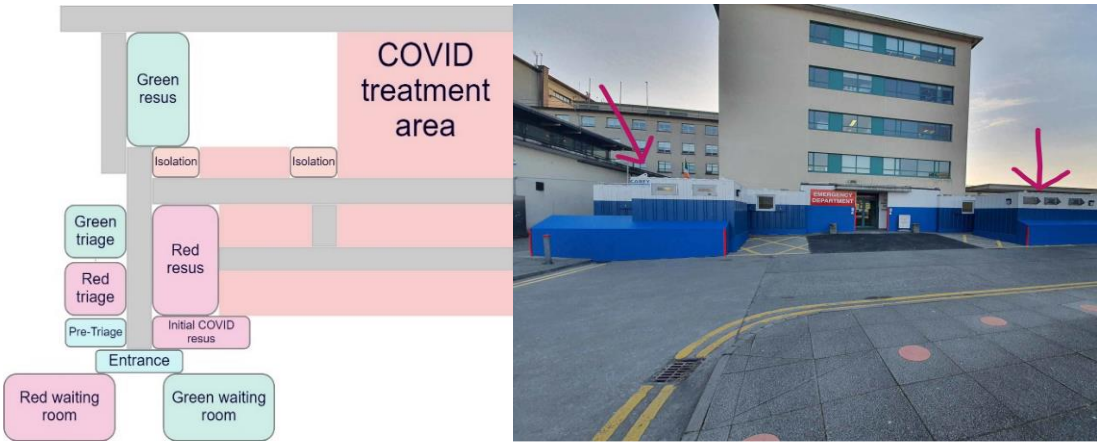


Figure 2.8. Example of exterior tents for screening and waiting area (Jee at el., 2020)

Several studies have recommended the key ED functions such as resuscitation rooms and portable X-rays to be replicated in the exterior tents and other expansions to provide independence and full segregation capabilities (Tan et al. 2020, Paganini et al. 2020, Noble et al. 2020). Based on their experience at National Centre for Infectious Diseases (NCID) in Singapore, Tsou et al. (2020) recommend restructuring the EDs to form a “fever” triage section with portable X-ray equipment embedded in the section to be able to scan the patients without bringing them physically into the ED or imaging department. Also, the exterior tent structures need to provide the necessary medical equipment support regarding oxygen, compressed medical air, and vacuum for suction (Paganini et al. 2020). Therefore, having enough open space and the necessary infrastructure available in close proximity to the entrance of the ED is an important built environment feature.

Valipoor et al. (2020) have recognized “maximizing the care area for critical patients by establishing an alternate care facility with separate entrance and exit doors from the emergency department for the least critical patients” as the most effective strategy in disaster situations and have confirmed that such facilities are recommended to mainly provide noncritical medical care either for both triage and treatment or for transferring non-life-threatening patients after being triaged in ED (Lam et al., 2006; Reilly & Markenson. 2010; Rubinson et al., 2005).

Summary of the findings: Based on the findings across the literature, the ED has a vital role in the overall pandemic response structure working as the front line of response, the first point of contact, and the primary entry point. The EDs are primarily responsible for the screening and testing of the surges of suspected patients and need to accommodate a large number of uncertain cases. However, the literature provided evidence of the EDs widespread lack of pandemic contingency plans, while working near or beyond their capacity (pre-stressed system) during normal times.

The EDs are further challenged by sporadic surges of pandemic patients through different arrival methods, presenting uncertain symptomology, various acuity levels, and of course, being highly infectious. Across the reviewed case studies, operational adaptation strategies including extra screening and testing, patient/staff/resources segregation, pre-triage, intensive PPE protocols, and cross-training are found to be effective. On the built environment side, airflow adjustments (pressurization), external and internal expansions, temporary partitioning, and various layout modification strategies (zipper walls, partitioning, etc.) were implemented.

In the diagram below, the main concepts of the ED's departmental attributes (effective in COVID response), role, challenges, adaptations, and the potentially supportive built environment features are summarized. This diagram is the result of thematic analysis of the literature review based on the final framework.

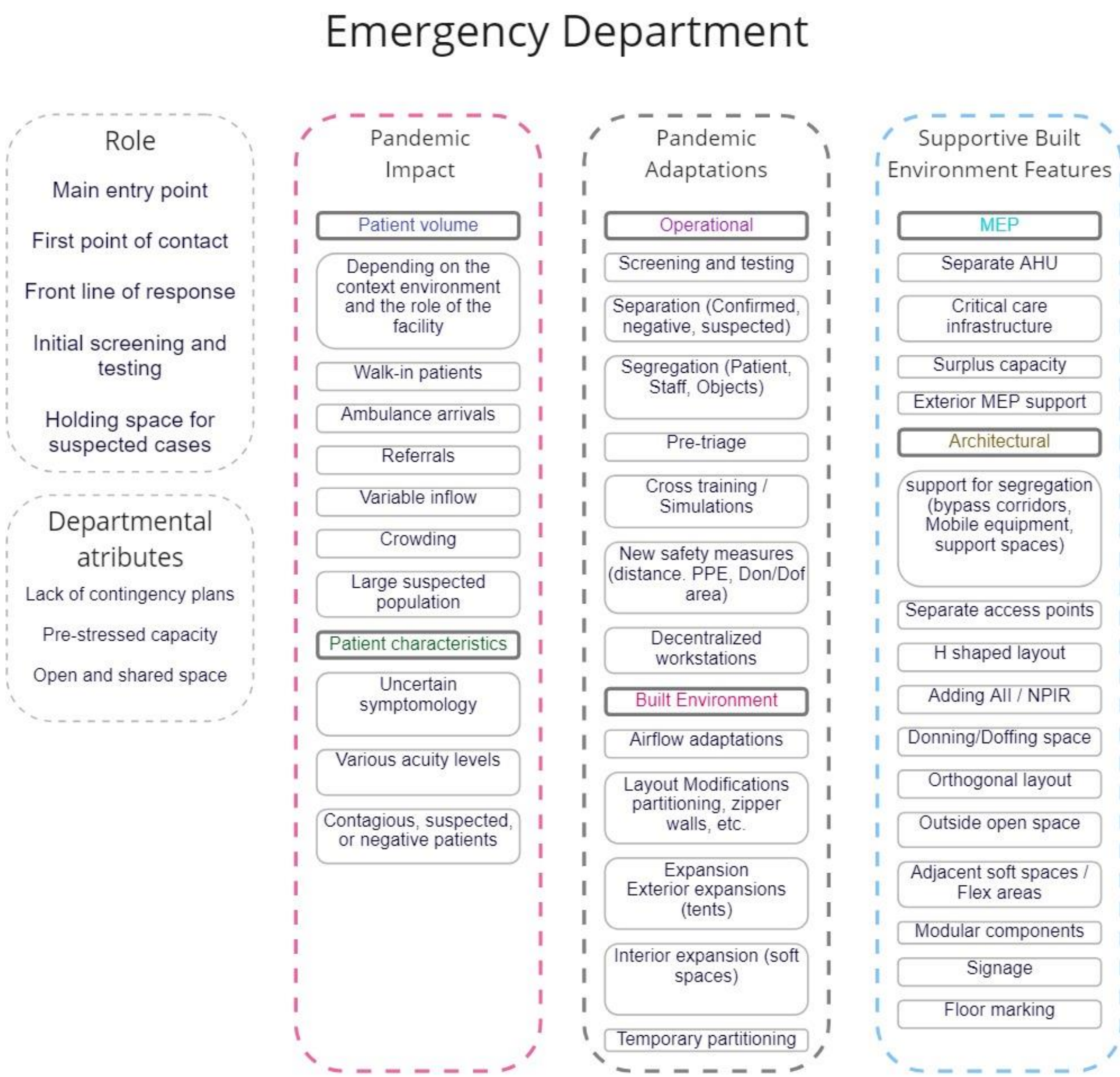


Figure 2.9. ED diagram of departmental attributes, role, challenges, adaptations, and the supportive built environment features.

Inpatient wards

Within the inpatient department, based on the patient's status, further separation is required. In the Med/surge units, ICUs, and also across other types of wards, the biggest requirement is the ability to separate and isolate the COVID-19 patients from the suspected and negative cases. This separation was achieved through various approaches depending on the physical features of the wards, the number of patients, and the role of each particular ward. Based on the findings across the literature, the spatial, airflow, supply/equipment, and team segregation are among the necessary components to achieve true separation between the infected and healthy patient populations inside the inpatient wards similar to critical care units.

Spatial separation: The spatial separation of patients can be achieved through different scales of interventions. In some cases, the entire facility and building were dedicated to COVID-19 while in other cases, departments, floors, entire wards, or segments of the existing wards were dedicated to the COVID-19 positive patients (Chen et al., 2020). However, the most effective practice is to spatially separate the negative patients, positive patients, and suspected cases as three separate groups (the suspected cases are temporary until their test results arrive). This approach was repeatedly considered as the most effective method, specifically for the suspected patients which could share the spaces with others. Also, three-group separation allows for optimized use of PPE in each section for staff team modules (Turcato et al., 2020) and use of separately shared spaces and units for negative and positive patients.

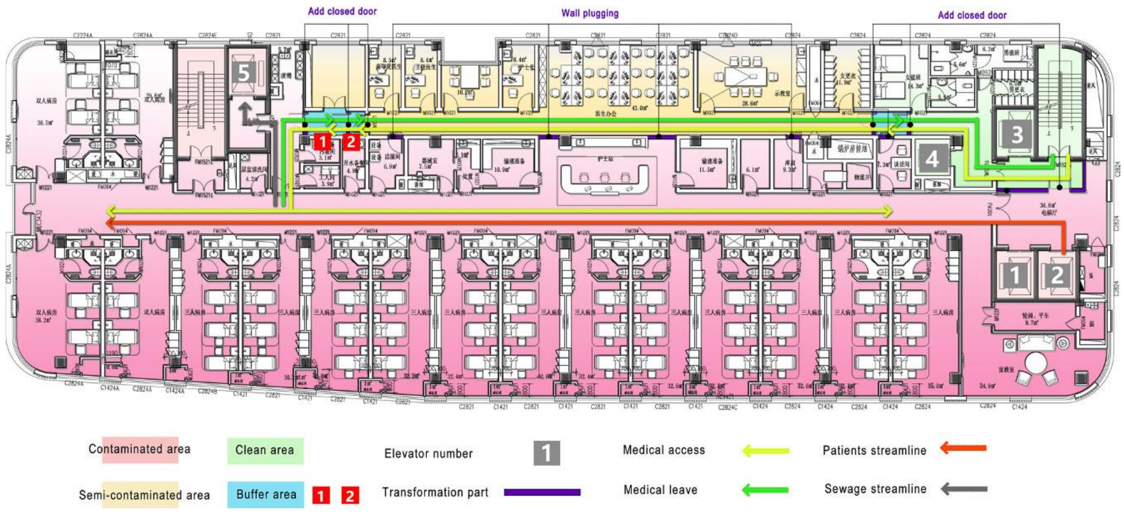


Figure 2.10. An example of flow and spatial segregation in inpatient wards. Special considerations for providing vertical access to both areas are evident through the layout. Also, segregated support areas eliminate the need for excessive use of PPE (Chen et al., 2020).

Team separation: To support the separated patient populations in different spaces, the care provider teams also need to be modularized and provide care without increasing the risk of cross-contamination between the staff and patients (Tan et al., 2020, Tsou et al., 2020). The segregation of staff teams was one of the main operational adaptations specific to the pandemic aiming to reduce the chance of transmission through the staff. This approach also indicates the need for further built environment and logistical adaptations to support the significantly different workflow of segregated team modules. Tsou et al. (2020) explain the logic of team segregation based on three key points including, providing continuity of care during the pandemic (potentially for normal patient population), reducing the chance of department shut down due to infection, and having a more resilient workforce in the event of one team getting infected and isolated.

Airflow separation: COVID-19 is an airborne disease and controlling the flow of contaminated air through the hospital is vital to prevent cross contamination. Despite the general ability of facilities to provide physically separate areas inside the building, most hospitals have struggled to also support separated airflows as they have overlooked the need to build in the required capabilities due to cost constraints (Huddy, 2020).

Lack of capability to separate the airflow in some facilities has reportedly forced the decision makers to limit the use or shut down the whole air handling system (Chen et al. 2020) to avoid transmission through the air distribution ducts. Features such as separate air handling units, Ultraviolet (UV) treatment for exhaust air, and single-pass airflow without recirculation are effective to supply clean air separately to different areas with filtration and limit the chance of cross-contamination (Tsou et al., 2020).

In an experimental adaptation project by Miller et al. (2017), a complete ward (floor) was turned into a negative pressured space with temporary installations. However, having structural features such as "dedicated air handling unit (AHU), dedicated bathroom exhaust system, separate dedicated exhaust system for return registers in existing isolation rooms (ISRs), and a firewall separating the ward from the rest of the hospital" was deemed effective to achieve true airflow separation capability.

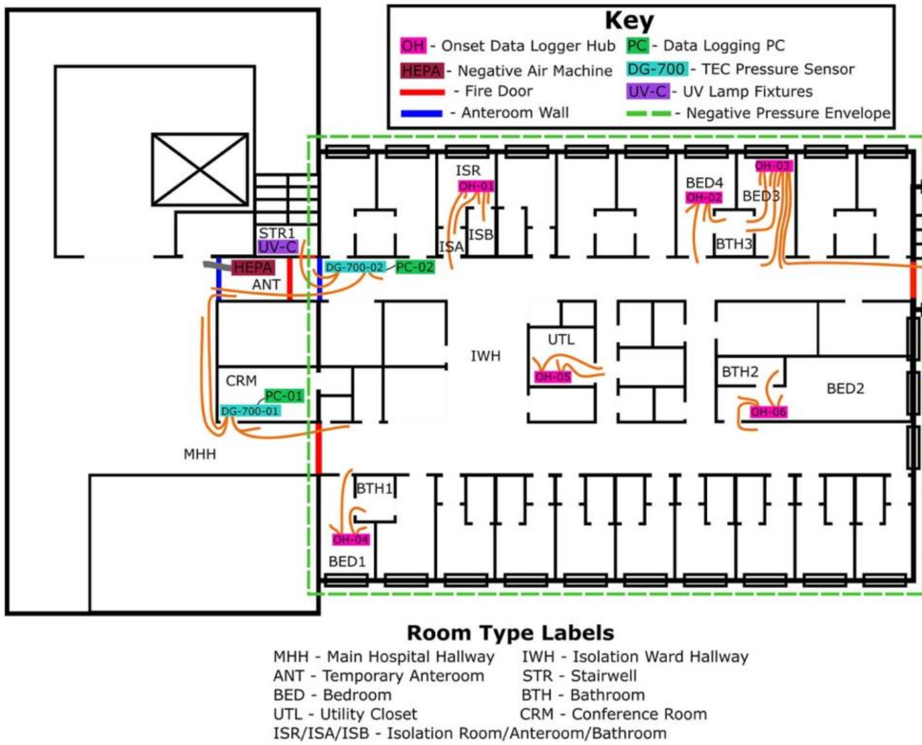


Figure 2.11. A negatively pressured isolation ward created with temporary installations (Miller et al., 2017)

Besides the shared space physical, operational, and airflow segregation, Airborne Infection Isolation units (AII) and Negative Pressured Isolation Rooms (NPIR) are the two most common solutions for the spaces required to segregate individuals from the rest of the ward space. Johnson et al. (2009) recommends the use of negative pressure and anteroom entrance for these spaces to effectively isolate infectious patients. As mentioned previously, US hospitals are generally underserved in this regard and are in the need of extra temporary and dedicated AII/NPIRs for the flexibility in air pressure for the normal patient rooms. This need is immediate and obvious as many of them have reportedly tried to replicate the same capability by temporary solutions and DIY type of interventions.

Surge capacity: Depending on the degree of involvement and the role of the hospital, some facilities were required to significantly increase their inpatient capacities as they were expected to respond to a large population of patients during the pandemic. However, this capability was limited by the physical and operational features of the inpatient wards such as available medical gas and electrical outlets, enough space (soft adjacent spaces), equipment, and manpower in each hospital.

As an example of successfully adding pandemic surge capacity expansion, the National Centre for Infectious Diseases (NCID) screening center (SC) in Singapore is a purpose-built facility to respond to pandemics of various scales equipped with negatively pressured isolation rooms, procedure rooms, imaging units, and dedicated pharmacies. Over the course of the pandemic, the NCID-SC increased its capacity from 330 to 586 beds (Manauis et al., 2021), changing the layout of the inpatient units (by utilizing an adjustable wall system) to provide an isolated environment for an increased number of contagious patients.

In the figure below, we can see different configurations that were possible to achieve within the same space at NCID. However, this process proved to be labor and time-intensive and resulted in a 6-week shut-down during the pandemic which is unacceptable. Therefore, the cost and time should be minimized in suggested solutions for major interventions and adaptations, since the pandemic is a dynamic and fast changing phenomenon, requiring the changes to happen in much faster paces than usual practice. Based on the experience from these case studies, we can argue that flexibility both in terms of scale and functionality of hospital ward units is a necessity.

Figure 2.12 the transformation of the NCID inpatient units to expand the capacity and provide isolation capabilities (Soh, 2020)

Intensive Care Units (ICU)

The considerations for infection control, and more importantly, building surge capacity are more critical for the intensive care units since these units have an inherently limited capacity (compared to what critical capacity is needed for COVID-19 pandemic) and a more vulnerable patient population. Surprisingly, worldwide, 25% of COVID-19 patients have required critical care resources which is very significant considering the overall number of patients (millions of cases) (Livingston, 2019, Arentz, 2020). To cope with the extraordinary number of critical cases, in highly populated areas, some entire hospitals were transformed into one large ICU, allocating all the available spaces and resources into critical care (Uppal et al., 2020).

The overwhelming surge of critical patients required a vast increase in such capacity, to an extent that even the ED dedicated critical care rooms were reconfigured into ICUs (Uppal et al., 2020). The added ICU spaces for COVID-19 patients require power supply and the necessary outlets with backup generators, oxygen line, in-room monitors with remote capability, and an isolated controlled airflow (Uppal et al., 2020).

Considering the sensitivity of other ICU patients, it might be not feasible to admit COVID patients to the same ICU unless there are sufficient and standard AII/NPIR rooms available. To overcome this issue, in many cases, extra operation rooms (available as a result of the cancellation of elective procedures), and isolation rooms were transformed into ICUs (Schoeffl et al., 2021). This has become challenging regarding the need for ORs to be functional, the limited space inside normal patient rooms considering the need for extra equipment and people for critical care delivery.

Summary of the findings: The case studies and reports across the reviewed literature explained the role of the inpatients wards to be flexible and different depending on the defined role of the department, wards, and units within the hospital. There are cases of dedicated COVID isolation wards, shared wards (between COVID and non-COVID), and dedicated units supporting the pandemic patients.

Within the various configurations of inpatient wards, there is a broad range of common attributes affecting the COVID response capabilities, including the limited isolation capacity, lack of airflow segregation capability, and in some cases, limited bed capacity. Also, the impact of context environment and local patient allocation strategies are effective in determining the final patient load and function of the inpatient wards. As most of the admitted COVID patients are transferred from the ED, the same themes of patient volume and characteristics (minus the uncertainty of patient status) are present at the inpatient department. Also, as a result of COVID-19 symptomology, faster deteriorations, higher acuity levels, need for respiratory equipment, and need for diagnostic (mobile) imaging are expected within the wards.

The response of the inpatient wards from an operational standpoint includes further segregation of patient, staff, resources (and potentially visitors). Moreover, considering the probable interdepartmental movements of the patients (between ED, inpatient, ICU, and imaging), the flow of the aforementioned groups is also segregated. Considering the certainty of patient's status (positive, negative) within the wards, more selective use of PPE was mentioned in the case reports. From the built environment point of view, spatial segregation through temporary and permanent solutions such as zipper walls, partitioning, and division of patient rooms (NCID case) are reported. Also, various strategies to segregate the airflow, and provide temporary negative pressured isolation units and rooms are successfully experienced. In the diagram below, the main concepts of Inpatient/ICU departmental attributes (effective in COVID response), role, challenges, adaptations, and the potentially supportive built environment features are summarized:

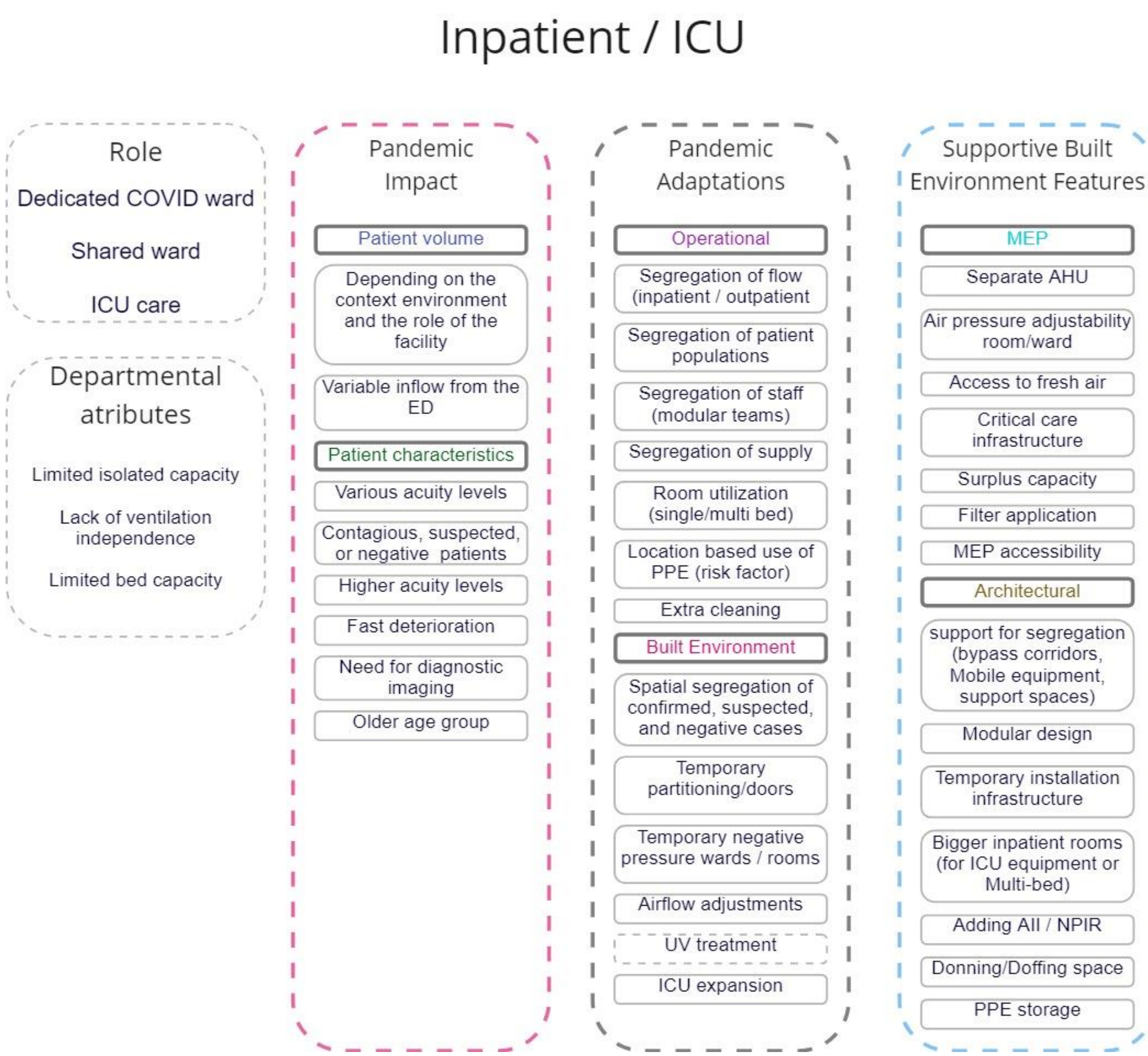


Figure 2.13. Inpatient/ICU diagram of departmental attributes, role, challenges, adaptations, and the supportive built environment features.

Imaging department

COVID-19 diagnostic procedure is heavily dependent on the imaging equipment and has forced a significant burden on the imaging department and staff. One of the ongoing issues in COVID-19 diagnostic practice was the excessive utilization of the imaging modalities and spaces for testing and diagnostic procedures. Chest radiography and computed tomography (CT) was the key techniques of fast screening and diagnostic procedures for the suspected COVID-19 cases (Tsou et al. 2020). During the initial phases of the pandemic, because of the lack of fast testing techniques, the use of imaging devices (results available in minutes) had a huge advantage over the chemical testing methods (taking up to 2 days for polymerase chain reaction (PCR) testing) (Zu et al. 2020).

However, according to Parri et al. 2020, the pneumonia-driven classification of patients with imaging techniques led to the overutilization of imaging modalities, increasing the risk of transmission (Zu et al. 2020), and excessive use of resources (Tsou et al. 2020). The logistics and time requirements for scanning the suspected or positive patients are tremendous as it makes the CT machine unavailable for several hours for disinfection (Tsou et al. 2020). Therefore, clinical classification of the patients rather than radiologic approach is a more resourceful and realistic approach.

Infection control: To contain the infection, as far as possible, imaging procedures should be done outside of the imaging department (Tsou et al. 2020) or within the dedicated space. In order to minimize the risk of spread while transferring the patients and the shared use of imaging spaces, use of mobile imaging devices (CT or X-Ray) should be considered in key spaces (Tsou et al. 2020, Zu et al. 2020), enabling the potentially isolated zones to conduct the diagnosis without the need of transferring the patient through shared corridors and imaging units. Chung et al. (2020) has reported the effectiveness of externally located imaging units in early isolation and containment of infectious patients.

Access to the imaging modalities can be also achieved through adjacent departments with CT, C-arms (operation rooms), and portable radiology devices located in different areas of the hospital. The proximity and secure (potentially isolated or bypassed) transfer paths to the ED and inpatient department are the key features for an effective pandemic response (Tsou et al. 2020).

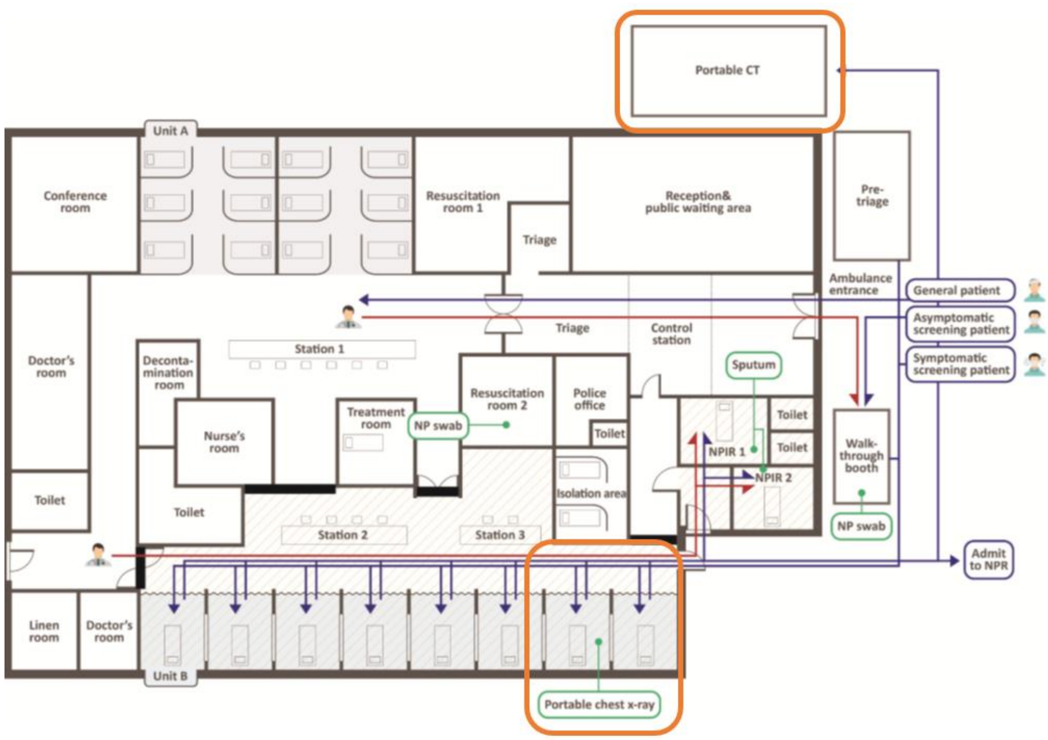


Figure 2.14. An example use of exterior mobile CT and X-ray units to limit the patient transfer inside the building, Cho et al. (2021).

