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Reimagining Temporary Emergency Hospital

By

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I would like to dedicate this thesis to my loving parents, Rade and Olivera.

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To my parents, aunt, grandparents, brother, best friends, and everyone who has contributed to my academic and personal growth, I extend my deepest gratitude. Your love, support, and belief in me have been the driving force behind my achievements. I am truly blessed to have such remarkable individuals in my life, and I am forever grateful for your unwavering presence and support.

ABSTRACT

This thesis provides an in-depth exploration of the architectural aspects surrounding modular hospital rooms, which have been specifically designed to address the pressing need for additional healthcare facilities during emergencies. The study focuses on developing a solution that is both flexible and scalable, aiming to bolster existing hospital capacities and ensure the delivery of adequate care for patients. The core concept of the modular hospital room centers on repurposing parking lots, utilizing lightweight materials, and implementing ingenious folding mechanisms to facilitate easy transportation and installation. The overarching goal of this research is to contribute to the field of emergency healthcare architecture by offering a comprehensive understanding of the design, functionality, and advantages of modular hospital rooms.

INTRODUCTION

The COVID-19 pandemic has presented the world healthcare system with unprecedented obstacles. Due to the increase in instances and the necessity to take care of infected patients, hospitals have been overburdened, and healthcare experts have been stretched to their breaking point. As a result, many countries were compelled to build new hospitals or repurpose current ones. However, these solutions have frequently been time and money consuming, and they could not constantly meet