In the diagram below, the main concepts of Imaging departmental features (effective in COVID response), role, challenges, adaptations, and the potentially supportive built environment features are summarized:

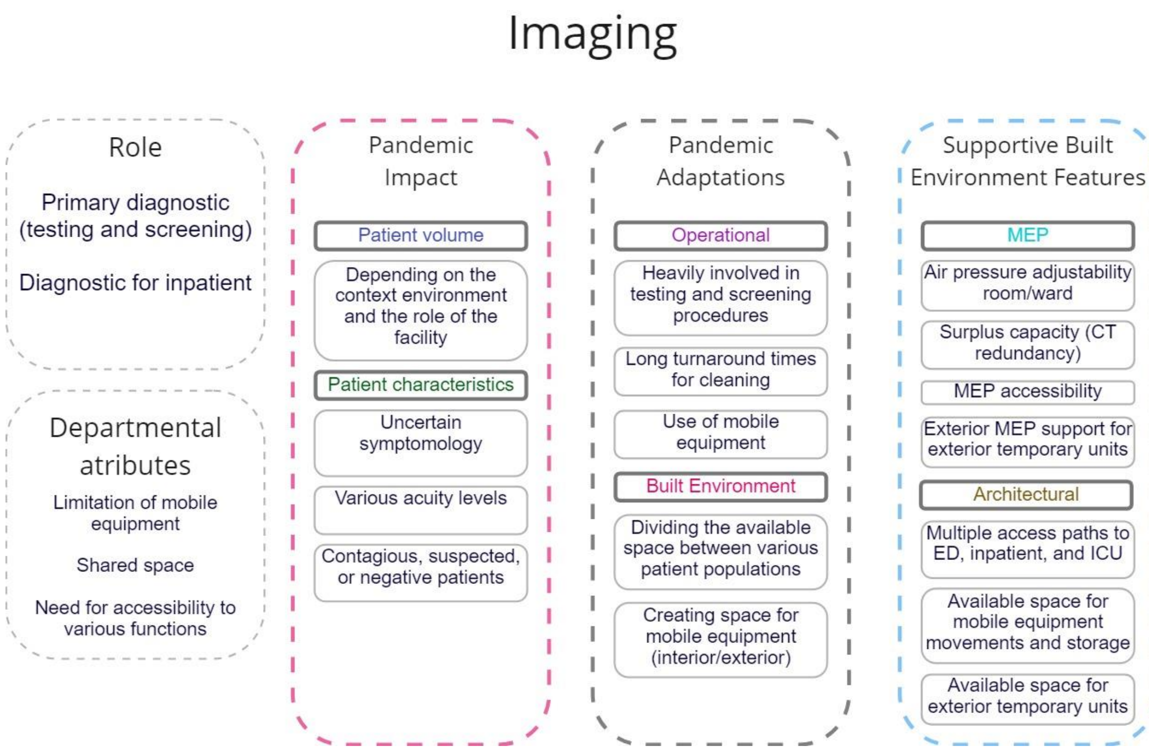


Figure 2.15. Imaging diagram of departmental features, role, challenges, adaptations, and the supportive built environment features.

Framework of the study

The key departments impacted during the pandemic were closely interrelated as the same patients may pass through each and every one of them during their stay at the hospital. Therefore, challenges related to the patient volume and characteristics would be applied through all of the selected departments continuously, indicating the need for similar and continuous themes of response adaptations.

However, the differences in the function, built environment, workflow, equipment, and patient population in each department potentially changes the scale and the details of the implemented operational and structural adaptations. Therefore, while it is important to identify the main themes of adaptations in general, it is vital to assess their particular implications in each department separately.

To provide a comprehensive analysis of the continuous implication of the adaptation strategies and the potential role of the built environment features in support of the required adaptations, we can describe the findings through an overarching framework of pandemic impact, pandemic adaptations, and the supportive feature of the built environment (similar structure used for the individual departments but considering a continuous implementation of the strategies).

Based on the previous discussions, considering the context environment and the disease type characteristics, the pandemic impact can be codified into the change in patient volume and characteristics. Further, the employed adaptations are grouped into two major categories of operational and structural adaptations, focusing on the concepts of segregation, surge capacity, and general infection control measures.

This conceptual thematic framework extends into the identified supportive features of the built environment and makes it possible to trace back each feature and adaptation to particular challenges. Based on this diagram, we can understand the logical relationships between the impact, adaptations, and supportive features.

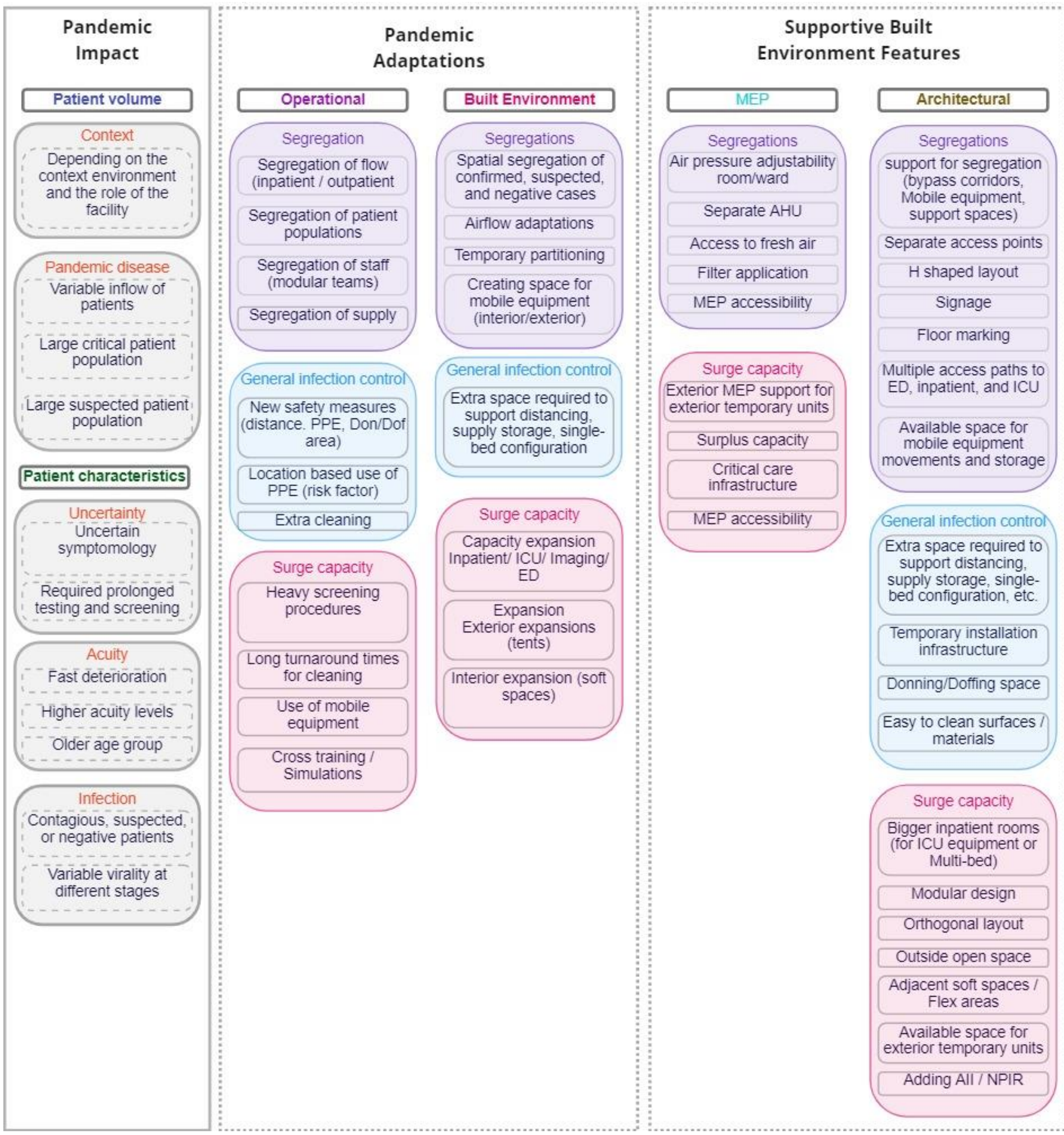


Figure 2.16. Study framework based on analysis of the existing literature on the COVID-19 pandemic impact, response adaptations, and supportive built environment features.

Summary of the findings: Overall, based on analysis of the literature review findings and thematic coding of the content, we can describe the structure of the pandemic from the impact, response adaptations and supportive built environment features standpoints.

The pandemic impact significantly changed the patient population and its volume. The impact itself was primarily determined by the context environment characteristics such as population and local policies, and the disease characteristics such as sporadic and variable surges, large numbers of critical cases, and large suspected patient volumes. The pandemic also changed the characteristics of the patients resulting in a lot of uncertainty, higher acuity level, and contagiousness.

As a result, operational and built environment adaptations were employed to respond to the pandemic challenges. Major themes of improvement in infection control capabilities (general policies and segregation approaches) and increase in surge capacity were observed as the primary goals of the response strategies.

Continuous segregation of patients, staff, visitors, supplies, and equipment appeared as the most prominent strategy for infection control. Providing isolated spaces, and the appropriate context for the infection control strategies to take place was also widely mentioned. Regarding the changes in volumes of the patients specially in screening and diagnostic spaces, a broad range of expansions, and use of alternate procedures and equipment were mentioned to be effective. Operation adaptations such as cross-training, and staff redeployment strategies were implemented to support the added physical capacities.

Similar themes were distinguished among the associated built environment features that have been effective in supporting of the adaptations. A broad range of features involving the MEP infrastructure, spatial components, and soft interventions such as markings and signage were used to enable segregations and infection control requirement in general.

The compatibility of the built environment with expansion interventions to support surge capacity was found to be associated with features such as modular design, layout configuration, MEP capacity and flexibility, and adjacency of soft and hard spaces in the layout. Having the possibility to increase isolation capacity, the availability of open spaces in the immediate outside areas and accessibility status (enter/exit points) were also found to be effective and vital.

Overarching factors: Besides the detailed relationships and technical factors of pandemic response strategies, there are also overarching factors across the literature that need to be considered while planning the pandemic response adaptations. Based on the available evidence in the literature and the CDC reports of the timeline of patient surges, we can argue that the outbreak is a time-sensitive event and evolves through various phases, impacted by a broad range of factors such movements of the populations, medical discoveries, and other types of developments along the way. Therefore, a gradual, real-time, and dynamic response is required as the pandemic event unfold and require adaptive response within the ED, patient wards, intensive care units, and imaging department (Liu et al. 2020, Hu et al. 2020, Tan et al. 2020, Fracas et al. 2021, Paganini et al. 2020).

In their study on the ED response, Liu et al. (2020) has described the “phased and dynamic” response strategy to be completed through multiple steps as the understanding of the epidemiology of the disease changed and the scale of demand evolved through the course of the pandemic. The gradual response adaptation strategy allows the facility to stay functional through optimized, and smaller-scale interventions (Cho et al., 2021). The smaller intervention steps are potentially less disruptive, more cost-efficient, and more suitable to avoid underutilization.

Moreover, as we could observe in the NCID case, large-scale physical adaptations (especially large-scale structural changes) require significant time and manpower, and sometimes lengthy licensing procedures (Whitwell et al. 2020). But, during the pandemic, as the demand quickly and significantly changes, the adaptations need to happen at a much faster pace than usual (Whitwell et al. 2020). Therefore, constant monitoring of the pandemic trends and providing daily census (COVID patient numbers by location and by medical need) and operational reports (the number of admissions, discharges, length of stay, ICU transfers, and readmissions) are vital to enable decision-makers to take the necessary actions in advance (Bowden et al., 2020) and plan the gradual adaptation steps.

CHAPTER THREE

PHASE 2: CASE STUDY ANALYSIS

Data description

In the second phase of the study, the data set of post-occupancy evaluation (POE) reports of nine U.S. Army Medical Command's (MEDCOM) medical treatment facilities' (MTFs) responses to the COVID-19 pandemic (provided by the HKS/WSP joint venture) was analyzed to understand the specific changes and adaptations made in response to the COVID-19 pandemic. These reports were aimed at summarizing the on-site assessments of the selected primary facilities and evaluating the existing, planned, and potential strategies for mitigating the COVID-19 pandemic impacts. Based on the observations, a set of recommendations and the associated costs are also included in each report.

Each report has the same standard structure and includes three types of data about the COVID response in each facility, including field observations, surveys, and interviews. For each of the sections, the data are presented separately for each department. The reports are mainly focused on the physical measures while providing some information about the operational aspects including policies, practices, and administrative measures in case of potential relevance and impact on the identified physical COVID response.

For the current study, only the transcripts of the semi-structured interviews with clinicians and administrations from the nine facilities were utilized since the interviews = provided the most relevant and richest source of data addressing the operational and built environment challenges and response strategies.

The semi-structured interviews were aimed at collecting the participant's feedback on their experiences during COVID-19 and their perspective on the implemented adaptations from the operational and facility (built environment) standpoints. The goal was to identify the main themes of adaptations, and the potential built environment facilitators and barriers (similar to our structure of supportive features) for the facility modification. The interviews were conducted during the site visits, lasting 15-20 minutes each, by at least two team members utilizing field notes to collect the responses in real-time. Besides the interview questions, the demographic and background information of the participants were also gathered. The list of questions along with the report survey construct definitions are included in appendixes F and G. The structure of the interviews and questions are as follows.

Demographic information	**Department: - / Rank: - / Role/Responsibilities: - / Length of Tenure: -**
Question 1	From the facility perspective, what was the greatest challenge you had to address in response to COVID-19?
Question 2	From the facility perspective, what was the greatest challenge you had to address in response to COVID-19?

Question 3	To what extent was your facility able to maintain continuity of non-COVID regular operations?
Question 4	What facility strategies did you implement during COVID-19 that were the most effective? Why?
Question 5	What operational strategies did you implement during COVID-19 that were the most effective? Why?
Question 6	What would you do differently to be more prepared for another surge/pandemic?

Table 3.1. The interview questions

Following the interviews, the areas of future exploration were evaluated, and on-site observations were conducted to assess noted facilitators and barriers. The observations were conducted through field audits and documented the significant spaces, inefficiencies, and positive design features through notes, photos, and annotations. The observations were focused (but not limited to) on the following factors:

- Critical modifications were made to the facility to remain operational during COVID-19
- Modifications made in response to changing needs during COVID-19
- Environmental or system challenges to effectively implementing

- COVID-19 modifications (barriers)
- COVID-19 Modifications that worked well (facilitators)
- Workarounds developed by the care team to maintain operations during COVID-19

Separate groups of observers focused on the MEP and architectural features of the facility starting from different points and levels. These observations were done separately for each department floor by floor and were completed by the set of recommendations and their associated costs (which are based on the particular cases). Each report includes a set of standardized appendixes including interview transcripts, survey goal comments, photo documentation, and engineering data.

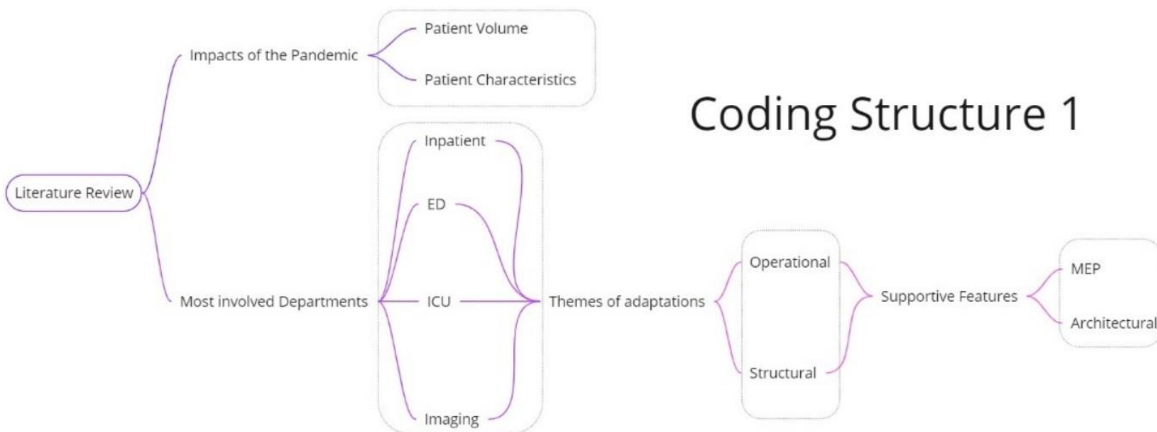
Data analysis

The interview response of the 217 staff members (some of the responses were provided as group, with overall 329 participants) across 9 facilities were analyzed as the primary source of information for the second phase of this study and the relationships between the identified adaptations and the built environment were discussed based on their general implications within the building systems. To extract a meaningful result from the interview comments, a more compatible version of the study framework was created. This framework was developed through a set of preliminary reviews and coding of the interview data set to achieve a compatible structure for content analysis.

Overall, three rounds of review and coding were conducted to achieve the most informative structure of data analysis coding. A comprehensive back and forth comparison of the data was conducted within each round to identify the similarities and differences between the interview content and the literature review outcomes. For the coding process, the PDF file of each review was imported directly to the Atlas.ti software and, by defining a separate project file for each round of coding, it was possible to analyze the documents through various coding structures.

Coding structure

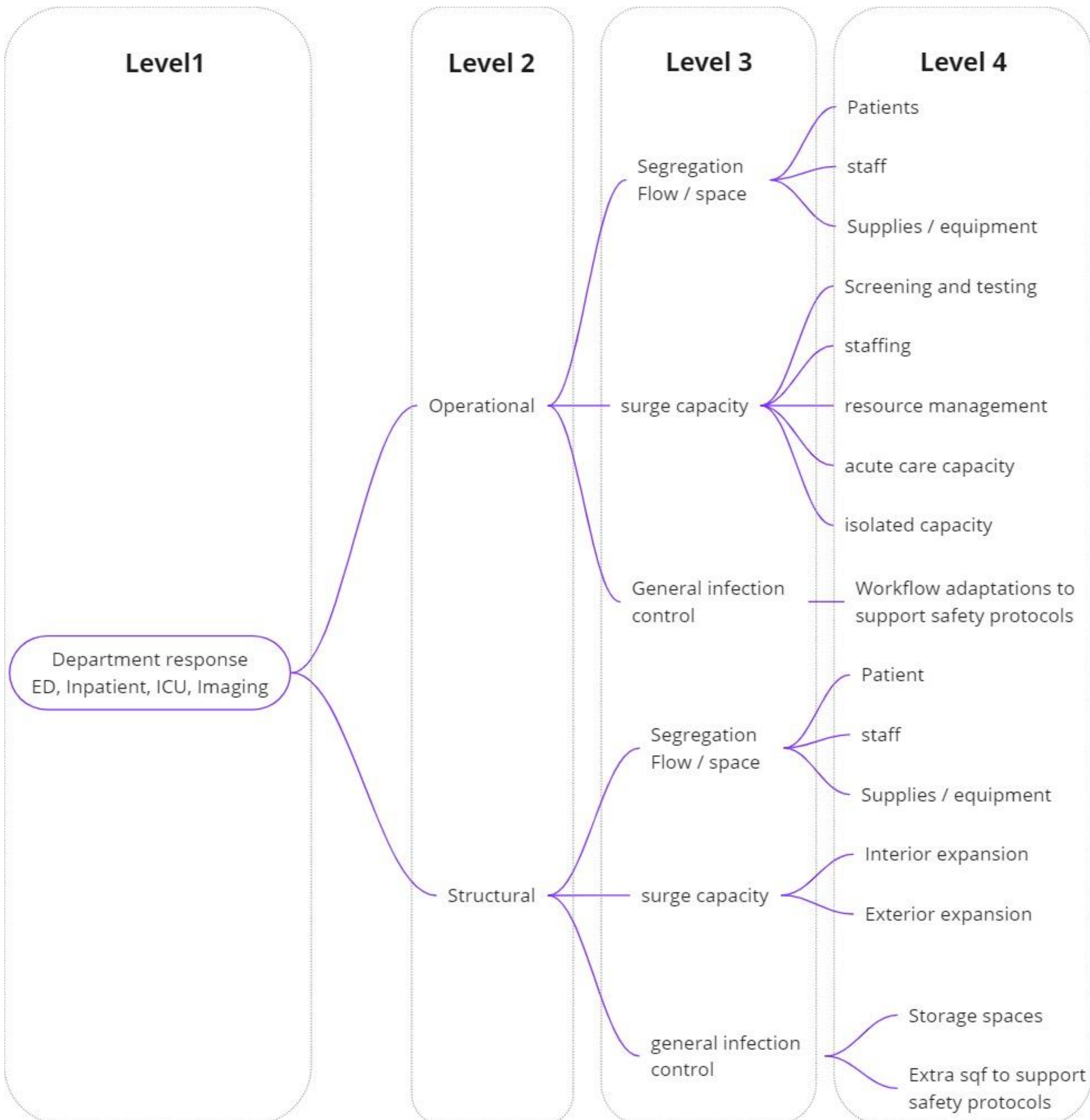
In the first round of coding, the framework of the literature review was used as the primary structure to develop the potential coding workflow that were expected to be applicable across the interviews. The impact of the pandemic regarding the changes in patient volume and characteristics and the operational and built environment adaptations were placed as the primary codes.



Frame 3.1. Preliminary reviewing structure based on the framework of the literature review.

Based on the preliminary review of the interview data, it was evident that there is no significant information across the interviews about the impact of the pandemic in particular or the role of the built environment features. The participant's comments were almost entirely focused on the challenges (results of the impacts), the response strategies and adaptations, and the recommendations along with some information about the overall performance of the facility.

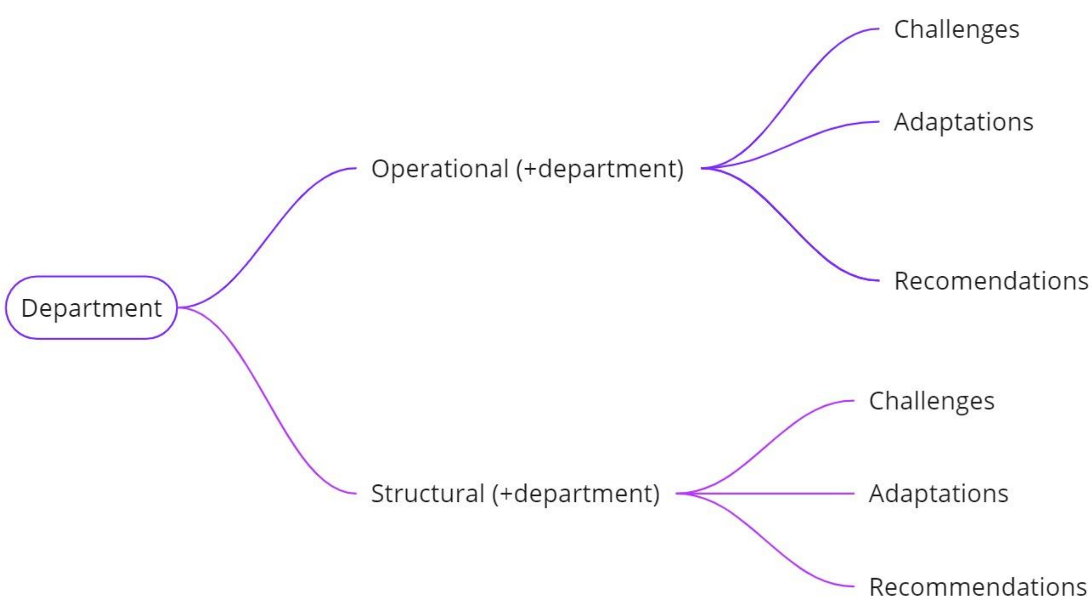
In the second round of coding, a more detailed structure based on the content structure and the identified themes of adaptation across the literature was suggested as the starting point.



Frame 3.2. Second round of coding preliminary structure.

This structure was further developed to a more adapted version (figure 2.1. below) which was based on the operational and built environment groups and the content of the interview questions as the primary groups for categorizing the content.

Within the selected departments, there was close proximity between the identified themes through the literature review and the structure of the reports (target information of the interview questions) which made it easier and more reliable to analyze the data based on the themes in the developed framework. Overall, the interview questions were primarily aimed to understand the greatest challenges and adaptations from the operational and facility (built environment) perspectives, along with gathering comments about the performance and the recommendations for a better implementation of the desired adaptations.



Frame 3.3.. Second round of coding structure.

The preliminary coding structure was used as the foundation for "redefining" (basically looking for similar or different trends of adaptations) the themes of adaptations, challenges, and recommendations across the interview comments. The following figure presents the raw list of the identified themes across the responses through the second round of coding of the first three reports. The items of this list went through a secondary analysis to reduce and eliminate the potential repetitions and create the code definition of the final list of themes based on the contents of theme comments.

1- Access
2- Access security
3- Accessibility
4- Airflow
5- Architectural flexibility
6- Behavioral staff segregation
7- Capacity
8- Capacity supply storage
9- Communication
10- Cross training
11- Cross training
12- CSTC capacity
13- CSTC infection control
14- CSTC location
15- CSTC manpower
16- CSTC waiting capacity
17- Disinfection
18- Disinfection process
19- Drive-through pharmacy
20- Drive-through testing
21- Entrance / Exit Flow control
22- Equipment capacity
23- Equipment storage
24- Exam / treatment patient segregation
25- Expansion
26- Expansion planning
27- External sites
28- External Tent
29- Facility / service modification
30- Flexible layout
31- Flow segregation
32- Food delivery
33- Gas outlet flexibility
34- Imaging
35- Infection control
36- Infection control protocol
37- Isolation
38- Isolation behavioral
39- Isolation capacity
40- Isolation testing
41- Isolation training
42- IT capacity
43- IT flexibility
44- Layout infection control
45- Manpower
46- Mobile equipment
47- One-way flow
48- Outdoor screening
49- Patient flow segregation
50- Patient population impact
51- Patient segregation
52- Plexiglass shields
53- PPE capacity
54- PPE preparedness
55- PPE protocol
56- PPE supply
57- Preparedness equipment respirator
58- Preparedness plans
59- Resource management
60- Room design
61- Scheduling
62- Screening
63- Staff cross training
64- Staff Segregation
65- Supply preparedness
66- Supply segregation
67- Tele-health
68- Tele-ICU
69- Tele-screening
70- Tele-working
71- Tele-working preparedness
72- Temporary adaptation
73- Testing
74- Testing location
75- Testing result time
76- Testing supply
77- Treatment
78- Vaccination location
79- Virtual communication
80- Waiting patient segregation

Figure 3.4. Second round of coding list of identified themes of adaptations, challenges, and recommendations

Through the analysis of the list, five main categories of data were identified including the source department types, infection control, surge capacity, preparedness, and general themes of adaptation. The findings of first group of codes (source departments) showed that besides the included four departments of ED, ICU, inpatient, and imaging, there are two other groups of "Overall" and "add-on" implications with valuable content regarding COVID response. The definition of the function and space for these departments are provided in the table below. These definitions were further used to decide whether the comments content apply to the target departments and spaces, or they should be excluded.

Overall	The functions, features, and spaces that have a direct implication in any of the included departments. These codes also include pharmacy services that are directly impacted by the COVID-19 patient population
Add-on	Dedicated spaces to either of Testing, Screening, and Vaccination services including permanent spaces or temporary add-on units.
ED	The functions and spaces related to the emergency department and its associated functions such as triage, testing, and screening (inside the ED), examinations, temporary hold/isolation, etc.
ICU	Intensive care units or any other critical care delivery functions and spaces, specifically related to the COVID-19 patients
Inpatient	The functions and spaces related to the inpatient type of care including inpatient wards, behavioral health (only inpatient), isolation wards, etc.
Imaging	Diagnostic services mostly done within the radiology department or through the mobile imaging equipment inside other departments or temporary structures.

Table 3.2. The description of the source department codes

Through further analysis and adjustment of the code definitions, the content of the "general" group (building accessibility, flexibility, and workflow) was divided between the three groups of infection control, surge capacity, and preparedness to create the final set of primary groups of application. The following diagram was created as the final structure of coding primary groups, working in conjunction with the set of subcodes (level 2 codes), and their areas of application (level 3 codes).

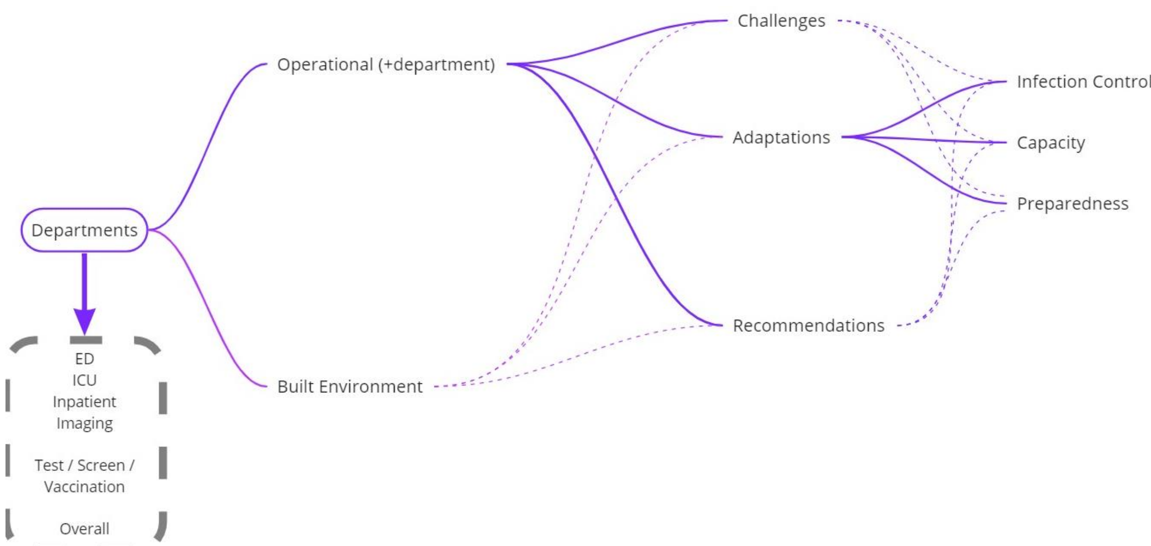


Figure 3.5 The final structure of coding

Based on this structure, each interview comment was coded primarily based on the above constructs, which enabled us to separate the responses based on their general area of application (department), being either operational or built-environment, transferring a challenge, adaptation, or recommendation, while addressing infection control, surge capacity, or preparedness measures as the primary purpose.

To determine the above attribute of the comments, the logical content of the response was used, since most of the participant's answers were not limited to the specific asked question. Therefore, the first level of the coding structure was created as follows:

Department **->** *Operational/Built environment* **->** *Adaptation/ Challenge/ Recommendation* **->** *Infection Control/Surge Capacity/ Preparedness*

All of these 4 steps of coding were defined as single code types grouping the comments into the associated categories of content. The reason to define this four-step coding as a single level was the limitation of the coding software, which is designed to handle only three levels of coding. After the primary distinction of the comments based on the above structure, the other two levels of codes (levels 2 and 3) were used between all of the potential combinations of the first coding level. The level 2 and 3 code titles can be described as the themes of challenges, adaptations, and recommendations. In figure 2.4. sample screenshots of the coding interface and the associated comments are presented.

This structure provided various opportunities to analyze and separate the content of the comments based on a broad range of factors and provide descriptive statistical information about the presence of each concept among in participants responses. The outcome of the coding makes the content of the comments distinguishable based on: Source case report, Departmental implication, Respondent information, Operational / Structural, Adaptation / Challenge / Recommendation, Infection Control / Capacity / Preparedness, level 1 main themes, and level 2 main themes.

Figure 3.6. The coding interfaces showing the methodology of three level of coding procedure. In lower section, sample comments of a particular code are presented.

Themes of challenges, adaptations, and recommendations

Based on the findings from the preliminary rounds of coding, 2 levels of primary concepts and detailed applications of COVID challenges, recommendations, and adaptations were created.

The level 2 codes were defined as general concepts and are either shared or defined particularly around each of the three concepts of infection control, surge capacity, or preparedness. The shared codes have similar definitions, but different applications for each response category within the first level of coding. These codes are the primary goals and application areas of COVID challenges, recommendations, or response adaptations across the case studies and represent the overall concepts. In the tables below, the list of level 2 codes is provided. It is important to understand that this list is limited to the content of participants' responses within the data set and should not be considered a comprehensive list of all possibilities.

Main Themes	Level 2 Codes				
Infection Control	Segregation	Protocols	Isolation	Disinfection	Physical Barriers
Surge capacity	Space	Manpower	Patient numbers	Scheduling	-
Preparedness	Contingency plans	Communication	Layout Features	Drive-through	IT
Shared themes	Equipment	Supplies	Remote Working	-	-

Table 3.3. The list of level 2 codes

Within the included level 2 codes, the concept of “segregation” was more complicated and was defined as separate versions to minimize the complication. This concept was defined as the set potential combinations of “flow/space/scheduling” and “patient/staff/supplies/visitors.” All of the other concepts are singular definitions without any types of overlap or complications.

The included content of the comments (participants' responses) within each of these codes was further analyzed and recoded into further categories (level 3 codes), to provide a more detailed and organized representation of the data. These detailed groups of data are the outcome of this study and are summarized and presented in the result section (next chapter) to provide detailed information about each theme of adaptation across the included departments. The diagrams and lists of level 3 codes and the full definition of each theme are included in appendixes A, B,C, D, and E.

The final goal of this coding process was to create an easy-to-digest input of data that could be summarized and reconfigured into a comprehensive set of challenges, adaptations, and design recommendations to address future pandemics. In the next chapter, the outcome of the coding procedure is analyzed and represented in a unified structure. Chapter 4 provides the main themes of the challenges, response strategies, and design recommendations to address infection control, surge capacity, and preparedness requirements across the facilities. It should be mentioned that a large number of comments were not added to the final text due to the redundancy of the content.

CHAPTER FOUR

RESULTS

Overview

In the initial sections of this chapter, the statistical results of the coding process are included to present the descriptive context information of the case studies and their share in the overall set of analyzed interview responses. Through this section, the distribution of responses across the individual departments is presented. Also, basic information about the similarities and differences between civilian and military hospitals' pandemic experiences regarding their patient demographics, defined role/mission, workflow, building programs, and staffing configurations are included.

Through the main sections, the outcome of the coding procedure for each of the nine case studies is analyzed to provide distinguishable groups of comments, representing the participant's background, the application department, operational/ structural status, type of comment content (challenge, recommendation, or adaptation), target concept (infection control, surge capacity, Preparedness), and level 1 and 2 themes.

Further, the content of each code (interview responses) was analyzed and separated based on their applications in the most involved departments to provide usable and clear outcomes applicable to each space. Following the study framework and to simplify the content of the scattered comments, major themes of challenges and adaptations were extracted and rewritten as cohesive paragraphs, each representing a single theme, distributed into the three sections for infection control, surge capacity, and preparedness.

In the figure below, the structure of the interview response content analysis and presentation is provided:

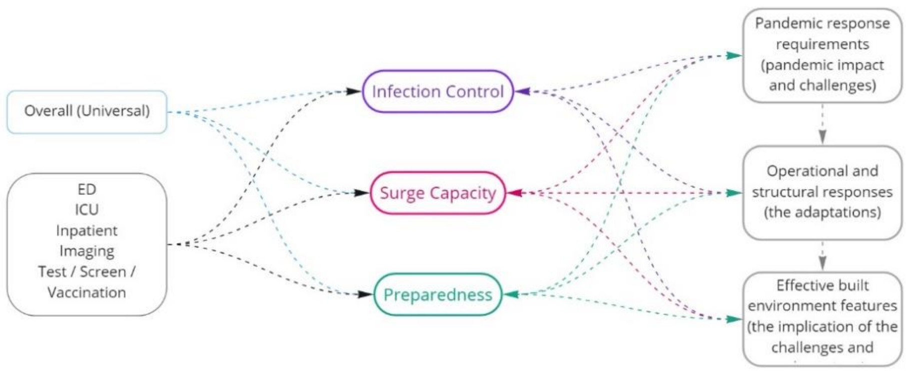


Figure 4.1. The structure of data analysis and presentation in the result section

At the end of each section (infection control, surge capacity, and p[preparedness) within each of the departments, a preliminary list of potentially effective built environment features is included. In the next chapter, these lists are further analyzed to create the final design guideline and the associated diagrams to show the potential applications. Considering the confidentiality of the main case studies' architectural, and MEP plans, generally available documents from other case studies are used to represent similar concepts of design.

Facilities Context information:

Overall, nine military hospitals and medical centers are included in this study. Regarding the sensitivity of the military facilities, no exact location or identifiers were provided in the case reports. However, the general location of the facilities and some background information were available and analyzed to add context to the data. All of the reports (interview sections) were sequentially conducted through the year 2021 across the United States. Throughout the interview, several responses were presented as shared comments from a group of participants within the same department. Overall 329 individuals were involved in the study, and 217 responses were used for the data analysis to generate 1529 overall comments. Some of the responses were excluded due to non-standard formatting or being completely irrelevant. In the table below some of the contextual information of the case studies is presented:

Location	SQF	Built	Levels	Responses	Participants	Comments	Interview Date
New York	120,000	1977	5	16	23	118	01/05/21
Alaska	260,000	2007	3	23	24	158	03/23/21
Georgia	435,474	1983	4	27	46	220	04/20/21
Colorado	519,190	1986	6	27	39	152	05/17/21
Kentucky	539,886	1982	5	26	32	191	06/15/21
Kansas	581,243	2016	4	23	41	180	07/13/21
Georgia	630,000	1976	14	21	37	163	08/10/21
Georgia	819,130	2012	7	29	51	224	09/07/21
California	217,744	2012	4	25	36	123	10/05/21
Overall:				217	329	1529	

Table 4.1. The context information of the case studies

Facilities departments

Within each of the case reports interview sections, the participants provided demographic background information, stating their departments and their roles within the facility. This information provided some insight regarding the potential involvement of the participants in the pandemic response, while also indicating the differences between the military and civilian hospitals regarding the composition of departments and functions.

The content of the interview responses was rarely limited to the asked questions and more importantly the participant's department. Therefore, regardless of the title of the question, the content was analyzed to identify the potential area of application for each individual response. The distribution of the participant's source departments across the case studies shows more focus on the surgery, inpatient, and emergency departments, being represented by a relatively larger group of respondents. The distribution of the respondents by the department is presented in the figure below:

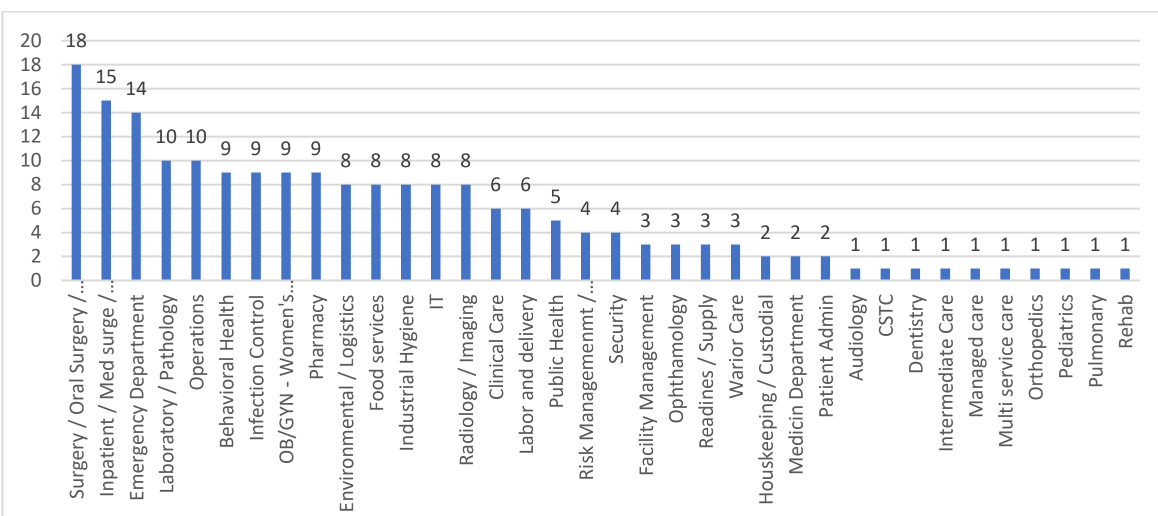


Figure 4.2. Distribution of response per department

Pandemic experience and response in the military and public facilities

Throughout the pandemic, each medical facility has a defined role within the structure of the health system in the overall pandemic response strategy and responsibility. Depending on the hospital's capabilities, the overarching health system structure, and the context of the hospital, the role and patient flow of the hospital are expected to be vastly different from case to case.

Across the civilian hospitals that were analyzed in the literature review, the role and the mission of the facilities were observed to be different based on their context environment and hospital capabilities. Some facilities were completely dedicated to COVID patients (such as public hospitals in New York) and completely stopped general services, transferring all of the non-COVID patients to other facilities. While in other cases a hybrid system was implemented, taking care of both patient populations within the same space with the implementation of segregation measures to ensure safety.

Mostly, these patient distributions and segregation measures were aimed to optimize the pandemic response capacity while minimizing the chance of cross-contamination inside the buildings.

Within the local networks of hospitals working in coordination to achieve these goals, various patient referrals and staff redeployment strategies were used to optimize the use of resources and available manpower across the neighboring facilities while separating the clean and contaminated patients as far as possible.

Across the case studies analyzed through the literature review (all civilian), the constant factor in all the civilian hospitals has been the responsibility to the general population of patients within its defined physical range and the overarching healthcare system. Providing service to this corresponding stationary local population of the facility in the most optimized and safe way is what is expected from a civilian hospital in a nutshell. Regardless of their defined role within their local network, civilian hospitals were responsible for a general population of patients that were directly defined by the context environment demographics. For instance, if the population is older, with high density, or particularly prone to danger (airport cities, confined spaces, etc.), more pandemic cases are expected to visit the hospital.

However, in the case of military hospitals, regarding the primary mission of the facilities to provide service to military personnel, unlike in civilian hospitals, the mix of the local population does not necessarily determine the hospital patient demographics and inflow. The mission and responsibility of the MHS facilities are vastly different from the civilian cases, and their specialized services aim to ensure that military force capacity and readiness were not put on hold or distributed to local civilian hospitals during the pandemic.

Regarding these special responsibilities, the program and functional composition of the military hospitals were observed to be different from the civilian. Across the included military case studies, several particular departments and functions were only included in military hospitals. Departments such as warriors' recovery center, warrior care, and military readiness and rehab units were among the military-only functions and spaces.

Besides the faciliitie's different physical and operational status, the demographic of the expected patients is different from civilian cases. Based on the reports from the CDC in 2021, the majority of COVID-19 patients belong to the older group. Different demographics of the military patient populations (generally young and healthy) have a potential impact on the expected volume and acuity levels of pandemic patients.

Also, the staffing composition of military facilities is reportedly younger than general civilian hospitals with significantly different workloads and lower experience levels. As a result of the special responsibility of the MHS hospitals, this workforce was expected to perform their tasks within a different schedule. For instance, mass testing procedures for soldier units were reported to be a part of the job in military hospitals.

Regarding the system-wide response strategies in response to COVID-19, no evidence was found to indicate military-explicit strategies that were enacted across the facilities. The MHS facilities are far more scarce and far apart than civilian hospitals, and due to the significantly different context factors, enforcement of overarching response strategies may not have been deemed effective by the decision-makers. Although, one of the primary complaints from the study participants was the lack of such a pre-defined and standard response plan across the military.

This factor was more prominent during the initial phases of the pandemic, within which even across individual military hospitals, no standard protocols for safety and risk management strategies existed. Based on the participant's comments, in the initial phases, departments of each facility had to develop individual safety policies (for instance, the PPE protocols), until a general standard was defined.

Emergency department

Overview

This section presents the outcome of the coding procedure for the emergency department by thematic coding of the comments and responses that had specific implications or relations within the ED. In the figures below, the distribution of the comments regarding their core concepts (infection control, surge capacity, or preparedness), their content category (challenges, recommendations, or adaptations), and their application context (operational or built environment) is presented.

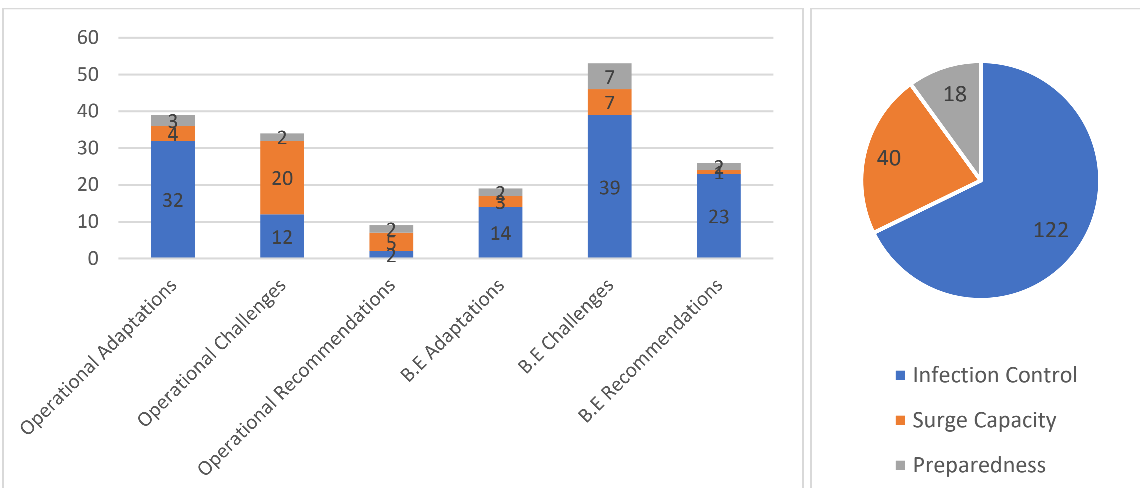


Figure 4.3. The distribution of interview responses among the three aspects of the pandemic response, B.E: Built Environment

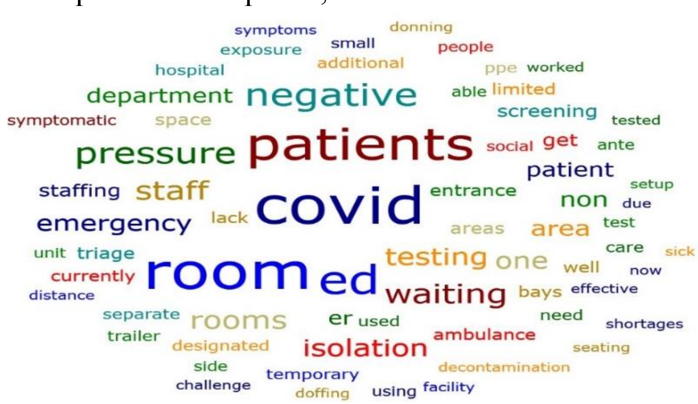


Figure 4.4. Presentation of the most repeated words across the comments

Infection control – Challenges, requirements, and recommendations:

Inadequate waiting space: In almost all of the case studies, the waiting areas in the ED were found to be generally too small for the larger patient population and social distancing requirements. The small size of the waiting areas is potentially increasing the potential clutter of the patients and the chance of exposure. In some facilities, the patients had to wait outdoors or in their cars using restaurant-style pagers to be notified of the entrance. Inside the EDs, the lack of segregation between the patients in the waiting, exam, and treatment was challenging and the solutions like temporary partitions were not effective in truly separating the patients in the waiting areas. Therefore, some cases had to extend one type of patient into the adjacent areas (hallways) to be able to effectively separate the COVID and non-COVID patients.

Isolation and segregation: Across the case studies, the existing ED layouts and MEP infrastructure did not allow for a designated COVID exam and treatment space. Having an open layout in the ED and other critical areas was challenging and made patient separation and isolation almost impossible. Besides the shared space concept, the shared air handling units (AHU) with other areas of the hospital were challenging for the separation of the airflow inside the ED. Most importantly, the lack of enough isolation and negatively pressured rooms inside the ED is widely reported among all of the included cases, which is suggesting the immediate need for an increase in the isolation capacity of the ED. Also, the ED's existing isolation rooms generally do not have an anteroom, which is particularly important for donning and doffing PPE, creating an operational challenge during the pandemic and forcing the staff to put on the PPE in the corridors. The ED Noncommissioned Officer in Charge (NCOIC) in facility 7 mentioned:

"Not knowing if a patient is COVID positive before taking to radiology from emergency was challenging."

Interdepartmental Transport: Besides the procedures that were limited to the ED spaces, patients frequently required interdepartmental transfers within the hospital to receive further diagnostics (imaging procedures) and treatment (admission to the inpatient) services. The uncertainty of the patient's COVID status was specifically challenging in cases where the patient needed immediate transport inside the building from the ED to other spaces.

Infection control - Adaptations

Testing and screening: The ED space was widely used for testing and screening patients; however, the screening workflow and space inside the ED and the related spaces were significantly different among the hospitals studied. In some cases, external trailers and tents were deployed in the immediate outside spaces and by reducing the traffic in the inside areas they were effective in reducing the chance of exposure (from the uncertain population) inside the ED. Also, in a number of cases, the ambulance bays were used for the same purpose but proved to be challenging due to staffing difficulties and exposure to the outside elements.

Mostly, the interviewees indicated that it was preferred if testing was done before the arrival to the main ED space as the primary goal was to keep the patients outside as much as possible. In sudden arrival cases, the patients were usually placed inside the triage area temporarily before being allowed to enter the ED.

The triage area and the pre-separation approach were effective in these facilities in reducing the exposure risk. In other cases, the testing was conducted in a completely separate space which is explained in the next section of the COVID Screening and Testing Center (CSTC). The ED NCOIC in facility 5 mentioned:

"Lessons learned – ED should not be entry point potentially exposing other patients unnecessarily (ED for emergency's only)."

Entrance strategy: As mentioned in the literature review section, the ED is the main entrance and the initial point of contact for the majority of pandemic patients. In some of the included case studies, reducing the entrance to a single point into the ED was reported to be effective in controlling the flow of patients. However, this strategy was also mentioned as a source of cross-contamination between different patient populations due to the shared entrance space. In most cases, all the patients had to go through the ED screening initially and then to the designated units inside the facility. Therefore, based on the availability of space in the immediate outside area and to mitigate the risk, temporary entrance spaces (tents) were utilized to provide a separate space from the ED main area for the initial testing and holding of symptomatic patients.

Waiting spaces: After entering the ED, inside the waiting spaces, the COVID and non-COVID patients were separated by physical interventions such as temporary partitioning, zipper walls, or utilizing separate waiting spaces. Also, the seating spaces inside the waiting areas were reduced (which consequently reduced the capacity) to achieve physical distancing and were found to be effective in controlling the exposure.

Segregated circulation paths: The path of movement of the ED patient inside the hospitals were significantly modified to provide segregation as much as possible. In some facilities, if there was a redundancy of movement paths, one elevator was dedicated to the COVID-19 patients; however, in case of unavailability, the same elevator was used by both populations and needed to be cleaned every time between the patients.

The segregation of patient populations (considering the space, supplies, and flow) is extended for the staff and the equipment to be effective. In most cases, separate teams have been created and dedicated to different patient populations inside the ED.

Isolation and segregation: In response to the challenges related to the isolation capacity and airflow control within the ED, various temporary solutions such as increasing the ventilation capabilities, zipper walls, changing the airflow direction, or repurposing the decontamination shower spaces were tried.

Infection control - Built Environment features

Based on the identified themes of challenges, requirements, and implemented or recommended adaptations, we can provide a list of potential built environment features that are potentially effective in increasing the infection control capability of the ED:

- Rethinking the measures for the required number of permanent and temporary isolation rooms and providing the possibility of creating the temporary rooms and spaces. (general)
- Providing flexibility for the ventilation system while segregating the source AHU units of the target areas. (general)
- Having the possibility of entire areas being temporarily negatively pressured inside the ED. (general)
- The ability to monitor the isolated rooms from a central location. (Shared with inpatient)
- Designated support spaces for separate patient and staff groups (storages, toilets, etc.).
- Possibility of adding pre-triage spaces.
- Providing potential bypass paths to the key functions inside the hospital (Such as Imaging, ICU, and Surgery) to enable separation of patient flow from the ED.
- Having small alcoves in the ED rooms for donning and doffing.
- Installing permanent plexiglass shields in the reception desks.

Surge Capacity – Challenges, requirements, and recommendations:

Among the included facilities, there was a widespread shortage of staff caused by various factors including the general lack of enough manpower, hiring caps, quarantine requirements, and providing extra manpower for other departments or the “added” functions such as testing, screening, contact tracing, and vaccination. In some cases, the testing and screening tasks were so intensive that prevented the ED staff from doing their primary tasks. Considering dedicated teams to the added functions and not rubbing the ED from its staff was effective in avoiding further shortages of manpower. The ED NCOIC in facility 7 stated:

“COVID trailer with dedicated team has relieved ED staff from majority of COVID testing.”

The fear caused other staff members to avoid entering the ED for consultation or similar responsibilities limiting the capacity of the ED for providing appropriate care. This shortage of manpower resulted in a lot of overtime and potential fatigue among the existing staff. Besides, the number of specialized staff (respiratory care and registered nurses) was significantly limited among the facilities, while the protocol for cross-training has not been successful in support of the larger number of trainees. Therefore, it is necessary to plan the cross-training capability far in advance and consider the extra staff for the added responsibilities and roles.

Moreover, because of the lack of space and capacity, the ED functions were extended beyond the physical borders of the ED into the adjacent areas such as hallways, entrance gates, isolations barracks, and ambulance bays. Inside the EDs, there was a general lack of appropriate space for screening tasks which has pushed the staff to the outside space in temporary structures such as tents and trailers. These screening tasks outside the ED have successfully reduced the load on the ED, but it requires free space and primary amenities and infrastructure such as MEP support, heating, bathrooms, etc.

Considering the limitations of the facilities for adding extra space to the EDs (specifically to increase the capacity and not for infection control and segregation), no comments were made about the physical adaptations aiming to increase the surge capacity of the EDs'

Surge Capacity – Built Environment features

- Enough space and MEP support (power, medical gas, etc.) for potential add-on structures such as tents or trailers adjacent to the ED.
- Extra storage for pandemic supplies with appropriate accessibility for separated groups.
- Adding the necessary amenities to the immediate outside area (toilets, heating, etc.) for potential patient influxes.
- Ability to change layout and footprint of ED for extra waiting while enabling the temporary separation of the waiting area.
- Providing more workspace in the workstations and behind the desks to enable social distancing for the staff while maintaining the capacity.

Preparedness – Challenges, requirements, and recommendations:

Patient movements: In many of the included cases, the testing and screening tasks were moved into separate spaces, which were not necessarily close to the ED. However, a large population of patients after the screening procedure needed to present at the ED, hindered by the distance of the closely related functions. Therefore, one of the preparedness measures of the facility is to consider the space for the "added" functions such as testing to be physically close to the related departments (specifically the ED)

PPE supplies and storage: As mentioned previously, the ED provides care for an uncertain population and therefore requires a significant supply of PPE; however, the shortage of PPE was specifically evident across the case studies. Besides the general shortage of PPE supplies, the storage for the PPE and COVID supplies was particularly limited inside the ED, forcing the staff to reconfigure adjacent spaces for temporary storage.

Mobile equipment accommodation: Over the course of the pandemic, it was widely suggested to move the equipment instead of the patients to reduce the chance of cross-contamination. According to the staff comments, providing portable solutions for imaging, ventilation and air sanitization was effective. Therefore, accommodating the movement and functional requirements of this equipment is required across the ED physical structure. In one of the case studies, having large windows in the isolation units was specifically helpful to utilize the mobile imaging equipment from the outside of the room and reduce the spread.

Preparedness – Built Environment features

- Large windows in decontamination rooms have been very effective in providing the necessary access for the mobile imaging equipment to work from outside and are recommended to become a common practice.
- The appropriate distance of the ED to the added functions (testing center) is very important, as having long distance have been reportedly problematic.

COVID Screening and Testing Center (CSTC) and Vaccination

Overview

This section presents the outcome of the coding procedure for the CSTC and vaccination spaces by thematic coding of the comments and responses that had specific implications or relations with the add-on spaces for these functions. In the figures below, the distribution of the comments regarding their core concepts (infection control, surge capacity, or preparedness), their content category (challenges, recommendations, or adaptations), and their application context (operational or built environment) is presented.

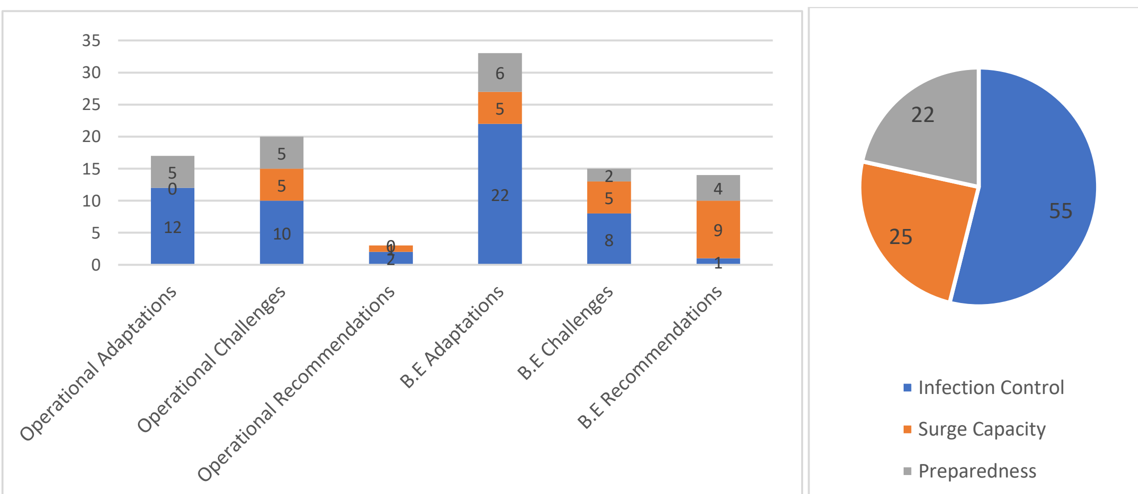


Figure 4.5. The distribution of interview responses, B.E: Built Environment

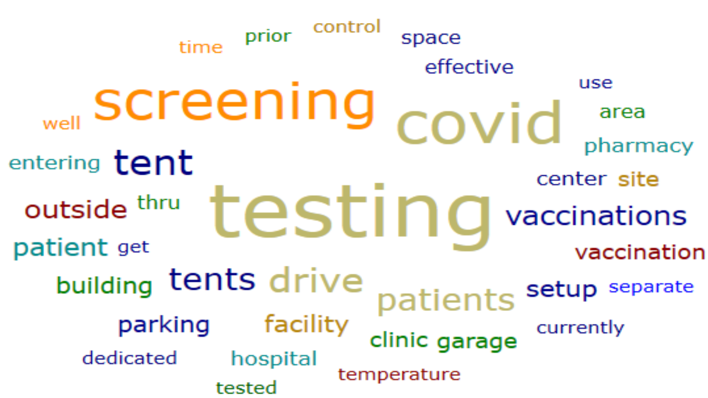


Figure 4.6. Presentation of the most repeated words across the comments

Infection control – Challenges, requirements, and recommendations:

External spaces: Based on the staff comments, having the ability to conduct the testing and screening tasks without bringing the suspected patients inside the building was considered to be very effective for infection control. This goal was achieved through various solutions such as using external sites, temporary structures (tents and trailers placed outside of the entrances), and conversion of the existing spaces (admin area, parking lots, etc.) inside the building or within the hospital campus. The ED OIC in facility 9 stated:

> *"COVID screening tent outside enabled the assessment of symptomatic and non-symptomatic patients before entering the facility."*

Segregated space and flow: Besides the initial control over the flow of the patients into the building, it was a challenge to maintain the separation through various steps as the patient progressed from testing. For instance, holding the patients temporarily until the test results become available was a challenge within the CSTC spaces. In some cases, due to the inability to provide the holding space, all the patients were treated as contaminated, which was more labor and resource-intensive. The oral surgery OIC in facility 9 mentioned:

> *"All patients were COVID tested in advance, but it was a logistical nightmare and were not able to see patients in a timely manner so now all patients are treated as if COVID-positive"*

Infection control - Adaptations

Establishing a separated CSTC successfully reduced the number of patients (majority of uncertain cases) inside the building and was an effective strategy to control the chance of cross-contamination inside the ED and the main building. The separated spaces were created through tents and trailers in close proximity to the main building if the spaces were available. Temporary lines of power and data were put in place to enable the added spaces to function properly; however, due to the distance and lack of MEP support, this adaptation was not possible in all cases. Primary care NCOIC in facility 1 stated:

"A separate facility for testing and vaccinations would further reduce the risk of accidental exposure for staff and patients."

To provide safety within the external CSTC and vaccination spaces, larger waiting areas capable of separating the patients and accommodating social distancing were recommended by the staff. The larger waiting areas are deemed necessary to avoid forcing the patient to wait outside which was in a significant portion of the cases. The tent structures are potentially superior in providing larger covered spaces; however, they are more exposed to outside elements compared to trailers or other more comprehensive solutions. The Inpatient Services Chief in facility 1 stated:

"Outpatient side, Covid Screening and Testing Center (CSTC) created in an administrative area, not optimal for patient care or infection control."

Infection control - Built Environment features

- Considering the necessary spaces outside of the hospital in close proximity to the ED for the temporary external screening and testing spaces is recommended. Also, considering the potentially large waiting and holding areas within these spaces should be considered.
- Having the MEP support and the required outlets for medical gases, power, and data lines in the outside area is necessary to enable the external CSTC spaces to function.

Surge Capacity – Challenges, requirements, and recommendations:

Shortage of manpower: Considering the limited space inside the facilities and the sheer number of patients requiring testing and vaccination, a separate space and staffing capacity is required to support the demand. The added responsibility of vaccination and testing put an extra amount of pressure on the available staff, especially stealing the ED staff from their primary tasks.

Besides the extra workload, certain factors contributed to the shortage of manpower as a result of CSTC and vaccination added functions. The positioning of the added functions had an impact on the staff shortage by taking the staff far away from the main building and making it difficult to return to their original positions. Overall, the added tasks resulted in a significant drain in manpower across the case studies, resulting in participants unanimously recommending extra teams and manpower dedicated to the CSTC and vaccination tasks. The security assistant in facility 6 mentioned:

> *"Parking lot for vaccinations across the street at the beginning stretched the staff thin."*

Space and MEP support: The deployment, support, and utilization of the tents and trailers outside of the building have been challenging due to various factors such as limited space, lack of MEP support, and logistical difficulties for movements and restocking purposes due to the distance.

Surge Capacity – Built Environment features

- Enabling the facility to accommodate temporary or permanent external CSTC and vaccination functions depends on providing appropriate external MEP support, and access paths, and also considering extra dedicated manpower.
- Enough space in the immediate outside area with MEP outlets and direct access paths is recommended.
- Having the mechanical headroom for supporting the external spaces is necessary and should be considered in the initial planning.

Preparedness – Challenges, requirements, and recommendations:

Disruptions to the original workflow: It is important to understand that only having the space and MEP support does not guarantee the effectiveness and functionality of the added testing and vaccination spaces and we need to consider the ongoing workflow and potential disruptions as well. The potential contradictions of the added tents or trailers with the existing functions (pathways, contaminating the building air intakes, etc.) have been challenging in a number of case studies and should be considered.

Drive-through services: The external structures for testing and vaccination were commonly used in combination with the drive-through concept for providing services that were effective to reduce exposure. Appropriate space and adjacency to accommodate drive-through services without contradiction with the ongoing traffic and exterior functions like parking spaces are necessary and mentioned by many of the participants. In some cases, the drive-through space occupied the whole parking level (ground floor) or the nearby parking slots and caused difficulties for the elderly patients to reach the building. Drive through tents was also difficult from the support and logistical standpoint.

The IT support for drive-through services and external expansion spaces such as trailers, and tents required various preparedness measures by the facilities. The infrastructure for power and data input and output for the expansions should be in place as a preparedness feature in the strategic locations outside the building. In the included cases, many of the participants from the IT department asked for a permanent solution to replace the temporary adaptations. The chief of information management at facility 7 stated:

> *"IT input required when trailer is installed would like to work on permanent solution for the future."*

Preparedness – Built Environment Features:

- Providing separated traffic routes to the potential areas for CSTC and vaccination stations is necessary to enable drive-through services for the external testing and vaccination spaces.

Inpatient department

Overview

This section presents the outcome of the coding procedure for the inpatient ward spaces by thematic coding of the comments and responses that had specific implications or relations with these functions. In the figures below, the distribution of the comments regarding their core concepts (infection control, surge capacity, or preparedness), their content category (challenges, recommendations, or adaptations), and their application context (operational or built environment) is presented.

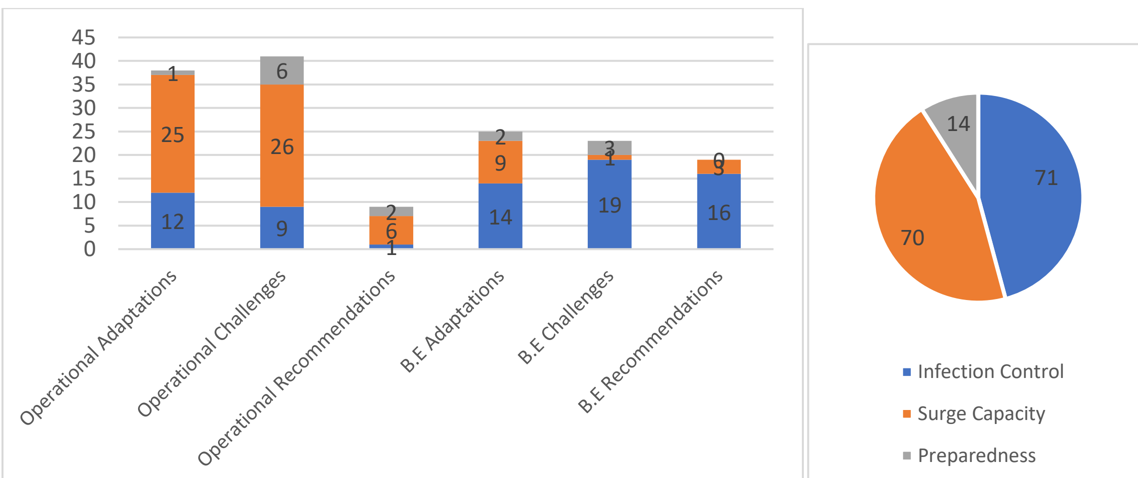


Figure 4.7. The distribution of interview responses, B.E: Built Environment

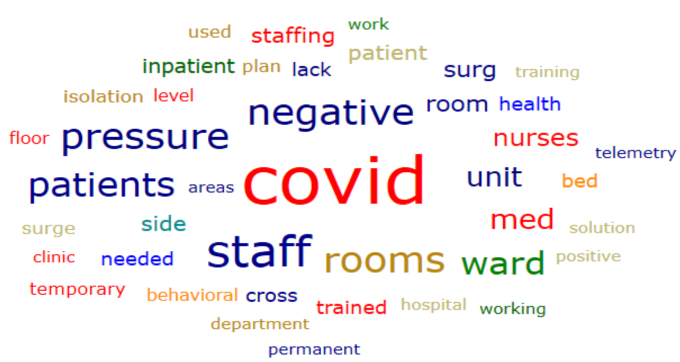


Figure 4.8. Presentation of the most repeated words across the comments

Infection control – Challenges, requirements, and recommendations:

Segregation of patients/staff/equipment: Many of the challenges regarding infection control moved with the patients from the screening and ED spaces into the inpatient wards. To avoid cross-contamination, the inpatient wards were similarly separated into COVID and non-COVID spaces, extending the segregation to the staff, supplies, and equipment. However, dividing traditionally unified functions into two segregated spaces created challenges regarding the required manpower and managing the scheduling between the two groups. Also, the support spaces needed to work separately, posing a challenge for the potentially singular staff support areas inside the building. The chief of inpatient unit in facility 3 mentioned:

"The challenge was to maintain staffing for two separate areas."

The segregation of the inpatient spaces was not quite possible in some of the included cases. In some cases, due to limited space, the ICU and med/surge units were shared to increase the critical care capacity of the facilities (case 1). This approach along with the scattered use of mixed units between COVID and non-COVID patients raised the chance of cross-infection. The failure of the existing layout of the facility to support the segregated spaces and flow was the primary reason for the mixed-use of inpatient spaces.

Lack of isolation capability: Through the included cases, the capacity and functionality of the isolation rooms have been discussed widely by the interviewed staff. Similar to civilian hospitals across the US, the proportion of the isolation units to normal

Med/Surge rooms was extremely low (only one or two between 22 or more beds in each ward across the cases). There was a significant need for extra isolation capacity and the possibility for an increase (by temporary changes in the airflow or adding physical barriers. Interestingly, in most of the included cases, the need for a dedicated isolated room for behavioral patients was also mentioned. The NCOIC at behavioral health in facility 1 stated:

> *"Not having a dedicated behavioral health room in the COVID Ward was not effective."*

Infection control - Adaptations

Creating isolation units: Across the case studies, various strategies were used to increase or create the required isolation capability including portable exhaust vents and conversion to a negative pressure by changes in air pressure difference (Facility 5). These adaptations were done at various scales from single rooms to entire wards depending on the layout features and the existing demand.

The need for additional isolated rooms or conversion of the temporary into permanent isolation units was widely requested by the staff and the particular capability of "switching" the normal pressured rooms into negative pressured spaces was desired. Also, being able to accommodate temporary isolating features such as zipper walls proved to be effective in a number of cases and was requested and recommended by the participants. The infection preventionist from facility 9 recommended:

> *"Design rooms so they can "flip a switch" to make rooms negative pressure."*

Infection control - Built Environment features

- The layout of the inpatient wards should accommodate the separated spaces for the staff, patients, and equipment. Creating the separable support spaces and the "close off" portals between the supposed segregated spaces for the installation of temporary walls or shields can be effective.
- Providing separated pathways and vertical access to the separated wards is also effective in infection control.
- Adding a significant number of isolation rooms to the existing wards is requested widely by the users. This goal can be achieved by providing the ability to change the pressure of the room through a single-step process and should be considered in the initial planning. Also, segregating the air flow of the potentially segregated spaces (separate AHUs) is necessary.
- Adding a specialized isolated behavioral health room is widely requested.

Surge Capacity - Challenges, requirements, and recommendations

Lack of manpower: The staffing restraints and more importantly, the shortage of specialized and skilled staff was one of the most repetitively mentioned operational challenges in the case studies. Factors such as general staff shortages, relocation of the available staff to other departments or facilities, and staff leaves (as a result of burnout, disease, or teleworking) added to the problem and reduced the available manpower even further. As a solution, the cross-training approach was widely used as a way to optimize the utilization of available staff for the increased demand during the pandemic; however, the required level of capability and experience (especially for critical care) was challenging to achieve by the staff through short term cross-trainings.

Lack of space: Across the included cases, various expansion plans were mentioned to be in place, but the limited availability of space to enact the expansions (or overflow plans) was a significant barrier to providing the required capacity. Moreover, it was not generally possible for the whole inpatient ward units to work as COVID wards due to the inability to separate and isolate the ward from the rest of the facility. Therefore, partial isolations and segregations were used to create the dedicated space for COVID patients. This approach was not possible in many cases, and mixed-use of units were reported in a number of cases.

Lack of monitoring capabilities in the converted spaces: The lack of telemetry capability in med/surge units and insufficient communication lines between the levels that were converted for inpatient units were challenging for the patient that needed constant monitoring.

Surge Capacity - Adaptations

Responding to pandemic patient flow: Various strategies were observed in the case studies to manage the flow of the pandemic patient into the inpatient wards. Depending on the scale of the hospital, different COVID patient "caps" considering their acuity levels, were defined for overflow or transfer to other spaces (if the COVID patients were more than a certain number they had to be relocated).

Reconfiguration of spaces: Some facilities used the dedicated COVID wards to the max and planned other available spaces (including PACU, L&D rooms, GI clinic, and pre-planned inpatient expansion spaces) for the overflow of the patients. In other cases, new COVID wards were established as a way to completely separate the patients. On the other hand, other adaptations such as the conversion of the day room (case 9) were also done in order to maintain the capacity for non-COVID patients. Mostly, these adaptations were temporary and proved to be sufficient. The manager of infection control ion facility 5 mentioned:

> *"Having the PACU become the med/surg unit during a surge is a good strategy."*

Staff and resource allocation: Across the inpatient department, to equip and staff the COVID units, other care providers, and necessary supplies and equipment were drawn from all over the facilities. However, this operational adaptation was challenging to reverse from a logistical and scheduling standpoint. To maintain the capability and capacity of the inpatient wards, cross-training (to utilize the outpatient staff) and reduction of patient visits were effective strategies.

Surge Capacity - Built Environment features

- Enabling the inpatient wards to utilize the overflow spaces is possible through certain features including, close proximity, similar dimensions and layout, and availability of MEP and medical gas support.
- To enable the expansion of the Med/surge units, the adjacent soft spaces can be considered for potential expansions. Also, based on the comments, the spaces dedicated to elective procedures (which were canceled) can be free and available.
- Providing the capability to act as a dedicated pandemic ward can be possible by adding segregated access paths and support areas. Also, having the ability to change the airflow and pressurization of the entire ward (or floor) would be practical.

Intensive care units

Overview

This section presents the outcome of the coding procedure for the ICU and other critical care spaces by thematic coding of the comments and responses that had specific implications or relations with these functions. In the figures below, the distribution of the comments regarding their core concepts (infection control, surge capacity, or preparedness), their content category (challenges, recommendations, or adaptations), and their application context (operational or built environment) is presented.

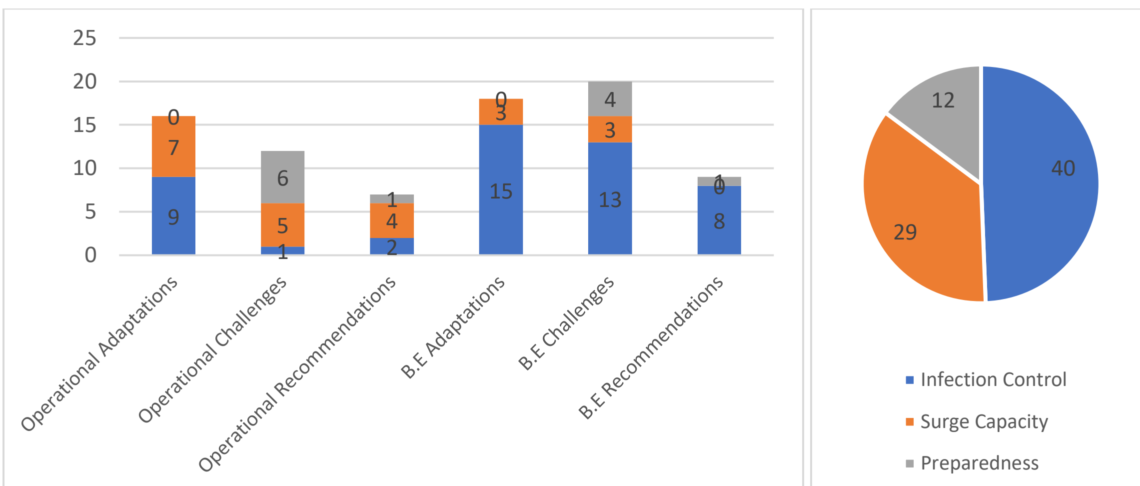


Figure 4.9. The distribution of interview responses, B.E: Built Environment

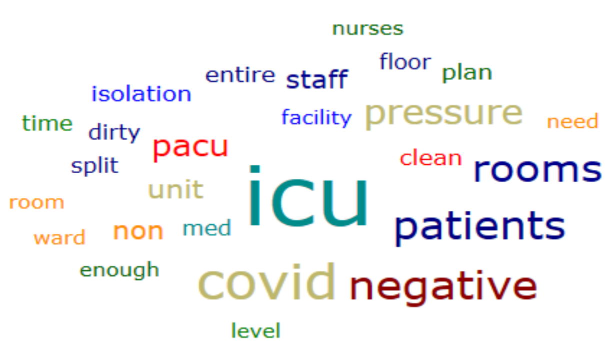


Figure 4.10. Presentation of the most repeated words across the comments

Infection control – Challenges, requirements, and recommendations:

Segregation of patients: Across the case studies, the ICU, along with the ED and inpatient departments, extended the segregation strategy regarding the space and operations for the patients. However, considering the acuity levels of the patients and the shared space layout of the ICU unit compared to the inpatient units, this separation faced a number of unique challenges within the ICU. In some of the cases, the entire ICU was turned negative pressured to house the COVID patients, and as result, the staff was required to stay in full PPE for the entire time within the ICU. This approach proved to be more resource-intensive and added to the workload and potential fatigue of the staff. The head nurse of critical care in facility 9 complained:

"When ICU suite is all negative staff must stay in PPE for entire time."

In other facilities, due to lack of space or segregation capabilities, mixed units (COVID & non-COVID) were used and potentially increased the chance of cross-contamination between the patients. There was a general preference among the ICU staff to have the capability of segregating the ICU into two separate zones, along with the availability of pressure adaptable, dual-purpose rooms as standard for the ICU rooms. This approach also enables the staff to use the PPE only inside the units and reduces the need for the constant use of the PPE in the shared spaces. Inside the ICU, it is important to have a standard approach toward the PPE guidelines and regulations that are coming from the outside (CDC). The unpredictable and various following of the guidelines (especially for PPE use) caused confusion among the care providers.

Infection control - Adaptations

Through the included cases, segregation of clean and dirty patients was utilized as a way to avoid cross-contamination inside the critical care units. The level of risk for the higher acuity patients and the shared layout concept of the traditional ICUs necessitated the use of entirely separate spaces to control cross-contamination. This separation was achieved through various approaches, mostly allocating completely separate spaces to each group (negative pressured units for the COVID group) with separate team modules.

Isolation: In the ICU units, the lack of negative pressure rooms and general isolation capability was evident among the case studies and many of the included cases did not have any isolation rooms within the ICUs. The required isolated spaces were created with temporary solutions such as adding a fan to the units to change the pressure, making the entire suite negatively pressured and also creating negative pressure inside the potential overflow spaces like PACU. The negatively pressured rooms were also required to separate the previously safe procedures (intubation) from the rest of the ICU suit. The head nurse of critical care in facility 9 recommended:

> *"Convert all of ICU rooms to be negative pressure adaptable, dual purpose, so they can flex as needed."*

Infection control - Built Environment features

- The open layout of the existing ICUs proved to be challenging for infection control. Having the ability to divide the inside area of the ICU into single bed isolation units with flexible air pressure should be considered.
- Based on the comments, the capability of the ICU to support segregated patients depends on the availability of separated spaces with independent accessibility and support areas. Double access points and the ability to divide the ICU into 2 separate units (with support areas) can be a solution.
- Considering the need for repetitive donning and doffing inside the ICU, the addition of an anteroom (temporary or permanent) would be beneficial.
- In case of overflow of the ICU patients into adjacent areas, the isolation capability should be considered within the planned overflow spaces.

Surge Capacity – Challenges, requirements, and recommendations

Lack of manpower: Across the case studies, the shortage of specialized staff was mentioned by a large number of participants. The ability to provide critical levels of care, and the required skills to utilize the related equipment and conduct high-risk tasks (intubations, attaching IV poles, etc.) were scarce among the available workforce of the hospital.

Extra required equipment: During the pandemic, especially within the ICU spaces, an extra number of equipment both with medical and disinfection functions were required. The medical equipment to care for the COVID patient (ventilators, tele-ICU carts, etc.) were needed to be provided along with the necessary training for the staff (which could be potentially sourced from other departments) to utilize them on critical patients. The presence of this equipment inside the ICU units (and inpatient units as well) requires extra space within the individual rooms. Also, in the case of ICU overflow spaces, necessary outlets and MEP support should be available to support the equipment that is not originally expected inside those spaces.

For disinfection purposes, an extra number of air scrubbers were mentioned to be needed across the case studies both within the ICU and inpatient spaces. Having the necessary cleaning supplies and equipment, and also the space to store them was pretty challenging across the case studies. Also, to provide the extra isolation capacity (temporary isolation units) of negative pressured spaces, the related equipment (fans, HEPA filters, etc.) is required to be installed.

Surge Capacity – Adaptations

Adding extra manpower: To provide the required manpower for the critical care units, a large amount of cross-training was conducted in the case studies. Pulmonologists, CRNAs, and generally any staff with past experience in ICU level of care were cross-trained to support the shortage of critical care delivery staff. However, considering the shortage of time, it was not a completely successful attempt and the need for in-advance cross-training for the reserved staff was evident.

Adding extra ICU spaces: Overall, the existing capacity of the ICU was not sufficient to support the potential surge of critical cases during COVID-like pandemics. The participants repetitively mentioned that they were capable to manage the situation only because there was no real surge of ICU COVID patients. Although, adjacent spaces with a critical level of care capability (PACU) were considered overflow (or the separated clean or dirty ICU) spaces for the ICU.

In some of the cases, the hospital did not have a dedicated ICU and had to establish and staff it from the ground up which proved to be very challenging and realistically impossible. It also is important to understand that the facility bed numbers are a dynamic factor as various parts of the included cases (inpatient and ICU spaces) were going through maintenance and temporarily reduced the capacity.

Surge Capacity – Built Environment features

- Based on the comments, the flexibility of the ICU units to work with a larger number of patients is required. This flexibility can be achieved by having the ability to accommodate more patients inside the same space or considering overflow spaces inside the adjacent departments.
- Within the potential overflow spaces, having extra room for larger equipment and more staff members, along with the capability to support the ICU equipment is necessary.
- Inside the ICU, there should be an extra storage space for the PPE and general supplies.
- Besides the physical features, planning the reserve manpower for critical care in advance is also important and should be considered.
- The inpatient and ICU care capacity of the hospital should be treated as a dynamic factor and in case of temporary reduction of capacity due to maintenance or other reasons, a reserve capacity should be considered.

Imaging department

Overview

This section presents the outcome of the coding procedure for the imaging department and mobile functions by thematic coding of the comments and responses that had specific implications or relations with these functions. In the figures below, the distribution of the comments regarding their core concepts (infection control, surge capacity, or preparedness), their content category (challenges, recommendations, or adaptations), and their application context (operational or built environment) is presented.

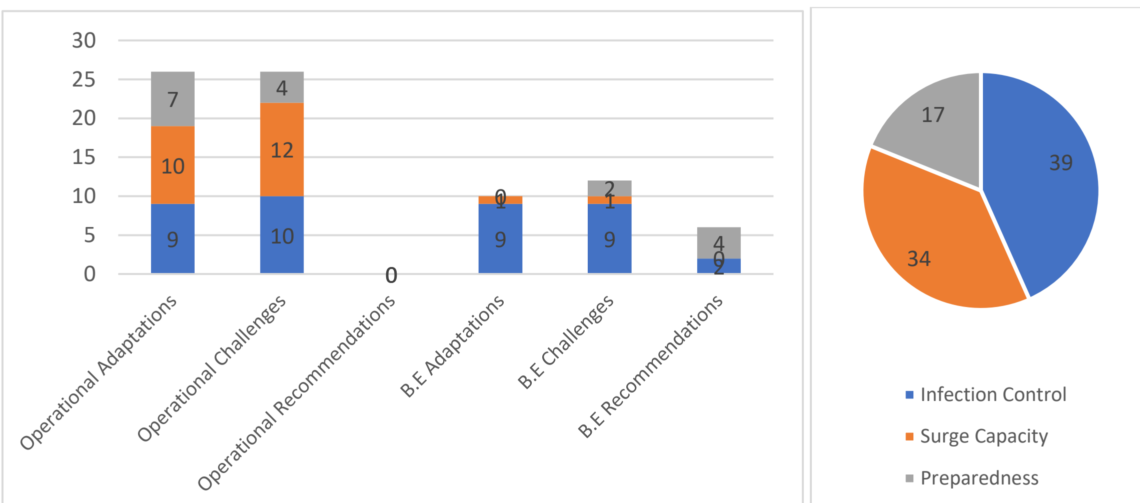


Figure 4.11. The distribution of interview responses, B.E: Built Environment

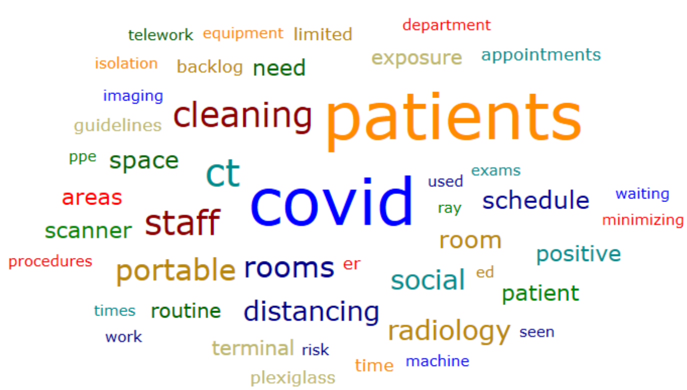


Figure 4.12. Presentation of the most repeated words across the comments

Infection control – Challenges, requirements, and recommendations:

Insufficient waiting space: The imaging department waiting areas were unanimously limited across the case studies, making it difficult to achieve social distancing and accommodate a large number of patients. This problem was intensified in response to the surge of patients requiring diagnostic imaging as part of the routing COVID-19 diagnostic procedure.

Shared imaging equipment and space: The accessibility to the appropriate imaging equipment was limited and across the case studies, very few provided redundancy in CT and radiography spaces. In the main procedure rooms within the imaging department, the terminal cleaning and disinfection of the patients was a significant challenge and increased the downtime of the main imaging equipment significantly. Besides the challenges related to the cleaning procedure itself, the lack of a standard cleaning guideline resulted in confusion among the cleaning staff and challenged the cleaning schedule.

The operational relationship with the ED: The emergency department patients, similar to normal time, were repetitively brought to the imaging department through the existing paths between the departments. Considering the potentially uncertain status of the ED patients, it was vital to provide a secure path between the emergency department and imaging. However, due to the lack of such a secure pathway, the patients were transferred through shared corridors and potentially contaminated the space and equipment. The chief of radiology in facility 5 stated:

"Patents were seen in radiology before COVID test results were known, some were ended up positive known after the fact."

To resolve this challenge, the radiology staff recommended providing a dedicated imaging space inside the ED. This approach would eliminate the need for interdepartmental transfer and limit the exposure to the ED space. Such redundancy of imaging equipment and space can also be used across other departments or be planned to provide service through separated pathways and waiting for spaces in the adjacent areas.

Donning and Doffing: To accommodate the contaminated patients, the use of PPE is required by the imaging staff. However, there were not enough appropriate spaces for donning and doffing through the imaging department and the creation of such spaces is recommended by the staff.

Infection control - Adaptations

Supporting patient segregation: The imaging departments across the case studies were not designed to work with separated patients, staff, or equipment. Due to lack of redundancy, it was not possible to dedicate the imaging rooms to the separated groups, and shared use was widely unavoidable. However, by adding signage, or temporary partitioning in the staff support and patient waiting areas, simpler segregation and social distancing was possible to achieve. Overall, due to a lack of space and flexibility, it was not possible to do much within the imaging departments to support infection control.

In case of redundancy of space and equipment, dedicating the space and equipment to one patient population was effective to improve usability by eliminating the need for repetitive cleaning between the cases. Converting the available spaces for COVID patients, preferably the spaces for elective procedures that were temporarily not functioning such as ultrasound or mammography was possible in some of the facilities.

Mobile imaging: Also, the utilization of mobile imaging equipment was very effective and recommended by the imaging staff to reduce the downtime of the main equipment and patient movements. The use of mobile equipment did not result in physical adaptation of the facility but required enough space within the corridors and patient rooms to be able to maneuver and function properly.

Infection control - Built Environment features

- Larger waiting areas with the possibility to support social distancing and separated patients are recommended.
- Redundancy in the overall capacity of the main imaging equipment should be considered to support the separated patients without the need for terminal cleaning.
- Proving a secure access path between the imaging and the ED is vital. However, by providing an in-house imaging unit inside the ED, to some extent, the problem of contamination can be resolved.
- An appropriate space for donning and doffing attached to the imaging rooms should be provided to support the contaminated patients.
- The dimensions of the corridors and patient rooms should support the use of mobile imaging equipment.

Surge Capacity - Challenges, requirements, and recommendations

Scheduling: The scheduling of the imaging department was significantly changed through the pandemic. In the majority of the cases, the routine procedures were completely suspended (for up to a year), dedicating the imaging space and equipment to the emergency and COVID patients. This approach caused various problems such as huge backlogs of elective appointments and a lack of availability of imaging equipment for non-COVID patients.

Manpower: The cohorting and reassigning of staff to other departments along with the reduced number of staff in some work areas as a result of COVID protocols (social distancing) resulted in a general lack of manpower through the imaging departments.

Surge Capacity – Adaptations

Scheduling: To overcome the challenges resulting from the cancelation of routine imaging procedures, in some facilities, the overflow of non-COVID patients were referred to the nearby civilian hospitals.

Overall findings

Overview

This section presents the outcome of the coding procedure for the overall functions by thematic coding of the comments and responses that represented the concepts with potential implications within the most involved departments. . In the figures below, the distribution of the comments regarding their core concepts (infection control, surge capacity, or preparedness), their content category (challenges, recommendations, or adaptations), and their application context (operational or built environment) is presented.

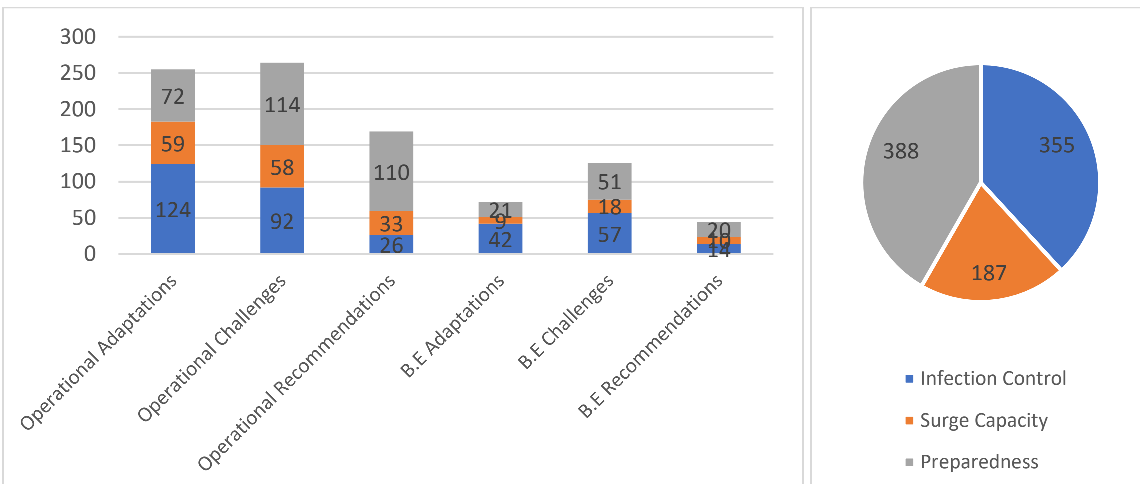


Figure 4.13. The distribution of interview responses, B.E: Built Environment

Figure 4.14. Presentation of the most repeated words across the comments

Infection control – Challenges, requirements, and recommendations:

Segregation: Across the case studies, separation of the patients through the facilities has been a serious challenge. The layout of the hospitals and their MEP infrastructure and features are simply not designed to support separated groups of patients inside the building. Also, this segregation extends to the staff that is caring for each group, their equipment, and the supplies. Moreover, to be effective, segregation needs to happen at all of the potential steps through the facility, from the first encounter through discharge.

Enter / Exit: To control the inflow of the patients, many of the included cases reduced the number of entrances to one enter and exit point (primarily through the ED). This approach resulted in a wide range of challenges for the patients such as delays and bottlenecks through the screening process, forcing the patients to wait outside in lines (in harsh weather conditions), and causing confusion and wayfinding difficulties (especially for the elderly). The chief anesthesiologist of the surgery department at facility 5 complained:

"Going to one entrance caused congestion with screening."

On the other hand, facilities with multiple entries faced challenges in controlling all of the entrances at once and ensuring the screening procedure for all of the entering patients. Also, multiple entrances meant multiple screening stations which increased the use of PPE and manpower. Overall, the participants recommended separating the staff entry from patients/visitors' entry, while planning to avoid bottlenecks by reducing enter/exit points.

Internal Flow: The segregation of the patients and staff through the building was required at different steps and spaces as they move about, receive care, or do different tasks. However, the layout of the facilities has not been successful in supporting the separated pathways. Besides the layout features, lack of adequate signage, and limited enter/exit points added to the challenges and made it more difficult. The head nurse of OB/GYN department in facility 3 mentioned:

> *"Patient flow requires positive patients to walk through other areas."*

Overall, it is preferable to limit the interdepartmental movement of staff and patients as much as possible by providing redundancy in equipment and staff while updating the scheduling and staff allocation strategies. The lack of dedicated elevators has caused a lot of disruptions and risks, requiring downtime for the elevators to be cleaned between use. To enable the segregation through internal flow, dedicated vertical circulation paths are recommended and utilized by the staff in case of availability.

Negative pressured rooms, isolation, and airflow: The included facilities were largely challenged by their limited capability for providing negative pressures and isolated spaces. The number of isolation rooms and rooms with negative pressure (or capable of having it) was significantly insufficient., and this problem was more serious in the critical care spaces (ICU).

The lack of isolation capacity in general, and lack of airflow handling capabilities are the most problematic factors. Most facilities had limited flexibility regarding the air pressure flexibility of the spaces (to change between negative and positive) and failed to provide individual pressurization for the separated spaces. It was an important goal for the hospitals to transform the existing spaces to have negative pressure and provide isolation capabilities, which was not supported properly by the building layout and MEP features. The age and condition of the buildings were directly related to their airflow management capabilities with older buildings having less flexibility and surplus capacity for the pandemic situation.

Remote working – Tele-health/work: One of the primary strategies for controlling the infection across the case studies was to reduce the number of people inside the building as much as possible. The remote tele-health/work workflow moved a large quantity of staff, tasks, and procedures to the virtual platform and was intended to reduce the number of people inside the building. However, this large transformation was needed to happen within a very short period of time, which proved to be challenging from the training, infrastructure, and equipment standpoints.

The existing bandwidth infrastructures were insufficient in many cases, while shortages of the equipment (laptops, cameras, etc.) delayed the implementation of the plan. Also, for many staff members (potentially the older population), extra training was required to use the equipment. Moreover, the quality of care through tele-health and virtual appointments was expected to be lower and less personal for the patients.

Disinfection procedure and support: The need for more comprehensive and more repetitive disinfection procedures (between each patient in some spaces) added to the workload of the cleaning staff significantly and consequently limited the number of patients that could use the equipment (imaging) or be seen by the physicians (exam rooms). Also, the lack of cleaning supplies and special equipment (UV lights, and air scrubbers) was consistent among the case studies and posed extra pressure on the cleaning staff while increasing the turnaround times.

Moreover, the lack of a standard and consistent cleaning protocol proved to be both labor and resource-intensive across the hospitals. It has also been challenging to keep track of the cleaning procedures and this issue cause more confusion regarding the usability and safety of the dirt / clean spaces and increased the turnaround times even more.

On the other hand, the surface materials of different areas of the building had a direct impact on the disinfection procedures. Materials such as carpets in large waiting areas proved to be not practical for the cleaning procedure while limiting the reconfigurability of the space for medical use.

Infection control protocols - Physical barriers: Installing Plexiglas shields were required and implemented in the reception areas in nearly all of the included cases, but the installation was associated with a number of challenges such as supply chain issues, and installation prolong delays, and vague regulations. The inconsistency in Plexiglas shield requirements and mandates (where it is required, what size, and how to install it) across some of the hospitals resulted in a no-shield policy and increased the concerns of cross-contamination over the reception areas.

Infection control protocols - Social distancing: Social distancing protocols reportedly required a lot of adaptations in the use of spaces reducing the number of people within the same spaces to reduce the chance of exposure. However, this approach exacerbates the problems related to the limited available space. As a result, social distancing reduced the overall capacity in waiting spaces, staff workspaces, and support areas including the staff breakroom and team rooms. The scale of these spaces was designed based on the limits of normal use and is not enough to accommodate the same number of users with social distancing. The chief of inpatient pharmacy at facility 8 mentioned:

> *"Waiting area too small for social distancing with large numbers of patients."*

Infection control - Adaptations

Wayfinding: During the pandemic, as a result of facility operational and structural adaptations, there were various factors that could potentially deteriorate the wayfinding capabilities of the users on the campus and inside the buildings. For instance, among the included cases, some of the functions were relocated, entrances were closed off or limited, new exterior functions were added (tents or trailers), and drive-through services were provided (pharmacy, testing, or vaccinations), all of which changing the existing entrance sequence and flow of the building. Therefore, strategies such as adding signage, temporary barriers, and dedicated staff members have been used to overcome this issue and direct the patients to the correct spaces.

Segregation - Enter/Exit points: Reportedly, being able to start the segregation from the beginning and controlling the inflow of the patients, staff, and visitors to the hospital was a vital factor to control the infection spread inside the building. Across the included case studies, there were conflicting views on how to maintain control over the entrances. In most cases, the staff have reduced the entrance to a single point, arguing that it would help with the control over the entrance, creates a "one-way" flow, and increases the effectiveness of the screening procedure.

However, this finding sharply contradicts the outcome of the literature review, in which segregated entrances for COVID and non-COVID populations is desired and deemed effective. Also, across the case studies, the single point of entry proved to be impossible to use for a number of patients due to the distance and their medical condition.

Segregation - Scheduling: The segregation practice was extended to the staff teams to avoid cross-contamination among the staff and between the patients. This staff segregation is majorly implemented by adapting the scheduling, creating team modules, and having on/off workdays for the cohort staff.

Negative pressure, isolation, Airflow: To improve the isolation capability and capacity of the hospital and managing the airflow within and between different spaces, a number of general changes and adaptations in the building layout and mechanical systems have been used through the case studies. The isolation capacity, along with the capabilities of the air handling system to provide clean air have been largely mentioned by the participant to be insufficient.

To overcome the problems related to insufficient isolation capacity and negatively pressured rooms, some facilities had plans for utilizing separated spaces (barrack buildings) as isolated units. It is reportedly rather difficult to reconfigure the spaces to be affected negatively pressured and isolated if they are not designed to do so. Providing a fresh supply of outside air and avoiding recirculation of air is necessary to have overall cleaner air inside the building. In spaces where there are no possibilities for isolation, increasing the air change per hour (ACH) rate was a helpful method to reduce the chance of contamination.

Remote working – Tele-health/work: Besides the segregation approach, reducing the overall number of people inside the building and avoiding face-to-face encounters altogether is another effective strategy to reduce the chance of exposure. In line with this idea, a significant number of tasks inside the hospitals have been done remotely (teleworking). The words tele-health and teleworking were used interchangeably throughout the reports; however, the comments were unanimous in terms of the challenges, required changes, and adaptations, necessary for effective use of remote working. All of the non-essential staff (non-essential in terms of the need for physical presence) were sent home and were asked to keep their work remote as much as possible.

The tele-work/health in the medical context was also effective for lower-risk patients in general, responding mainly to the non-COVID patient populations and elective appointments to reduce the chance of exposure during the non-emergency procedures\. For remote working to be effective, the supply of required equipment should be planned far in advance and the necessary infrastructure inside the building (private offices with cameras, monitors, and sufficient data lines) should also be designed accordingly.

Disinfection: Compared with normal cleaning protocols, the pandemic requires more intensive cleaning procedures and scheduling. Some of the shared spaces with heavily used equipment (imaging department) by a large number of patients and staff and high touch areas, in general, require more repetitive cleaning. There are also new surfaces to be cleaned (plexiglass shields) that add significantly to the workload of the cleaning staff.

The more intensive cleaning tasks required extra resources, manpower, and workload from disinfection staff, potentially operating as segregated teams across the building. To support the extra workload and segregated spaces, there was a need for a pre-planned strategy supporting the potential changes in disinfection tasks. This plan requires the necessary reserve manpower, training programs, cleaning supplies, storage, and support areas for the extra (and separate) staff.

Infection control - Built Environment features

- The AHU and all the involved mechanical components of the buildings are required to provide more flexibility, while being able to act independently for the potentially separated and isolated units.
- Overall, the MEP capacity of hospitals requires extra headroom, specially for the spaces that are working near their limits such as ED and ICU.
- The IT departments required extra bandwidth and a ready supply of equipment (laptops, etc.) to support the large-scale transition to remote working.
- Also, the accessibility to MEP support and IT lines for potential expansions, and temporary external add-on spaces should be provided.
- Multiple entry points for staff and patients with adequate space for screening procedure and holding areas should be considered.
- Across the most involved departments, support areas for separated teams should be considered.
- The building circulation paths, and vertical access points should support segregation through redundancy.
- Inside the building, dedicated spaces with data access and minimum noise should be considered for remote working and virtual appointments.

Surge Capacity – Challenges, requirement, and recommendations

Manpower - Cross-training: Cross-training was one of the primary strategies across the case studies to improve the capacity of the facility, however, it was also a challenge from a logistical and scheduling standpoint. Many of the staff did not have the needed experience and knowledge to care for the critical COVID patients, requiring an extra amount of training and resources. Also, despite the benefits of cross-training in optimizing the available workforce within the hospitals, relying on this strategy deprives the source departments of their staff and causes collateral damage and delays to the less-vital functions of the hospital. The participants recommended optimizing the cross-training by directing it to the more vital roles, with a regular yearly refresher training structure.

Manpower - Staff Allocation: The staff allocation strategies have also been significantly impacted by the pandemic. The shortage of staff was at both times resolved and exacerbated by the uncoordinated allocation decisions. In many cases, staff was cross-trained and sent to help with the COVID mission in other departments and even other hospitals, leaving the source unit understaffed. Lack of preparedness plans for the replacement of the lost manpower resulted in a lot of shortages across the case studies and caused holds in other departments functioning.

To resolve the staff allocation challenges and the consequent shortages, a more comprehensive assessment of the hospital staff members' numbers and capabilities is recommended. Having a more focused strategy in redefining the tasks can potentially optimize the performance of the staff that is appointed to these tasks and could also prevent overworking and unnecessary multitasking.

Manpower - Extra staff: The complicated and time-consuming administrative procedure for hiring new staff made it extra challenging to add the needed manpower in a timely manner. This issue pushed the facilities to overuse the staff from other departments via cross-training, causing shortages in other departments. To overcome the challenges, requesting the staff earlier, and having reserve manpower available were recommended.

Manpower - Staff numbers: The available number of staff through the facilities was generally insufficient, especially within the most involved departments of ED, ICU, and inpatient. Besides, the lack of coordination between the scheduling (fixed deadlines) decisions and the number of staff (which was subject to change) resulted in delays and contradictions. Loopholes and time off opportunities also incentivized the staff to take a leave of absence and further reduced the manpower capacity. The limitation of manpower increased the load on the present staff, adding significantly to their workload and resulting in a lot of overtime, fatigue, and burnout.

COVID cross-infection caused a lot of damage to the available workforce of the hospitals. In many cases, staff were quarantined due to exposure (14 days), or sent home because of extra risk for their health, while not having any replacement planned.

Evidently, it is important to have plans in place to operate the hospital with reduced staff. Besides, the participants recommended establishing rapid hiring procedures, to be able to increase the capacity of the hospital in a timely manner. Having a pre-planned reserve of staff is the key to facilitating the replacement of the lost staff due to relocations, or other factors.

Manpower - Specialized Staff: The problem of staff shortage was mentioned to be more severe for the specialized staff with COVID-related skills and experience. Roles such as registered nurses, respiratory therapists, and infection preventionists were in high demand while in reality being provided by a very limited number of staff.

Space - Expansion: The overall shortage of capacity was more evident in the departments that had been operating near their limits. In some facilities, the number of available beds was simply not enough, while due to physical limitations, expansions (both within the building or through the external space) were not possible. The participants recommended the use of completely separated and dedicated buildings to COVID and non-COVID patients.

Surge Capacity - Adaptations

Manpower - Equipment and manpower allocation: Across the most involved departments, it was common to pull the equipment and manpower from other parts of the hospital. Some specific equipment (testing instruments) had an important role in maintaining the flow of the patients by providing more capacity. The staff was needed to work fluidly between the departments. The adaptations in the scheduling freed up manpower capacity (mostly from the elective appointments and procedures to be used for COVID tasks including disinfection and cleaning, screening, testing lab work, nursing, ICU care, and respiratory care.

The adaptations in staff allocation and scheduling were done by dedicating the staff to COVID teams working at different locations and generally through more working hours and increased workload. More importantly, the “new” functions and spaces including screening tents and trailers, and the drive-through services (testing, vaccinations, and pharmacy) required the whole team to be provided from the existing departments. The lack of constantly available staff members for these functions causes confusion.

Space - Expansion: Within the included facilities, the limitation of space, bed capacity, and availability of staff and equipment forced some of the hospitals to expand their physical capacities of different departments. These expansions took place through various approaches including relocation of patients to other spaces, reconfiguration of adjacent spaces (waiting rooms, PACU, etc.), layout modifications, adding external structures (tent or trailers), or using external sites (other buildings). To decide when the facility or a department needs eighter of these strategies, trigger points were defined (specific number of patients) as the limit to go for the expansion strategies. As the patient numbers reached the limit, they were transferred (overflowed) into the planned expansion spaces.

Besides the lack of capacity for COVID patients, because of new safety measures, alternate locations for some of the functions were considered to increase the capacity while improving the infection control capabilities. In other words, the limitation of space was not the only factor to necessitate the need for expansion spaces, the infection control requirements also had an important role in the expansion-related decisions.

Surge Capacity - Built Environment features

- Providing the necessary MEP outlets in strategic locations for temporary support lines to tents and trailers is recommended.
- Accommodating temporary partitioning and zipper walls with isolation capabilities is vital for key connection points. Adding appropriate mounting points along with dedicated air exhaust can facilitate these adaptations.
- Considering enough open space near the building entrances for screening spaces is necessary. Also, having the necessary MEP support to maintain the temperature in the temporary tents and trailers is requested.
- Considering the secondary functions of the pre-planned overflow spaces is vital to enable compatibility and smooth transitions. Also, the closeness and secure pathways between the main and overflow spaces should be provided.
- Overall, having some sort of headroom in unit capacities is important and working near capacity should be considered as a warning sign.
- Having larger waiting rooms with possibility of separation of access and the main area should be considered.

Preparedness – Challenges, requirement, and recommendations

Communication - Call center: Maintaining the communication line between the facility and patients proved to be challenging across the case studies. Various types of temporary call centers or answering staff were utilized to respond to the outside. The staff recommended establishing an actual call center for individual units to improve the functionality of the units through the pandemic. However, the required space for adding a call center was not available within the limited space of the buildings. Also, being able to operate 24/7 with social distancing consideration added to the required main and support space for the call center.

Communication - Coordination: Lack of coordination in information distribution and decision-making was evident across the majority of the case studies. The participants were reportedly challenged by the constantly changing and competing guidelines coming from various sources at the leadership or from the outside. The uncoordinated directions and decisions on regulations and protocols resulted in a lot of confusion and frustration among the staff, causing delays and disorganized implementation of physical and operational adaptations.

The staff recommended having a solid communication plan in place in advance, considering the end-users perspective, and involving the staff in decision-making procedures. Clearer and more cohesive output from the leadership and having a singular point of coordination with more frequent synchronization events (meetings and reports) were also mentioned as effective measures to improve the operational coordination among the staff. Based on the comments, the operations, public health, environmental services, and command staff are evidently the key point of coordination for the rest of the facility.

Guideline/Regulations/Policies: The constantly changing guidelines, delays for information accessibility, and lack of clear communication from CDC to the leadership, and from the leadership to the staff exacerbated the situation. Better and more centralized command communication of guidelines (CDC or local) and real-time coordination for the dynamic policies were required by the staff as a way to improve the implementation of the regulations and guidelines.

Information accessibility: Overall, the lack of preparedness in the existing workflow and infrastructure to support the chain of information proved to be extremely challenging. In some cases, misinformation was reported and caused extreme confusion among the staff. Within the individual facilities, the performance of the leadership and "operations" are the key factors in transferring the latest updates and information around COVID. More centralized points of distribution and clearer communication methods are mentioned as effective methods to improve the accessibility of information.

Neighboring facilities: It is also important to maintain communication between the neighboring facilities. The real-time updates can be used to optimize the use of manpower and resources between the facilities at a larger scale. The NCOIC of primary care in facility 3 stated:

> *"Need to have a local connection with outside hospitals that will allow for discussion on supplies and capacity."*

Contingency plans: The contingency plans are the core concept of preparedness and were mentioned to be non-existent or dysfunctional by a large number of staff. The "unknown" nature of the COVID-19 novel disease pandemic was mentioned as the greatest challenge by the participants regarding how they needed to prepare for response. The existing contingency plans were not clearly defined for a pandemic of such characteristics and scale and considering the amount of uncertainty around COVID-19, the staff had to prepare for the absolute worst which put extra pressure on the facilities and cause a lot of delays for the updating protocols to put in place.

The contingency plans for the "unknown" should be as flexible as possible and act proactively. Also, the system should be tested for its resilience through the potential implementation of contingency plans both from the physical and operational perspectives. The speed with which the response measures are required is different through the pandemic and the short-term and long-term solutions within the plan should be considered accordingly.

IT - Equipment/training: The transition into remote working for a significant number of staff was expected within a short period and needed to be done by the IT staff. However, providing the required number of laptops and other necessary equipment along with the necessary training proved to be challenging. Besides, the limitation of the teleworking platform was also an issue. The staff should be provided with teleworking packets with ensured access to the VPN, adequate bandwidth, and the necessary training.

Supply management: The shortage of sanitization and PPE supplies (such as gloves, masks, safety glasses, etc.) was widely mentioned by the participants as one of the main challenges in supply management throughout the pandemic. Supply chain issues, dependence on single vendors, and lack of coordination between the manufacturers, vendors, and hospitals were among the primary reasons for supply management challenges and lack of preparedness. Due to the lack of adequate PPE, various strategies such as multiple reuses, prolonged usage, and even shutting down the care delivery services were mentioned by the participants.

Although the supply-related issues are primarily sourced outside of the facilities, based on the experience from successful cases, having contingency plans for early restocking of the supplies was effective to prevent shortages. More flexibility for the available supply vendors, enough storage spaces, rotation of supplies (to avoid expiration), and having additional supplies in place and available are the key factors.

Preparedness - Adaptations

Information accessibility: The circulation and accessibility of information through the hospital was a key feature of the staff's ability to cope with the fast-changing requirements throughout the course of the pandemic. Daily updates and announcements about the COVID requirements and protocols were very effective in keeping staff informed and optimizing the use of resources, manpower, and equipment.

COVID-related team meetings and briefing sessions were among the most effective operational adaptations to enable the circulation and accessibility of information for the staff. The meetings were held at various levels from units to interdepartmental and facility (with representatives from each department) levels to coordinate the COVID response and optimize the use of available manpower and resources. The meetings have also been an effective way of distributing information about the latest guidelines and regulations and providing updates about the pandemic progression.

Supply Management: The preparedness of the facilities to provide the necessary supplies was significantly different from case to case, emphasizing the importance of supply management strategies and preparedness plans. The vast shortage of supplies in some cases (PPE, disinfection supplies, and general COVID supplies), resulted in many adaptations to cope with the demand and resolve the shortage difficulties. Among the successful cases in managing the supplies, early planning and restocking of the necessary supplies far in advance have been the most effective measures in increasing preparedness and avoiding shortages. These facilities were also able to support other hospitals that faced significant shortages.

CHAPTER FIVE

PHASE 3: COMPARISON OF THE FINDINGS & PANDEMIC RESPONSE DESIGN GUIDELINES

Overview

The first two phases of this study have generated evidence of COID-19 impacts, challenges, and the implemented response adaptation within international civilian and United States (US) military medical centers. Throughout the military case studies, no significant information about the particular impact factors of the pandemic including the changes in patient populations were mentioned, but the results of the impacts were comprehensively included in the shape of pandemic challenges.

The comparable challenges, along with the response measures and built-environment features made it possible to analyze the data from both sources as a whole. By conducting a comparative analysis, focused on the most involved components of the hospitals, we were able to provide evidence-based insights to identify the potentially effective built environment (MEP and architectural) features and understand how we can support these features through the design and decision-making process.

In the current chapter, the findings of the two sources of data are standardized and compared to highlight the potential similarities and differences. This comparison aims to generate a more comprehensive perspective on the topic of pandemic response and ultimately respond to the final research question of this study. The outcome of this comparison is a comprehensive list of main themes of design guidelines to support pandemic response strategies.

Before presenting the outcome of the comparative study and design guidelines, we need to gather some insights about the similarities and differences between the civilian and military health system (MHS) facilities in terms of patient populations, staffing, healthcare system strategies, and special functional characteristics (role of the facility).

Comparison procedure:

To be able to compare the results of the literature review and case studies, the structure of the findings needed to have a standardized format using similar constructs and definitions. The standardization of the outcomes was possible through the standard framework of the study as the shared structure between the two phases of data analysis. The framework is easily applicable for the case study coding output since it was used as the main source for developing the coding structure from the beginnings.

Similar to the framework, the case study information was analyzed to distinguish the data based on the departments, the type of application (operational/structural), and the architectural or MEP implications of the design features (through the previous chapter). In most cases, depending on enough evidence for the similarity of the content, the definition of the similar themes was standardized between the two data sets to represent the same factors, and the content of the thematic analysis was updated to represent the standardized definition of the themes.

In the following sections, the main themes of pandemic challenges, response adaptations, and the supportive built environment features are presented for each department and were compared to the literature review findings. The comparison is done at departmental and holistic scales, assessing the main themes along with sub-code definitions and implications.

There are a few points of major differences between the two data sets with are resulted from the available content in each case. As previously mentioned, the content of the case study reports have not provided direct information regarding the impacts of the pandemic; however, a significant number of comments addressed the resulting challenges from the impacts and the deficiencies of the operational and built environment structure of the cases. In the end, the contents of these two columns were not directly comparable, but there were many cases of close similarities between the themes of impacts and pandemic challenges (challenges being the direct result of impacts) that were discussed.

Both sources have provided enough evidence to distinguish between infection control and surge capacity factors as the primary categories; however, only across the case studies, as a large number of themes did not belong to either group. and was dedicated to the more general category of preparedness against the pandemic. The content of this group is not comparable to the findings from the literature review and should be considered separately.

By comparing the results to the outcomes of the literature review, we can clearly see that the case study analysis has provided a much more detailed and comprehensive source of information for understanding the pandemic challenges and adaptations. The majority of the themes and concepts across the case studies are completely applicable for the civilian hospitals.

Also, the case study themes were associated with much clearer comments from the end-users of the spaces, and therefore are potentially more reliable. However, the literature review findings include a more holistic perspective and represent a broader range of case studies in terms of scale, involvement in response, and defined roles through the pandemic and can potentially cover the gaps of the case study analysis.

The outcome of this comparison is presented as a final list of design guidelines contributing to more effective pandemic response. These guidelines are designed to facilitate the implemented or desired adaptations and respond to a particular set of challenges that are expected in future similar pandemics. The guidelines are presented at the final section of this chapter from the implementation concept perspective along with the associated diagrams and sample plans.

The specific guidelines that were only applicable within the individual departments are addressed by samples and documents representing the general structure of the associated department as the context of implementation. The sample standard plans and documents from various sources are used to represent the before (existing practice) and after the guideline's implementation.

Emergency department and CSTC functions

Comparison of the findings

In the following figures, the list of identified themes of challenges, adaptations, and supportive built environment features through the literature review and the included case studies' ED and CSTC/vaccination space are presented. By comparing the identified themes through findings, we can highlight the similarities and differences in terms of response strategies and draw the connections between the challenges and solutions.

Both sources have mentioned the crowding and large suspected and uncertain patient populations within the EDs as major challenges. However, the case study analysis provides a much more detailed thematic presentation of the challenges, directing the problems towards small waiting spaces, shortage of manpower, and open layout of the ED. Also, lack of isolation capacity was significant in all of the cases.

Regarding the response adaptations, both sources have mentioned segregation as the key goal and contributor to infection control, and similar temporary solutions such as partitioning, zipper walls, and utilization of separated spaces were mentioned to be effective. Similarly, the utilization of internal soft spaces is mentioned as a strategy to increase the capacity, but it proved to be challenging through military case studies.

Although the thematic analyses were conducted completely separately and at significantly distant times, through the identified built environment features, a significant number of similarities were evident.

The items of critical care capacity, layout configurations (orthogonal and H shape), and modular components were identified as the points of difference and were added to the case study's list of supportive features to achieve a comprehensive list. In the following table, the overlapped themes are coded as green, and the differences are red. The text in black are representing the general information about the impact of the pandemic and therefore were not comparable.

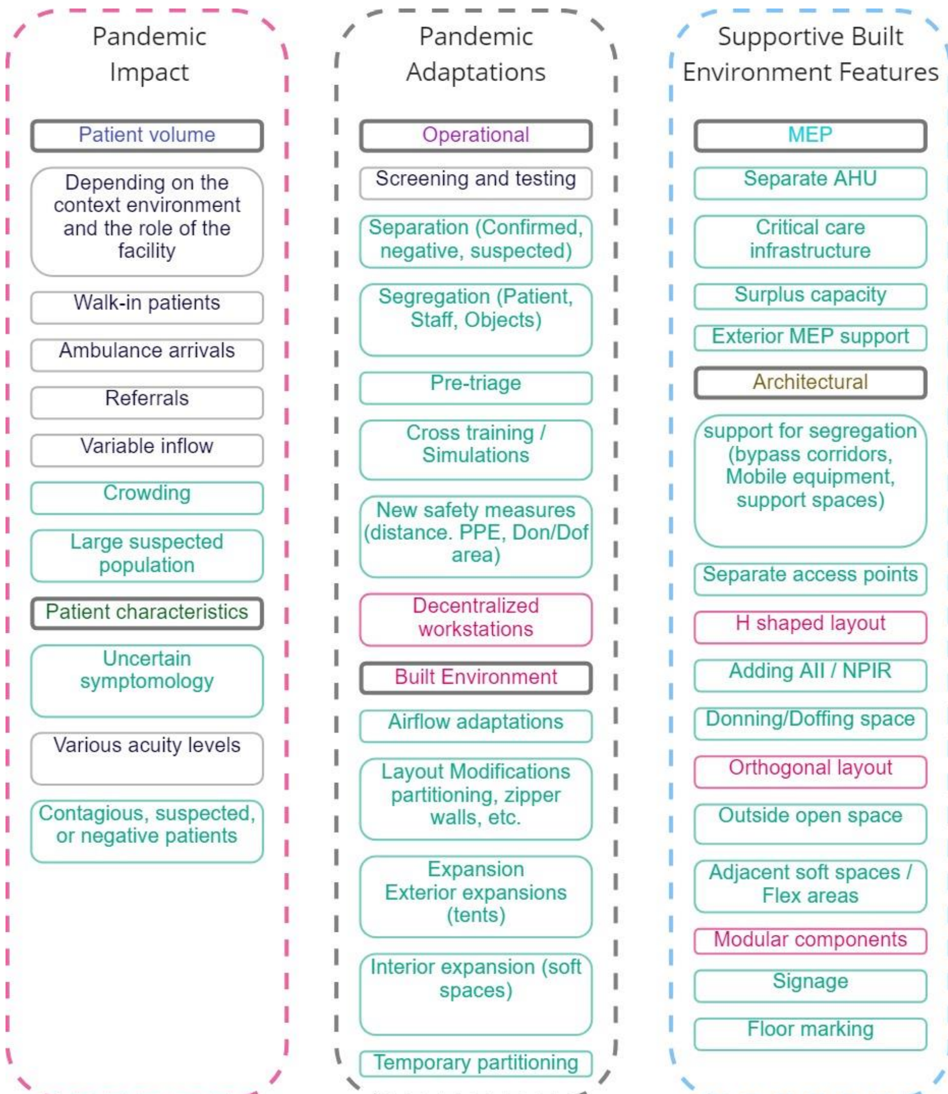


Figure 5.1. Thematic analysis of the findings within the literature review for the emergency department (and the integrated testing/screening functions),

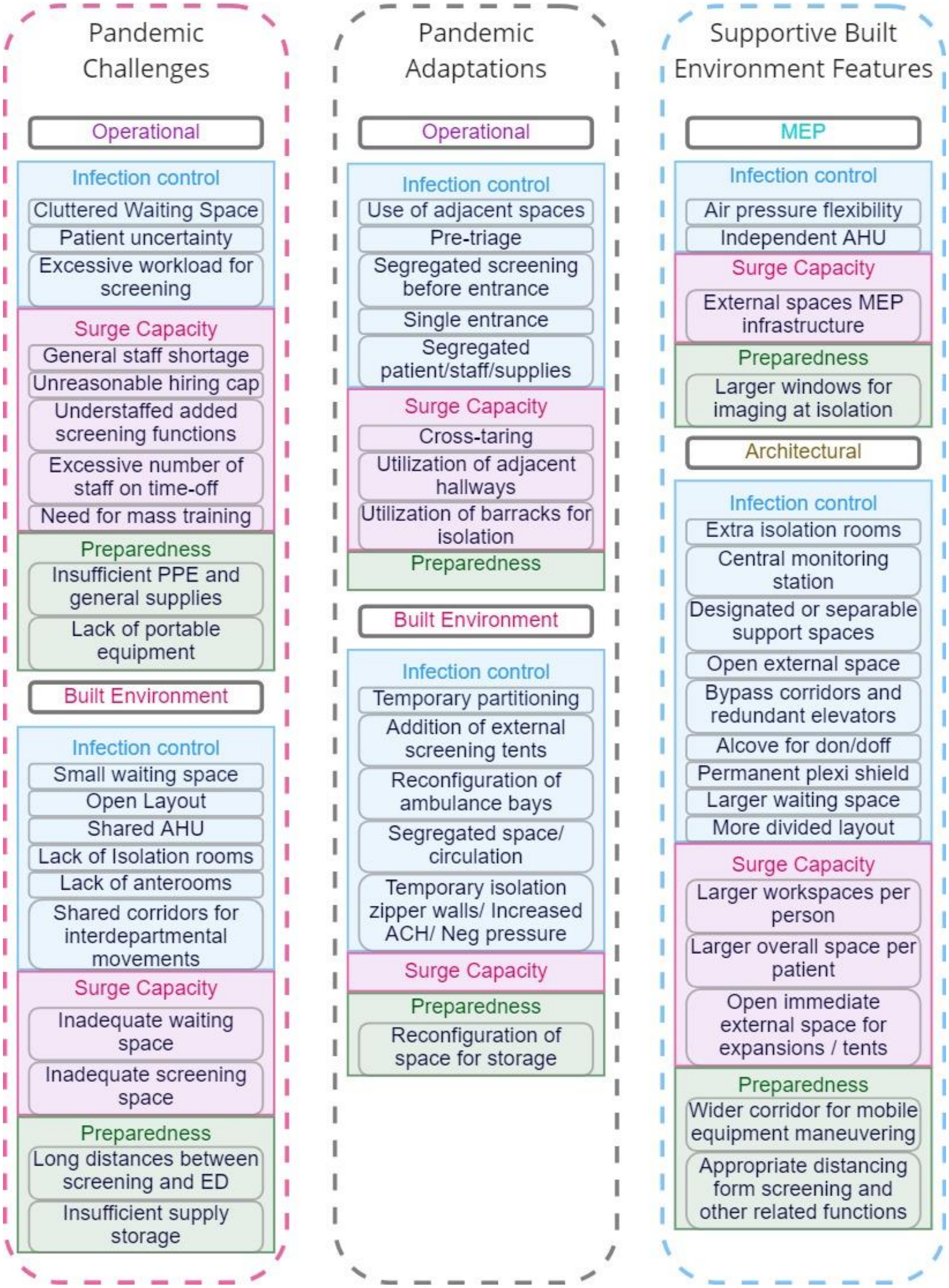


Figure 5.2. Thematic analysis of the findings within the report case studies emergency departments

Through the case studies, an evident distinction between the ED space and CSTC and vaccination functions was evident. These functions along with pharmacy were provided through separate spaces (in some cases as drive-through stations). Therefore, the following list directly represents the "separated" CSTC and vaccination functions that are potentially provided separately from the ED.

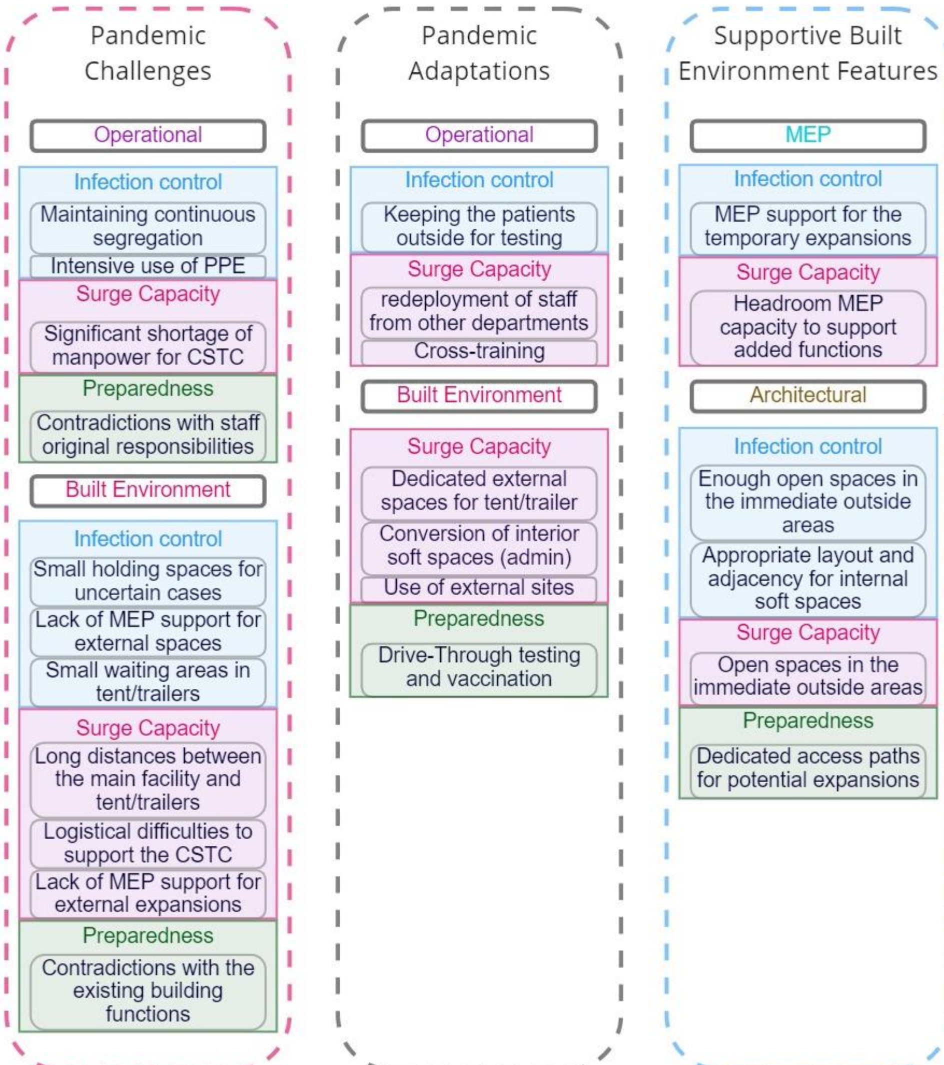


Figure 5.3. Thematic analysis of the findings within the report case study's separated CSTC and vaccination

Inpatient and ICU departments

Comparison of the findings

Within the literature review case studies, the reconfiguration of multi-bed patient rooms into single bed units was mentioned which was not the case throughout the case studies. However, the general limitation of capacity due to infection control protocols were mentioned by some of the staff.

Access to fresh air and the overall accessibility of MEP equipment were other special items mentioned exclusively in the literature. Moreover, the general concept of modular design, regarding the repeated units with potential for expansions into the adjacent soft spaces (following the same modules) was mentioned as an effective design approach across the literature.

On the other hand, through the inpatient departments, a significant degree of overlap was evident between the case studies and the literature review findings. Similar challenges regarding the need for a critical level of care and access to diagnostic (mobile) imaging devices were unanimously mentioned.

The concept of segregation is extended through the inpatient and ICU departments, with a difference of patients being divided into certain groups of contaminated or clean with no uncertain or awaiting cases. The segregation of patient flow from the ED to either of these departments was another point of difference.

Similar adaptations including partitioning, temporary zipper walls, and airflow adjustments were mentioned in both resources. Also, extensive cleaning procedures and UV treatment of patient rooms between cases was unanimously mentioned.

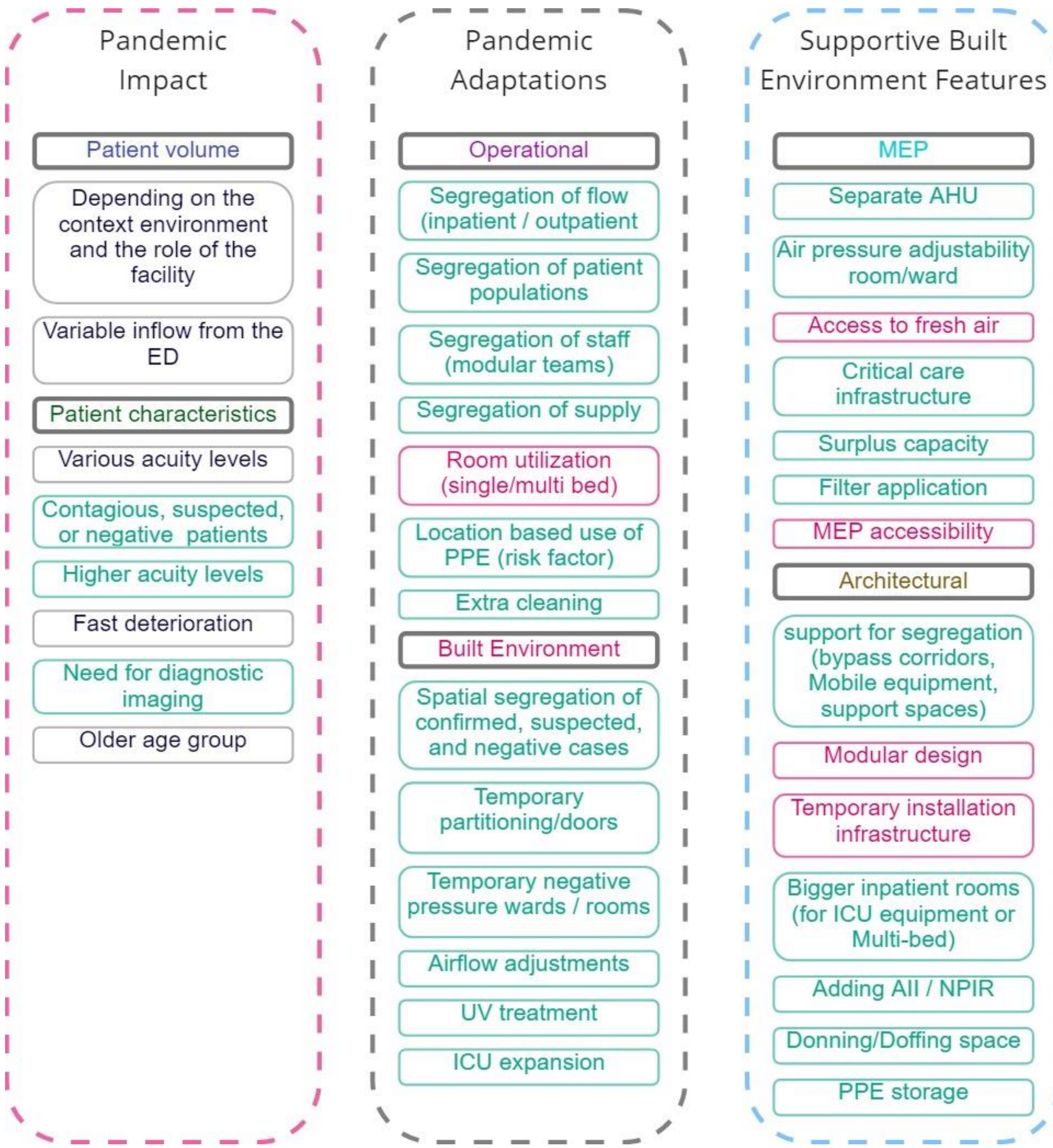


Figure 5.4. Thematic analysis of the findings within the literature review for the inpatient and ICU departments.

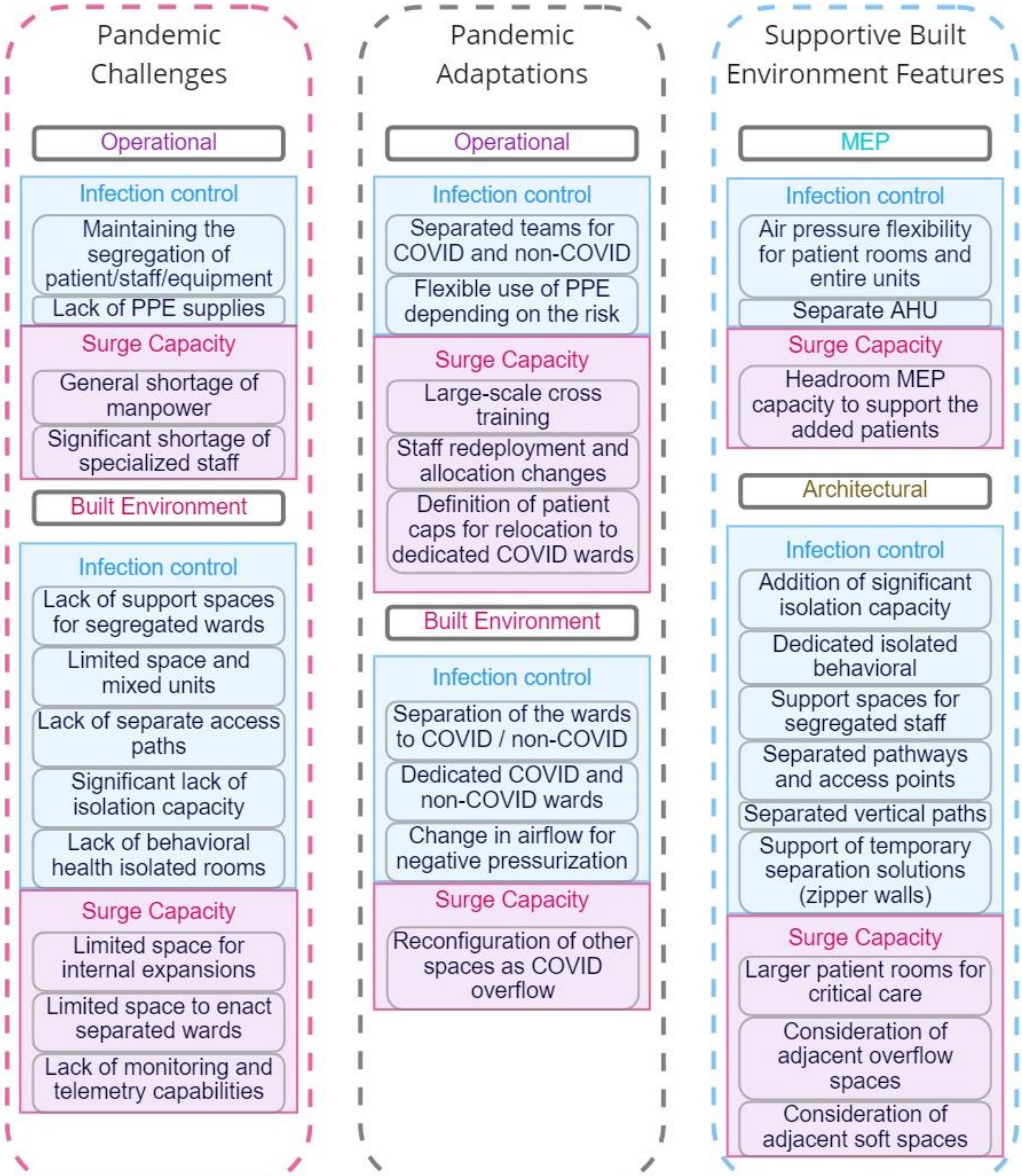


Figure 5.5. Thematic analysis of the findings within the report case study’s inpatient departments

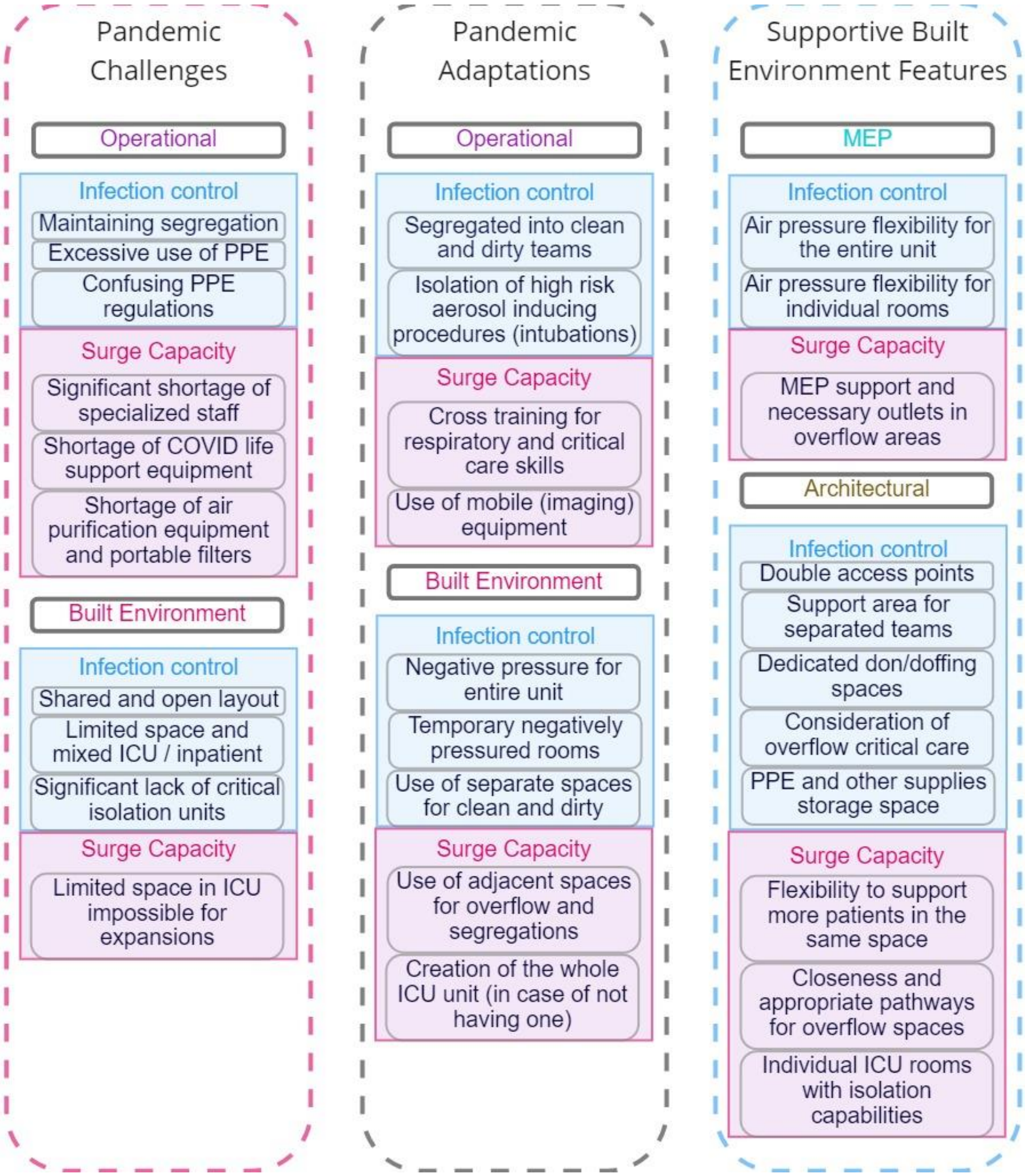


Figure 5.6. Thematic analysis of the findings within the report case study's ICU departments

Imaging department

Comparison of the findings

Within the imaging departments, the case studies presented a far more detailed set of challenges related to the pandemic compared to the findings from the literature review. Insufficient and cluttered waiting areas, lack of donning and doffing spaces, and long distances from the key functions (specially ED) were among the unique challenges mentioned in the case studies.

On the other hand, the use of temporary external imaging units was the main point of difference in the response adaptations between the data sources. Based on the literature review findings, in the initial phases of the pandemic and lack of faster chemical testing procedures, heavy reliance on the imaging modalities was common among the facilities. A number of cases in the literature utilized external imaging units for screening and testing purposes.

This strategy was very effective in eliminating the need for bringing the uncertain patient inside through the shared spaces to the imaging department. However, this strategy was not mentioned across the included military case studies. Also, through the case studies, unique comments were mentioned to recommend the use of dedicated donning and doffing spaces.

Both resources provided evidence regarding the cancelation of elective procedures due to a lack of redundancy in the main imaging equipment. Similar strategies were used to continue the segregation of staff, patients, and equipment; however, through the case studies little was done to achieve segregated space. This factor was mainly due to the limited available space and lack of redundancy. Other less intensive strategies such as signage and reconfiguration of furniture were used to improve safety, although being not so much effective.

Similarly, the implementation of segregated and redundant access paths between the most involved departments and imaging, along with the accommodation of mobile imaging equipment was mentioned in both resources.

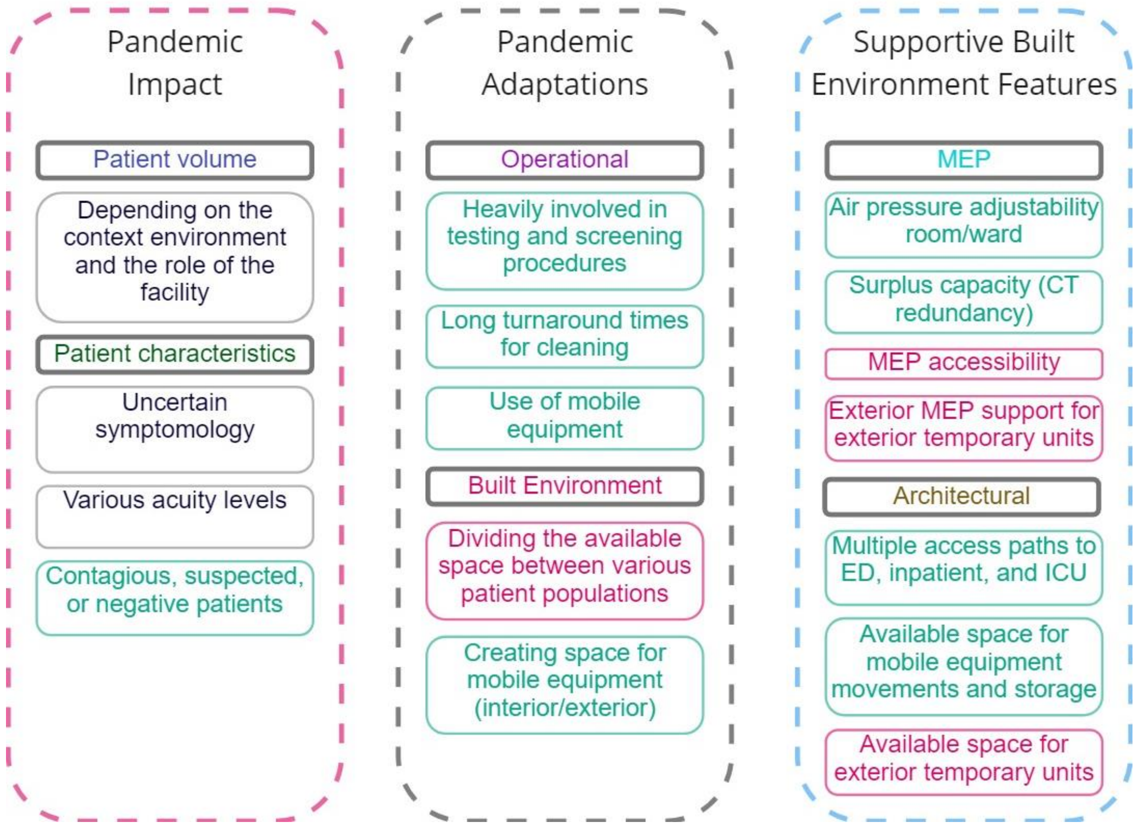


Figure 5.7. Thematic analysis of the findings within the literature review for the imaging department.

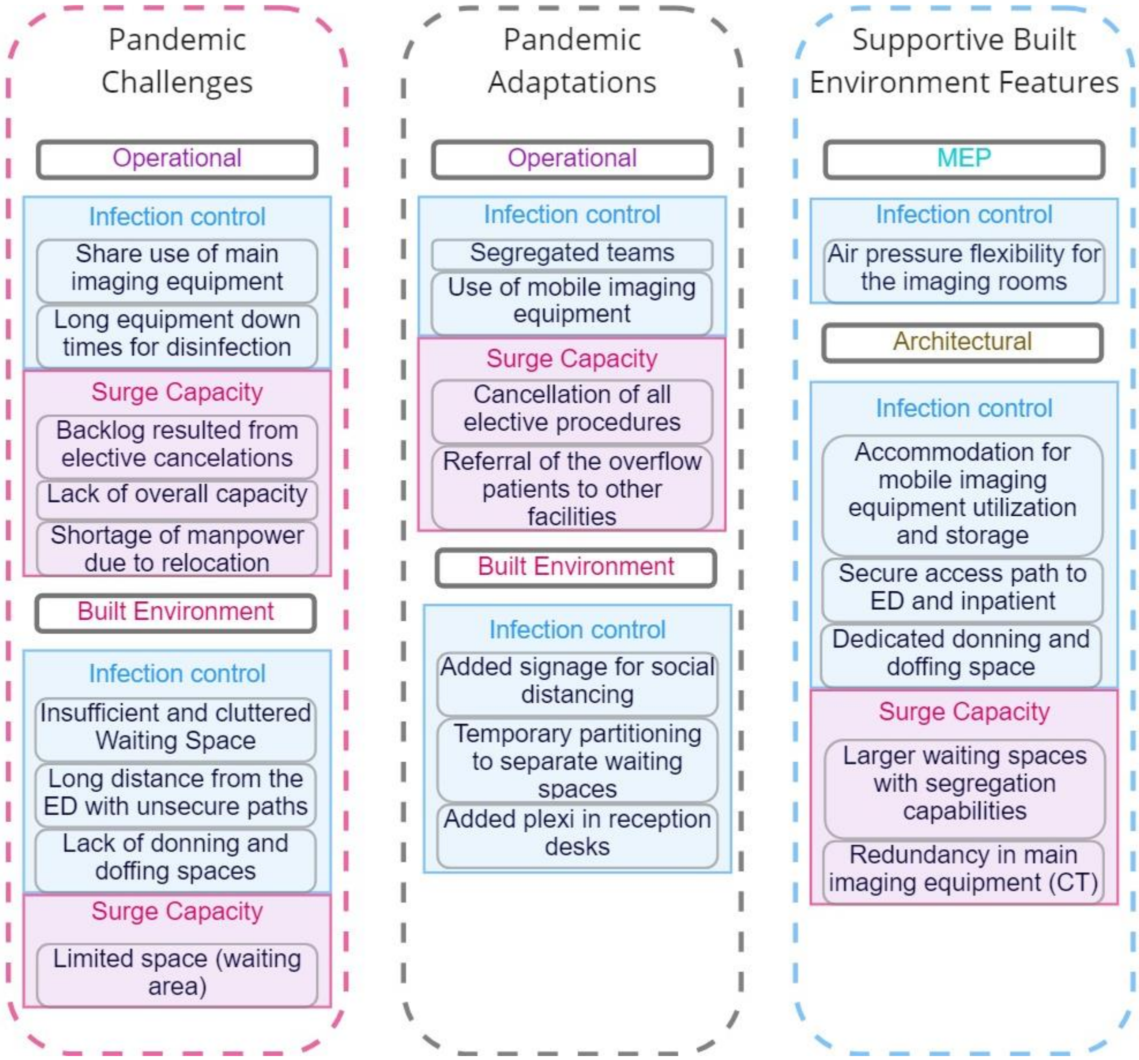


Figure 5.8. Thematic analysis of the findings within the report case studies imaging departments

Overall findings

The literature review was completely focused on the included departments of ED, ICU, Inpatient, and imaging, and was not aimed to gather data on the overarching challenges, responses, and features. However, due to the importance and effectiveness of the general COVID-related challenges, adaptations, and features with potential implications or impact in each of the included departments, the related information through the case studies was coded and analyzed to provide a comprehensive body of knowledge. Another factor contributing to this part of the data was the vagueness of a significant portion of interview responses regarding their specific areas of implication while showing clear applications in COVID responses.

Therefore, in the following figure, the overarching factors with potential implications for COVID response in each of the included departments are presented. From the design perspective, besides the included departments, the “overall” section covered the interdepartmental elements of the hospitals including the overarching protocols, horizontal and vertical circulation paths, and holistic characteristics of the building.

This section also provided a generalized version of departmental strategies to improve infection control, surge capacity, and preparedness. From the infection control aspect, the concept of continuous segregation (people, spaces, and objects) and overall isolation capabilities were included. In the case of surge capacity, manpower enhancements through, adapted scheduling, cross training, and redeployment, along with space capacity increase through expansions, and layout modifications were mentioned.

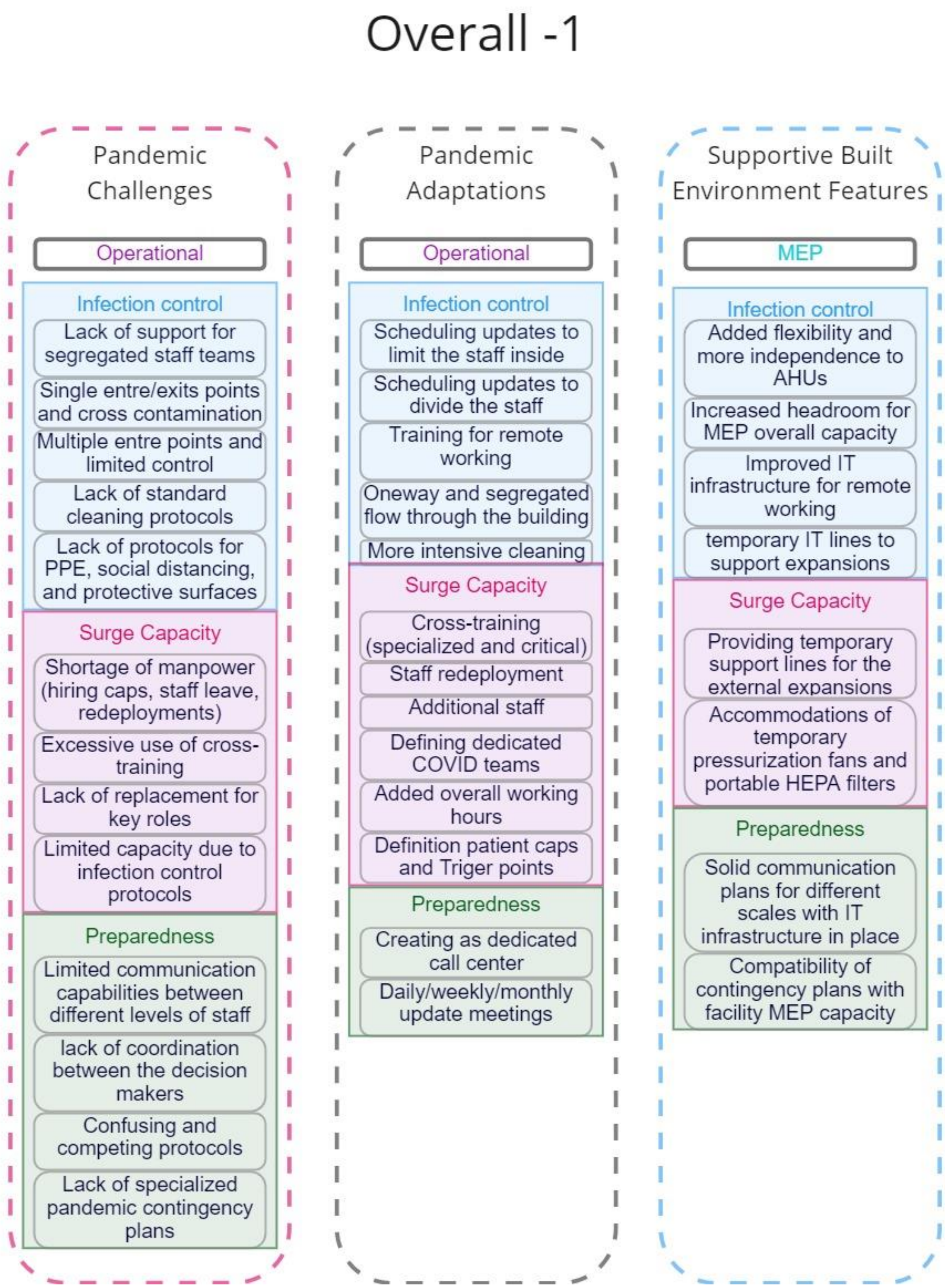


Figure 5.9. Thematic analysis of the findings within the report case studies overall findings

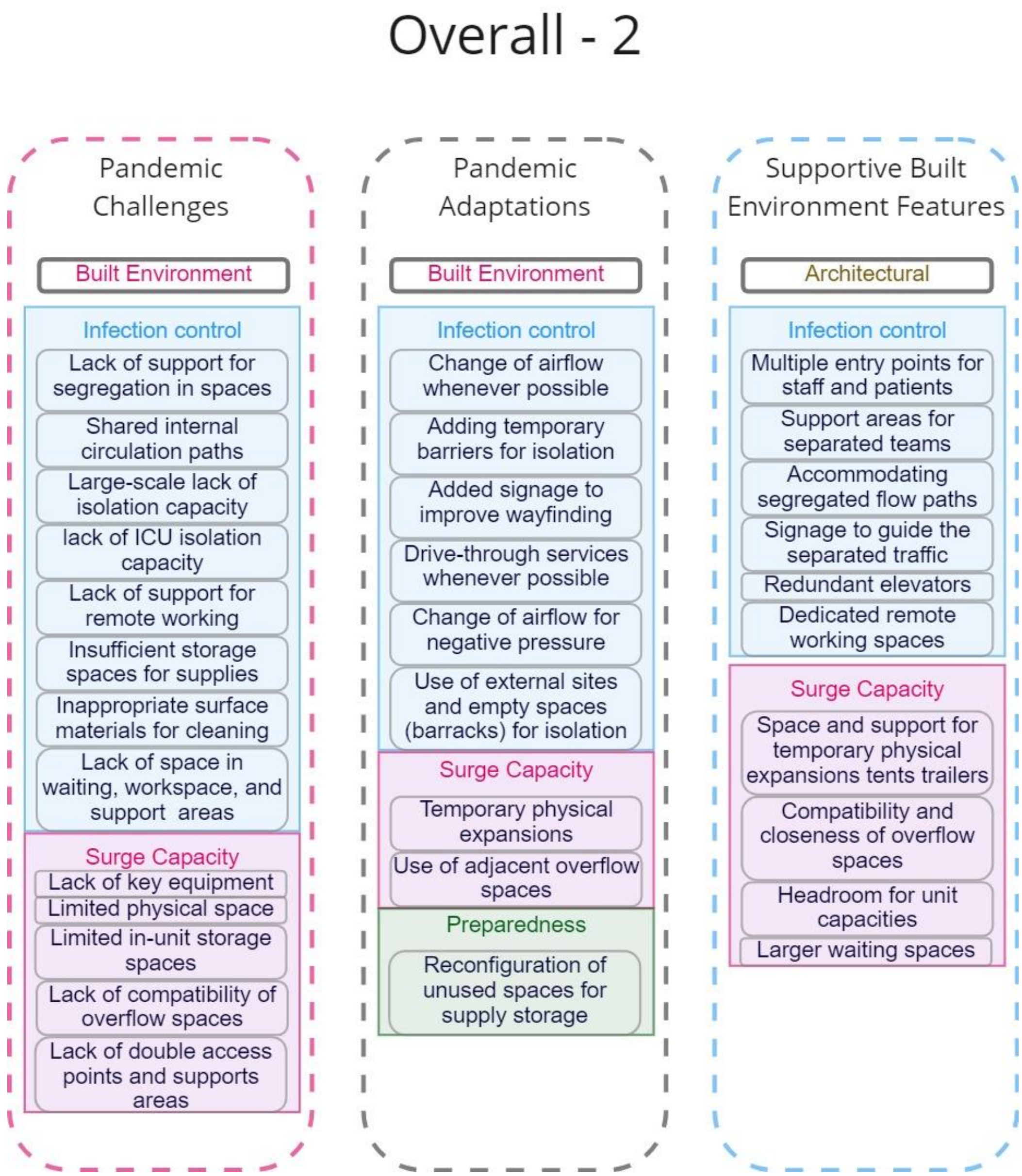


Figure 5.10. Thematic analysis of the findings within the report case studies overall findings

Departmental implementation of design guidelines:

Based on the comprehensive list of effective design features resulting from the comparative analysis, the final list of design guidelines to support these features was created. The guidelines were initially generated and grouped based on their departmental applications, addressing specific architectural or MEP features of the building. In the following tables, the design guidelines items for each department are presented.

Imaging	**Architectural Design guidelines**
1	Larger waiting spaces with double access points and separation capabilities while maintaining access to the imaging procedure rooms.
2	Multiple access paths to the key departments, especially the ED.
3	Permanent protection screens in the reception areas.
4	Accommodation of mobile imaging equipment in the host departments (ED, ICU, Inpatient)
5	Redundancy for the key imaging equipment (CT) with separated access points.
Imaging	**MEP Design guidelines**
6	Flexible air pressurization for the waiting and main procedure spaces with separated AHUs.
7	MEP equipment being easily accessible for immediate adjustments.
8	Exterior MEP and data line accessibility for mobile imaging units.

Table 5.1. Pandemic response design guidelines in the imaging department

ED	*Architectural Design guidelines*
1	Larger waiting area with the capability to be divided into two zones. Double access points to each of the defined zones. Larger entrance alcove with the possibility to be transformed into a pre-triage and screening space.
2	Decentralized and larger workstation able to accommodate social distancing.
3	Permanent shield for reception desks.
4	H shaped layout with double access points and support areas to support separated staff teams and patients.
5	Orthogonal layout with repeatable modular design to accommodate linear expansions.
6	Consideration of alcove spaces to double the use as flexible space for temporary anterooms and donning and doffing.
7	Large window in isolation units for mobile imaging from the outside. Wide corridors and storage spaces to accommodate mobile imaging.
8	Open space within the immediate exterior space.
9	Surrounding the hard spaces with a ring of soft spaces ready for reconfiguration and overflow. The open and flexible layout within the soft space with accommodating dimensions to support the overflow functions.
10	Dedicated pathways to imaging and inpatient departments with redundant vertical access points.
ED	**MEP Design guidelines**
11	Central monitoring station with remote telemetry capabilities.
12	Extension of MEP lines to the outside area with plug and play outputs for tents and trailers.
13	Overall air pressure flexibility with a fresh supply of air without the need for recirculation. An extra amount of isolation rooms. Potential flexibility for the exam rooms to have negative pressure.
14	Segregated AHUs for each wing of the H-shaped EDS.
15	Overall headroom for the MEP capacity of the unit. Easy accessibility to the MEP equipment for fast adjustment (depressurizations and change of airflow).

Table 5.2. Pandemic response design guidelines in the ED

Inpatient ICU	Architectural Design guidelines
1	Addition of significant isolation capacity, preferably through flexible air pressure capabilities and inclusion of anteroom spaces for all of the units.
2	Consideration of hybrid isolated behavioral health units with specialized features to contain the behavioral health cases.
3	Redundant pathways with a double access point to the planned segregated spaces. Redundant vertical access between the inpatient, ED, and ICU.
4	Support temporary isolation and segregation barriers.
5	Defining the portal points to place the potential partitioning and zipper walls along with considerations for filtered air intake and exhaust.
6	Larger inpatient units to accommodate life support and critical care equipment.
7	Direct access to fresh air and safe outside exhaust points for temporary negative pressured rooms.
8	Consideration of the adjacent soft spaces with the appropriate layout to work as overflow capacity.
9	Dedicated donning and doffing spaces for the isolation (or temporary) units.
10	Segregated of separable support spaces for the team modules.
11	Separated ICU units with negative pressure capabilities.
Inpatient ICU	**MEP Design guidelines**
12	Flexible and separated AHUs with the capability to change the pressure for the designated areas or the entire ward.
13	Headroom in the overall ward MEP capacity to support more patients inside the same space along with the use of ICU level of care equipment.
14	Redundant outlets for equipment and medical gases inside the rooms to support multi-bed configurations.
15	MEP support and necessary outlets within the planned overflow spaces.

Table 5.3. Pandemic response design guidelines in the inpatient and ICU department

Conceptual implementation of design guidelines:

Through a secondary analysis of the content of departmental tables, the primary design approaches are categorized, and the concept-based approach for implementation of the guidelines is defined. Within each design concept group, the applications of design guidelines in the included departments are presented through before and after diagrams. Generic documents and layout samples with generalizable applications are used for this section to transfer the core values of each design guideline and make it a useful tool for architects and decision-makers.

Infection control:

Social distancing: One of the primary infection control challenges identified through the analysis of data was the lack of capability of various spaces to support social distancing. The limited available space in waiting areas and staff workspaces has been the primary reason for this safety risk. To support social distancing in the waiting spaces, the square footage and furniture configurations should support the required distances between the users during peak hours (ED Guideline (G)-2, Imaging G-1).

This feature can be achieved by designing redundantly larger waiting areas or having accommodating features to support temporary expansions. Regarding the potentially limited available space in the project's site plan, temporary expansion capability is much more sensible and could result in a more resourceful use of space while eliminating the chance of underutilization.

The temporary expansion of the waiting spaces requires various strategies depending on the department of application. For the ED, considering the adjacency of waiting space to the outside area, external temporary add-ons such as tents or containers have been successfully implemented. External MEP and structural support, along with the availability of immediate open spaces and dedicated access paths are among the necessary features for a successful implementation of ED waiting area (or for screening or holding functions) expansions. In the figure below, an example of the external ED waiting, and screening expansions are provided. (ED G-1,6,8,12).

Figure 5.11. University of Pennsylvania hospital ED expansion (Penn Medicine, 2021)

For the waiting areas of the internal departments of the hospital such as imaging department, external expansion is not an option. This might also be the case for the EDs in case of a lack of open spaces in the outside area. In this case, through various types of architectural and MEP adaptations, the adjacent soft and easily reconfigurable spaces are modified to be used as the overflow or separated waiting for spaces. Features such as an open plan, and direct accessibility are required to enable the overflow waiting spaces to support social distancing (Imaging G-1, ED G-9)

Within the staff workspaces, social distancing should be considered in the final calculations for the placement of the staff members and their movement patterns considering their specific workflows and task configurations. In many cases, lack of capability to support social distancing in the working areas forced the decision-makers to reduce the physical presence of the manpower.

To overcome this challenge, more than ergonomically minimum dimensions should be considered to support social distancing inside the same space while decentralizing the tasks as far as possible. Medical staff workspaces can be vastly different, however, within the included departments, the limited distancing between the reception staff, and the nurse stations were the primary challenge (ED G-2).

Segregation: Across all of the case studies, the concept of segregation has been mentioned as the fundamental approach for infection control and avoiding cross-contamination within the facilities. Based on the findings, the segregation of COVID, non-COVID, and suspected patients needs to happen continuously from the first to the last point of exposure ("from triage to discharge"). True segregation should be extended through users (patient, staff, and visitors) flow, airflow, spaces, and the associated equipment and objects. In the following paragraphs, each of these segregation concepts is discussed and examples of the associated design guidelines within the selected departments are provided.

Space: The segregated space for different patient populations should be possible to achieve within the existing layout and program of the buildings. Internal segregations can be achieved by passive solutions such as relocating the patients into separated spaces, or active interventions, like separating the previously shared spaces by different methods such as zipper walls, partitioning, and other types of barriers. To function effectively, the supposedly separated spaces should be able to work independently, eliminating the need for shared use of resources and support infrastructure, and cross trafficking (ED G-1, Inpatient G-10, Imaging G-1)

This required independence brings us to the next factor of effective segregation, which is the separated flow and accessibility of the spaces. Besides the space itself, the corridors, elevators, and other transitional spaces need to be separated and work without cross-movements. This feature is of great importance as many of the pandemic patients moved through the shared corridor between the ED, inpatient, ICU, Imaging, and in some cases surgical departments.

The circulation network should provide double pathways, working in conjunction with the separated enter/exit points of the individual departments. The service corridors of the impatient department and clean/dirty corridors of surgery units can be considered as potentially effective approaches to achieving a separate flow of patients. In the following figures, some of these features are highlighted and adapted in the emergency department to address the separation of space and flow as the architectural aspects of the segregation strategy (ED G-10, Inpatient G-3, Imaging G-1,2).

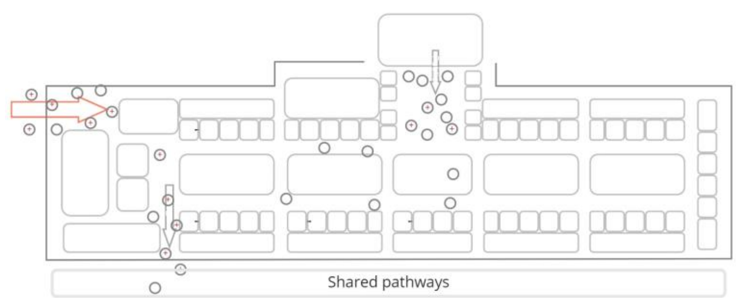


Figure 5.12 ED standard orthogonal layout showing the use of open shared spaces along with single points of enter/exits and shared pathways (Huddy, 2016)

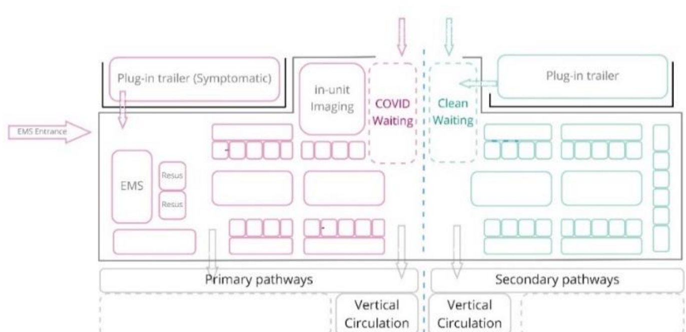


Figure 5.13 The suggested ED layout is based on segregation of space and flow with separated waiting areas, exam areas, dedicated access points, and interdepartmental corridors and elevators

The layout structure of the department (ED or inpatient) has a direct impact on its capability to support temporary separation. In the case of the ED, a symmetrical layout with double access points, workspaces, and support spaces can fulfill all of the architectural requirements to support the space and flow separation.

The L, T, Cross, and most effectively, the H-shaped ED layouts are some of the potentially effective contexts to implement the separations. Mainly because, based on the arguments by Huddy, 2016, these layouts are capable of functioning partially, having one section shut down while the other wing or section is completely functional. This feature is invaluable in the case of COVID, in which independent functionality and separated spaces are required. In the figure below, the sample H-shaped layout is presented, and the potentially separated sections are highlighted by the dashed line (ED G-4,14,15).

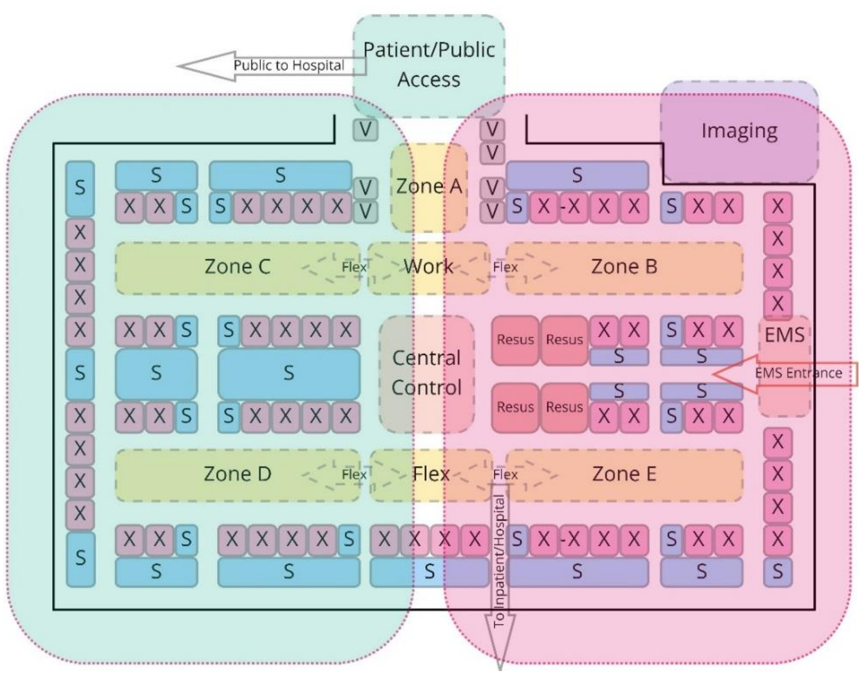


Figure 5.14. The H shaped layout, suitable for separated flow and space

The space and flow segregations are not effective if the patients and staff are exposed to contaminated air. Therefore, a safely separated airflow and circulation pattern are required to complete the segregation of clean and dirty patient populations. The safe airflow depends on various factors, including the air change rate (ACH), air pressure differences, and the source of the air inflow.

In the analyzed case studies across the literature review and the MHS facilities, the use of shared air handling units (AHU) was among the most problematic factors, increasing the chance of airborne cross-contamination between the supposedly separated spaces. Having dedicated AHUs with access to fresh air and no recirculation of contaminated air was widely requested by the users and study participants. In the diagram below, the effects of shared and independent AHU units are presented (ED G-14,15, Inpatient G-12, Imaging G-6).

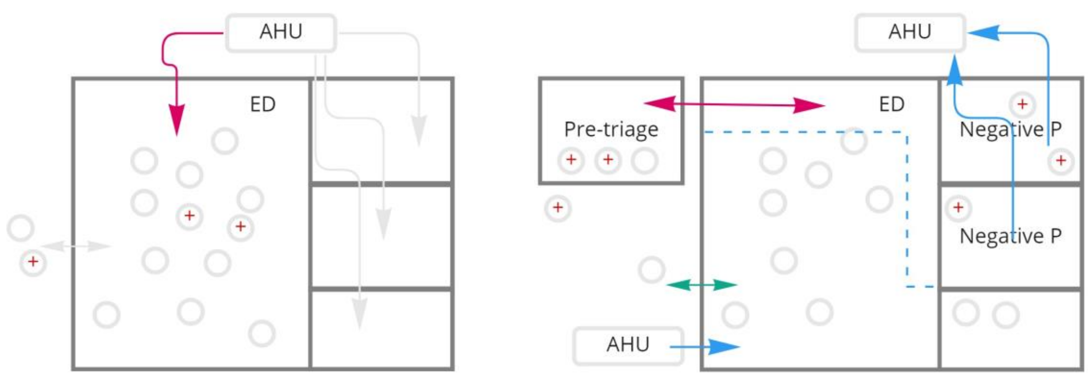


Figure 5.15. The independent air handling unit configuration along with appropriate pressurization of contaminated spaces are effective in infection control

Besides the AHU units, the pressure differences between the clean and contaminated areas are very effective in the airborne spread of infection. Based on numerous comments from the study participants, having an appropriate number of dedicated negatively pressured units (exam rooms, patient room, behavioral health rooms, etc.) is vital to contain the contamination and limit the unwanted air exchange. Also, the capability to instantly adjust the air pressure of the units or individual rooms was widely requested by the participants. This leads to the overall concept of isolation of contaminated or suspected patients.

Isolation: The isolation capacity of the included case studies and the literature review cases were unbelievably insufficient in response to COVID-19 patient volumes. Besides an increase in the rates of dedicated and permanent isolation units, the capability of transforming normal rooms and spaces (floor, departments, etc.) into isolated spaces was vastly desired and deemed effective by the end-users. Consideration of air-sealed doors along with the appropriate AHU and ducts should be considered as standard for the majority of future exam, inpatient, and ICU rooms. This feature can also be effective for dedicated waiting spaces and imaging procedure rooms (ED G-13, Inpatient G-1,2,4,5,7 ,11).

To accommodate the isolated spaces from a functional standpoint, necessary space for donning and doffing should also be considered through the addition of anterooms. Also, having large and full-height windows in an isolation room can enable the mobile imaging units to perform from the outside area, minimizing the chance of contamination and need for terminal cleaning procedures (ED G-7, Inpatient G-9)

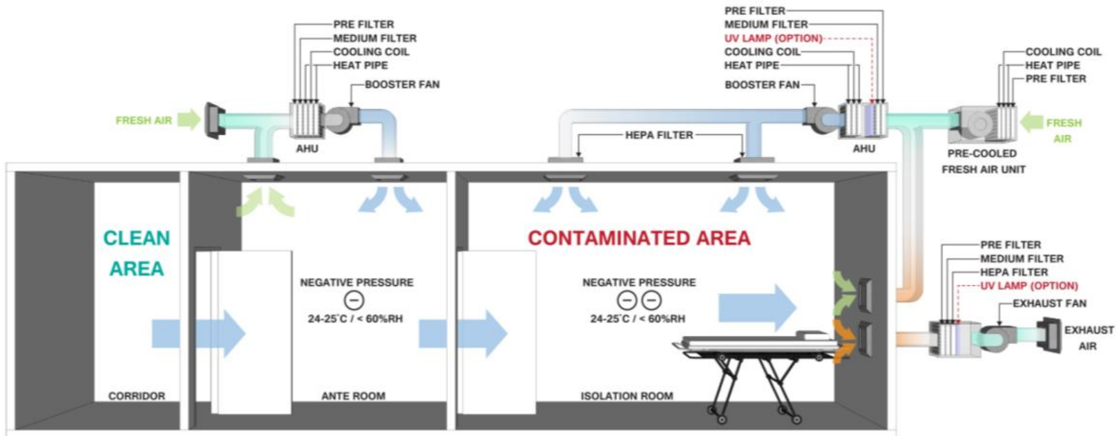


Figure 5.16. The mechanism and MEP detail of negatively pressurized isolation rooms (lighthouse solutions, 2021)

Minimizing exposure: Minimizing the need for face-to-face and physical encounters between the staff and contaminated patients is also another important goal that can be achieved by design features. According to the participant's comments, the addition of central monitoring capabilities in nurse stations, and permanent physical shields in the reception areas are effective measures to reduce the chance of exposure (ED G-3,11).

Surge capacity:

The capacity of the facilities within the included departments has been reported to be insufficient, inconsistent, and uncoordinated. The flow of pandemic patient needs to be handled across the involved functions of the hospital continuously, and the disproportionate capacities of each section resulted in bottlenecks and backlogs of patients. Therefore, various strategies are implemented or recommended to increase the overall capacity, while homogenizing and coordinating the interdepartmental response capabilities.

Overall, the required surge capacity is possible to achieve by internal or external expansions while being supported by MEP infrastructure. Internal expansions are the increases in specific spaces' capacity by breaching into adjacent or reserve overflow internal areas. To enable such adaptation, surrounding the "hard" spaces with a ring of soft and easy-to-reconfigure functions (like the admin area) is effective.

These internal overflow spaces should be equipped with necessary MEP, medical gas, and data outlets to be able to support their secondary functions with minimum cost and time. Besides, appropriate dimensions and direct access between the overflow areas and the main areas are primarily important (ED G-9, Inpatient G-8,14,15).

In the case of external expansion, due to the limitation of the available spaces inside the building, the over-the-top functions were transferred to temporary and permanent structures outside of the building. For instance, within the ED, the accommodation of screening procedures has been a significant challenge. Having a limited and pre-stressed space left no opening for the added screening tasks. This limitation forced the screening to be placed in the outside areas. The important factor for the successful implementation of external expansions is the accessibility of MEP and data lines and outlets. While having enough MEP capacity headroom to support the added external expansion spaces, potential plug and play outlets in the immediate outside area near the entrances is effective (ED G-5,812,15)

CHAPTER SIX
CONCLUSION

Conclusions

A large-scale pandemic event such as the one we experienced with COVID-19 has proven to have extremely complex impacts on the healthcare system and healthcare facilities where care is provided to patients. This was manifested as different changes in patient characteristics and volumes in various locations. In this study, we had the chance to improve our understanding of these impacts by reviewing some of the available evidence through peer-reviewed articles and valid case studies. The purpose of the current study was to learn from the experiences of this global pandemic to inform future healthcare facility planning, design, and preparedness.

The pandemic impact appears to be determined by the characteristics of the context environment as the primary factor while showing some smaller-scale effects from the local policies and patient allocation strategies among the neighboring facilities. The overarching factors related to the type of the disease and external elements such as waves of incoming patients from more contaminated areas have also significantly changed the flow of patients at each facility.

On the other hand, the responses to these effects have been implemented at various scales, from large-scale infection control regulations to micro-scale adaptations in patient rooms. Overall, these response strategies have been focused on improving the capabilities of the facilities in infection control, surge capacity, and general preparedness in relation to the pandemic patients. These responses were implemented as adaptation strategies within the existing facilities' physical and operational structures.

This study provides a comprehensive body of evidence to highlight the particular challenges of the pandemic along with their associated responses or desired capabilities mentioned by the front-line end-users in hospitals. This evidence was further analyzed to provide a set of architectural and MEP design guidelines and features that are expected to support the response adaptations in a future similar pandemic. The outcome of this study is a source of general concepts and design features that need to be considered in a future hospital design project with special consideration for each case.

Limitations

For this study, the status of the building, its architectural and MEP characteristics, and the implemented or planned adaptations are of the greatest importance, and the building background information and existing modification plans are the richest sources of data. However, due to the confidentiality and unavailability of the military building layouts, architectural and MEP assessments of the case studies are generally assessed, and a more detailed architectural and technical analysis will be conducted in future studies upon the availability of the documents.

Moreover, this study is limited to military medical facilities, which are potentially designed and operated under different requirements and regulations than civilian hospitals. In the initial section of the results chapter, some of the differentiating factors related to the military facilities are included. However, the inclusion of published case studies of civilian hospitals allows us to provide a broader and more holistic set of findings and guidelines. Within the included military case studies, lack of information regarding the impact of context environment and the overall changes in patient volumes and characteristics compared to the normal situation is another limiting factor. The effects of the context environment was limited to a few comments about the weather conditions for some of the case studies and did not provide a comprehensive resource to understand the impact.

Contributions

This analysis of the pandemic impacts, challenges, and response adaptations provided an evidence-based source of information to be used in contingency plans for future similar pandemics. Regarding the thematic distinction between different items of each category of information, similar themes and detail can be applied partially or generally to future pandemic response strategies. Should another pandemic of this kind and scale occur (which is highly possible), the decision-makers will have a more profound understanding of the potential impacts and would prepare to respond and adapt (or even prevent) the consequential challenges. The design guidelines developed as part of this study shed light on some of the previously overlooked features of the built environment that could significantly improve the response capability and flexibility of the hospitals to implement the response adaptations with minimum cost, disruption, and time. This whole study is a tool to make the pandemic "unknown" more predictable and prepare the context for more realistic design measures and features for a more effective result.

Future Research

This study opens up the path for more systematic and comprehensive research on the topic of pandemic impact and response in healthcare facilities. Future work will be potentially focused on a more data-driven, and evidence-based approach, using medical reports, building plans, and other valid and standard sources of information. To achieve a more precise understanding of the pandemic impact, a context-based study to compare the pre, during, and after the pandemic flow of patients, staff workflows, and physical status of the facilities could be beneficial.

For a start, a study with a similar data collection structure (to the case reports) can be done on several civilian hospitals working within various healthcare networks in different context environments. Also, a more technical and specific assessment of the application of effective design features will be necessary to generate useful output for decision-makers and architects. The ultimate goal of a series of studies on this topic can be a development of a comprehensive design and architectural detailing instructions to address various aspects of pandemic response requirements.

APPENDICES

Appendix A

Coding structure definitions – Level 1

Category type 1 – Departments:

- Overall: The functions, features, and spaces that have a direct implication in any of the included departments. These codes also include pharmacy services that are directly impacted by the COVID-19 patient population
- Add-on: Dedicated spaces to either of Testing, Screening, and Vaccination services including permanent spaces or temporary add-on units.
- ED: The functions and spaces related to the emergency department and its associated functions such as triage, testing, and screening (inside the ED), examinations, temporary hold/isolation, etc.
- ICU: Intensive care units or any other critical care delivery functions and spaces, specifically related to the COVID-19 patients
- Inpatient: The functions and spaces related to the inpatient type of care including inpatient wards, behavioral health (only inpatient), isolation wards, etc.
- Imaging: Diagnostic services mostly done within the radiology department or through the mobile imaging equipment inside other departments or temporary structures.

Category type 2 – Operational:

The content of the operational comments should address the challenges, recommendations, performances, or adaptations of non-built environmental objects. The inclusion criteria for operational content consists of the comments addressing the functions, workflow, resource management, end users (staff, patients, and visitors) movements and functions, non-attached equipment, and movable furniture.

Category type 2 – Built Environment:

The content of the built environment comments is limited to the physical aspect, attributes, and components of the permanent or temporary built environment objects. The inclusion criteria consist of all building systems (structure, MEP, partitioning, fixed furniture, etc.) and physical spaces, attached equipment (imaging equipment), and temporary or permanent expansions (tent and trailers),.

Category type 3 – Challenges:

The content of the comments should address specific challenges, impact changes, or any types of difficulties related COVID-19 as the primary topic.

Category type 3 – Response adaptations:

The content of the comments should address specific responses, adaptations, or any types of responsive strategies related COVID-19 as the primary topic.

Category type 3 – Recommendations:

The content of the comments should address specific recommendations related COVID-19 as the primary topic. (how the participant would like things to be)

Category type 4 – Infection control:

The comments that primarily target the challenges and responses related to the control of the spread of the disease. The active measures such as segregation and isolation capabilities along with the protocols and workflow strategies to control the cross contamination are among the potential infection control content. Also, disinfection and cleaning procedures are included.

Category type 4 – Surge Capacity:

The comments that are particularly targeting the volume of various concepts including patients, staff, resources, and spaces. The content of these comments is focused on capacity measures and exclude any infection control concepts.

Category type 4 – Preparedness:

The preparedness measures are the resilient attributes of the facilities and healthcare systems that potentially enables them to cope with the challenges and changes resulted from the pandemic. These comments are either an inseparable combinations of infection control and capacity measures or neither focused on the volume nor the infection control aspects. The preparedness concepts are primarily address the structural readiness of the case studies and covers the controversial content that could be place in both groups. The in-advance measures and attributes of the facility along with the components of the contingency plans are the best candidates for this group.

Appendix B

Coding structure definitions – Level 2 and 3

Group 1 – Infection Control:

- Segregation: the application of segregation strategies for patients, visitors, supplies, and equipment are the primary factor for distinguishing between the content. The three concepts of flow (movements), space (stationary functions and procedures within a stable space), and scheduling (operational changes to segregate the working hours to limit exposure) are the nest decisive factors.
    - For the flow, concepts of one-way movement, procedure-related movements, wayfinding, enter and exit points, internal flow (corridors and vertical circulation), and security are included.
    - For the space, waiting areas, procedure rooms, tents, support spaces, equipment storage and maneuver spaces are included. Also, layout modification such as partitioning, zip walls, and other types of interventions for segregation purposes are also included.
- Isolation
    - Various contexts of isolation related capabilities and capacities such as layout modifications to create isolated spaces, airflow handling, isolation room numbers (capacity), quality testing of isolation effectiveness, space attributes, and supplies are included. Also, special trainings for appropriate utilization of isolated units are included.

- Remote working
    - Different types of virtual and remote workflows that aimed to limit the spread including tele-health, tele-working, tele-screening, and tele-ICU are added.
- Protocols
    - Overarching protocols and regulations that are enforced to limit the spread are included. The content indicating the enforcement of protocols of PPE use, PPE donning/doffing spaces, social distancing, required air change rates, screening tents and trailers workflows, risk assessment approaches, contact tracing, triage strategy, and visitor acceptance strategies are included.
- Disinfection
    - All of the content addressing cleaning and disinfection supplies, procedures, trainings, and scheduling are important. Also, the role of the surface materials in cleanability and the consequent workload and downtimes of the spaces is included.
- Physical barriers
    - Physical barriers including plexi glass shields and zip walls that are added to limit the exposure and cross contaminations are included.

Group 2 – Surge Capacity:

- Scheduling
  - The changes and challenges in workflow scheduling that are aimed to optimize the capacity of the facility included. Also, the changes in the scheduling of the existing functions of the hospital that are causes by the added functions and spaces are also included.
- Space
  - Various physical space-related challenges and responses that are aimed to increase and optimize the existing space are targeted. Various expansions of the existing space, use of external sites, tents, trailers, screening spaces, and waiting areas are included. Also, reconfiguration and use of shared spaces, along with modifications in MEP output to support the expanded spaces are important.
- Patient numbers
  - Factors that are effective in the number of patient present or expected to be present at the facility are the primary targets. Surge waves of patients, patient allocation strategies, EMS transfers, and the consequent availability of beds are the potential contexts to consider.
- Supplies
  - The volume of available COVID supplies and the dedicated storage spaces are included.

- Equipment
    - Including the comments focused on the number of most important equipment for COVID response specially the main imaging devices, mobile imaging units, ventilators, screening equipment (hands free stands), and air scrubbers. The allocation and distribution strategies for optimizing the use of available equipment are also included.
- Manpower
    - Challenges and response strategies to provide enough manpower and optimize the available staff of the facility are the focus point for this code group. Coping strategies such as cross-training, and staff allocation and deployment approaches are included. The comments regarding the use of manpower during the pandemic are coded into categories of number of staff (available numbers), extra staff (addition of manpower), staff resilience (how well the staff workforce stayed functional), and specialized staff (number of vital staff members for COVID r3esponse such as respiratory therapists, critical care specialists, etc.). Also, the changes in the workload and its distribution among the team members along with the utilization patterns rate of staff (resource tracking) are included.

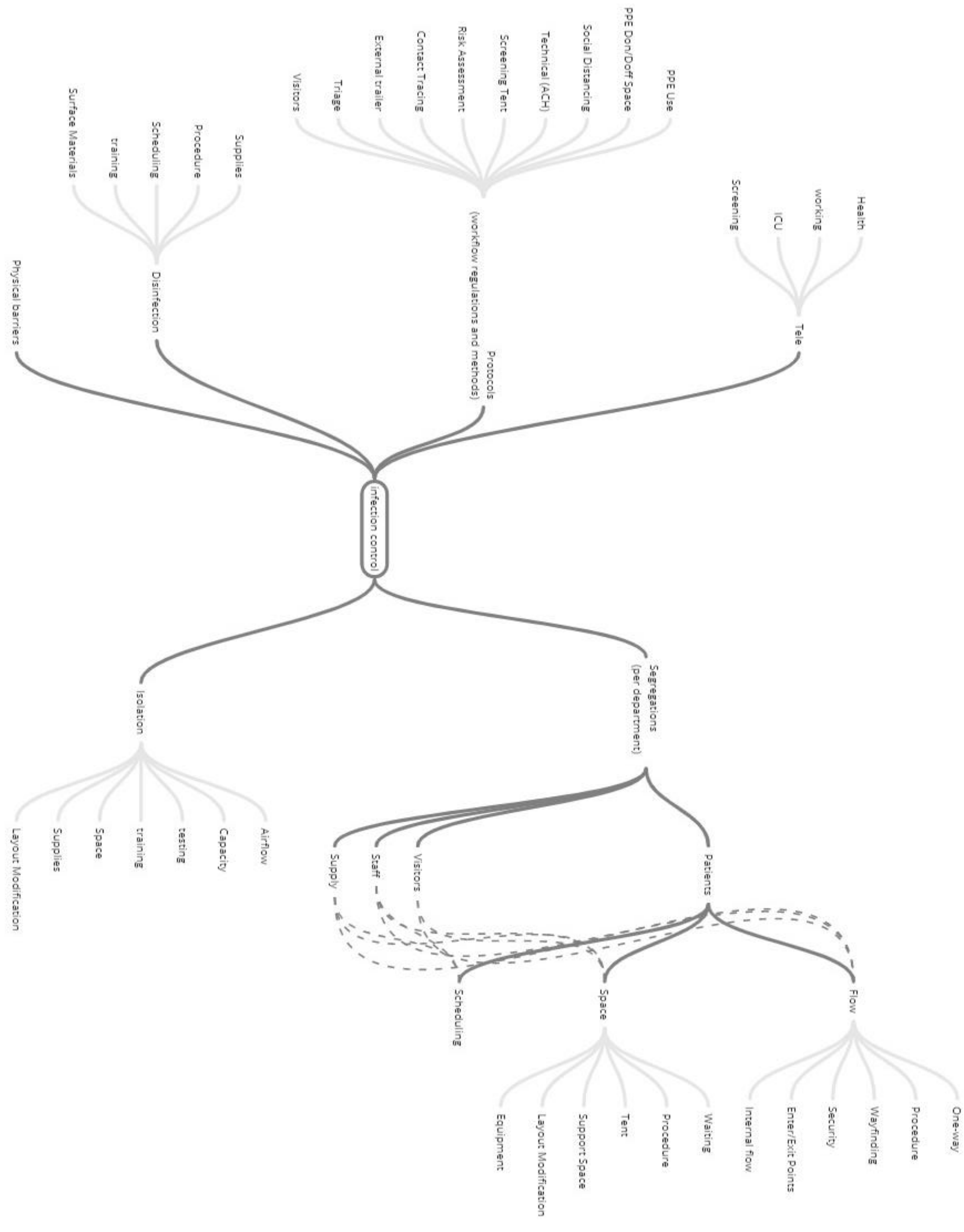
Group 3 – Preparedness:

- Contingency plans
    - Any comments transferring information about the in-advance contingency plans that have or might contribute to the pandemic response are included.
- Communication: the communication category belongs to the comments that are focused on the circulation of information between facilities, team members, and regulatory organizations.
    - The communication comments include the transfer of information through different parties and contexts such as individual in-person encounters, virtual platforms, team meetings, COVID call centers, and neighboring facilities. Also, the accessibility of information about the latest pandemic updates and the coordination between various individuals, units, departments, and facilities should be considered. Moreover, the availability of external protocols and guidelines should be included.
- Layout features: the inherent architectural and MEP attributes of the case studies that are mentioned as effective in response capabilities are the focus point of this category.
    - Flexibility features such as openness, overall adaptability of the space, isolation adaptability and capabilities, external MEP outputs, walking distances, equipment and vaccine storage, clear visibility, and surplus MEP capability of the facility are included. Also, the accessibility features of the key departments should be considered.

- IT department
    - The IT infrastructure, equipment, and space that are mentioned to be adapted, being effective or challenging for pandemic response are the primary codes for this group. Moreover, the specific strategies of the IT department in supporting the COVID requirements, and the remote working training should be considered.
- Drive through services
    - Drive through services including pharmacy, testing/screening, and vaccination stations and all of their associated challenges, requirements, and adaptations are part of this category.
- Supplies
    - The comments targeted at the in-advance readiness of the facility regarding the management of general and PPE supplies are the primary focus points of this category.
- Equipment
    - The in-advance readiness of the facility regarding the availability of enough vital equipment such as disinfection equipment, respirators and ventilators, isolated transfer equipment, mobile imaging equipment, monitors, beds, carts, and portable HEPA filters. Also, comments mentioning the general redundancy of the equipment should be coded separately to avoid confusion.

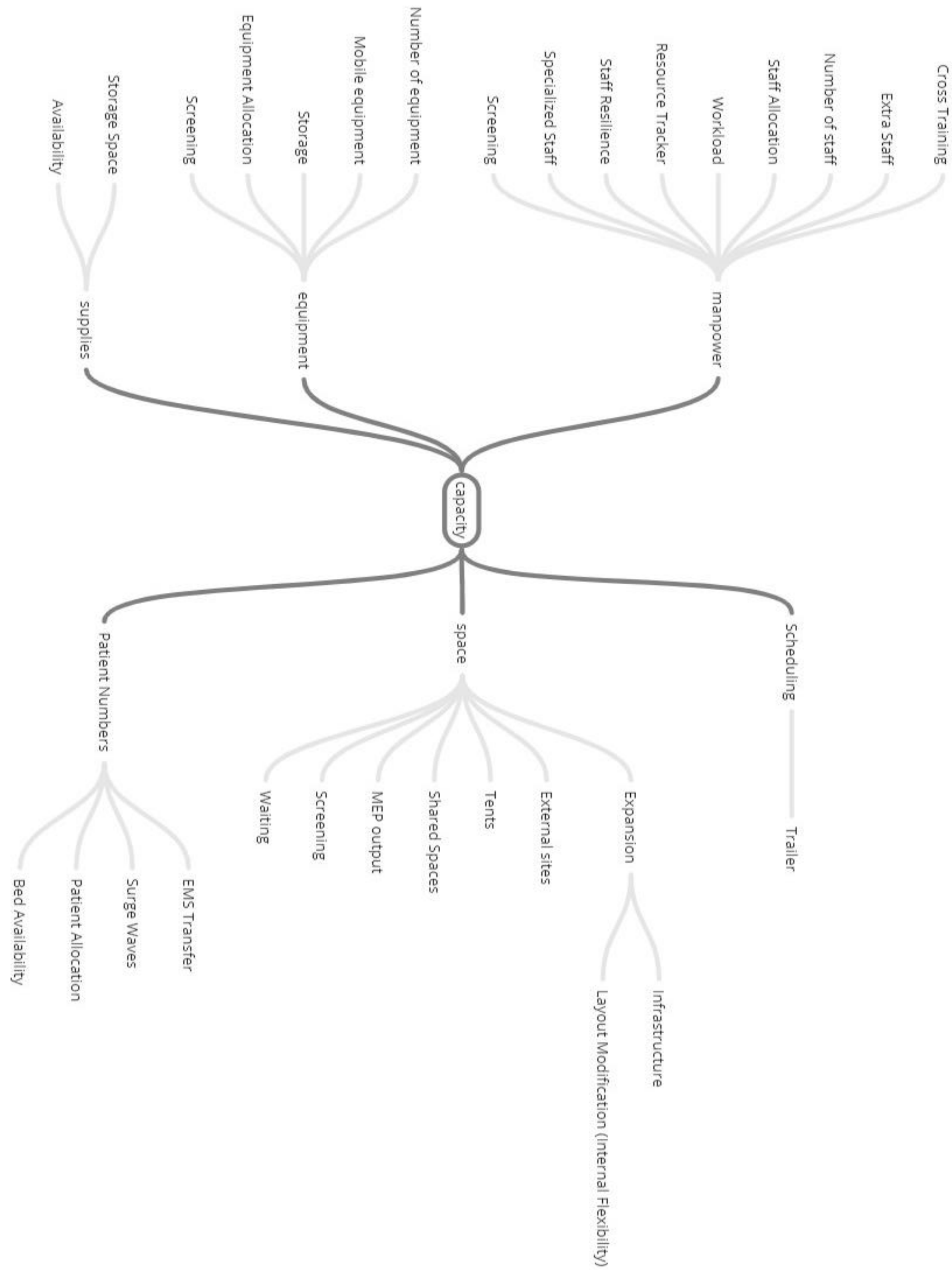
Appendix C

Tree diagram of the final coding structure – Infection Control



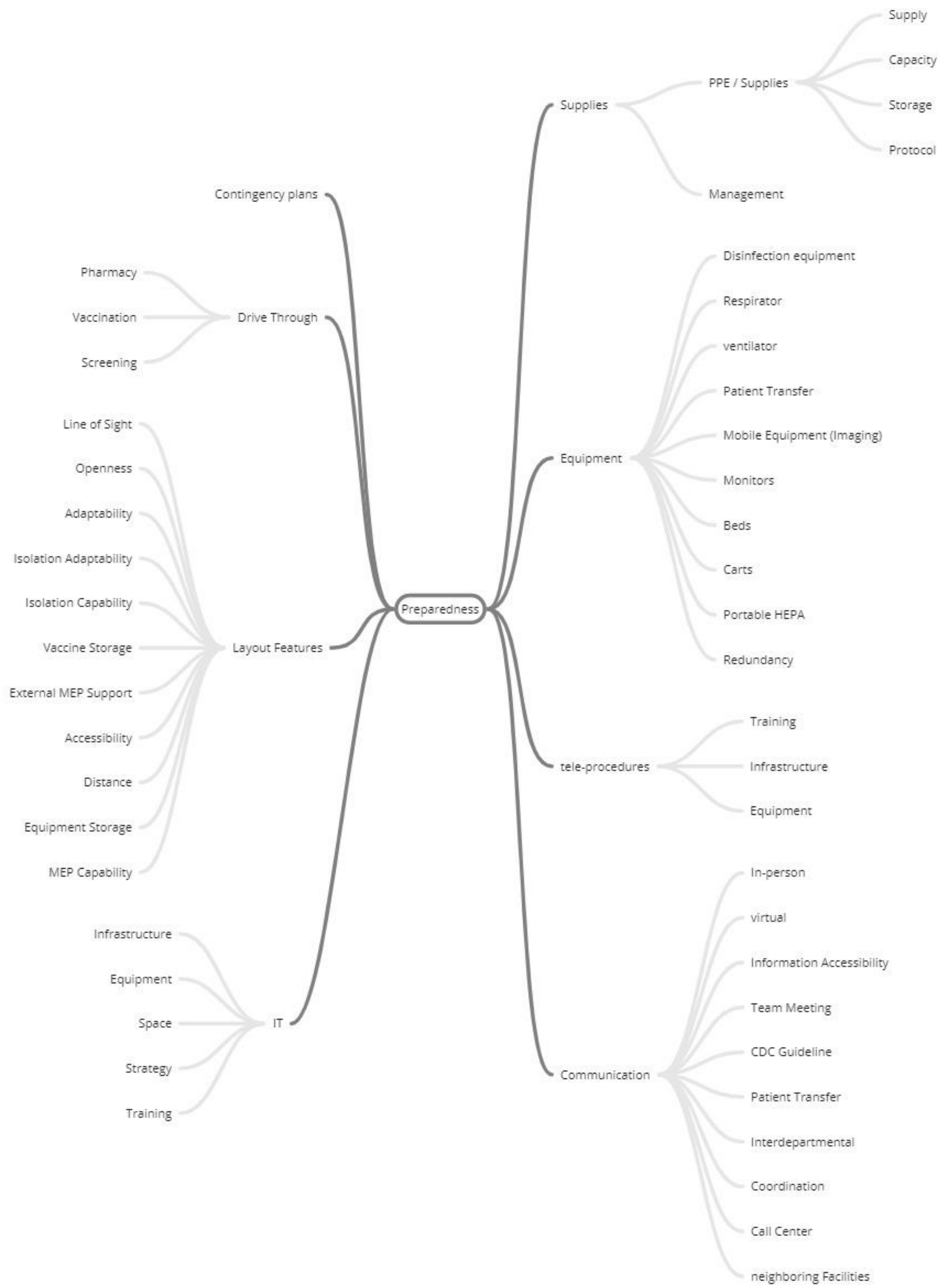
Appendix D

Tree diagram of the final coding structure – Surge Capacity



Appendix E

Tree diagram of the final coding structure – Preparedness



Appendix F

Report structure- Semi-structured interviews

Intent: Semi-structured interviews were conducted during investigation. The purpose of the interviews is to garner user feedback regarding their experience with the MTF during pandemic and identify potential operations and maintenance facilitators and barriers and provide context to COVID-19 facility modification.

Number of Participants: -

Department: -

Rank: -

Role/Responsibilities: -

Length of Tenure: -

1. From the facility perspective, what was the greatest challenge you had to address in response to COVID-19?
2. From the operations perspective, what was the greatest challenge you had to address in response to COVID-19?
3. To what extent was your facility able to maintain continuity of non-COVID regular operations?
4. What facility strategies did you implement during COVID-19 that were the most effective? Why?
5. What operational strategies did you implement during COVID-19 that were the most
6. What would you do differently to be more prepared for another surge/pandemic?

Appendix G

Report structure-survey constructs

The available data includes the results of the survey including 105 closed questions focusing on 5 constructs including safety, flow, surge capacity, and flexibility targeting the participant members from command leadership, heads of the involved department, front line clinical staff that needed covid related modifications, facility management, environmental services, infection control, and security. The definition of each construct is provided as follow:

Safety:

The ability to implement and maintain infection control strategies such as the separation of flow between people (COVID-19 and non-COVID patients and staff), provision of security and access control measures, space condition monitoring, dedicated areas for donning and doffing and access to PPE, and physical distancing between patients and staff.

Flow:

The movement of people (inpatients, outpatients, family, and clinical and support staff), interdepartmental movement of equipment, supplies, medication, PPE, waste, and food to support patient care, and the transfer of information to patients, families, staff, community, and the greater emergency management network.

Surg Capacity:

The capability of a facility to handle an influx in patients by increasing clinical care capabilities (screening, testing, triage, patient cohorting and isolation) and treatment areas (emergency and critical care), support services (materials management, general and emergency supply storage, environmental services, PPE waste, and ambulance parking), monitoring, communication, and virtual care technologies, and mechanical, electrical, and plumbing infrastructure.

Staff Well-being:

The provision of areas and amenities that support staff mental, physical, emotional, and spiritual health, happiness, and welfare.

Flexibility:

The ability for a facility to respond to rapidly changing demands by being versatile (immediate multifunctional use), modifiable (quickly reconfigurable for different uses), convertible (make minor renovations), and scalable (expand or contract according through new or temporary construction).

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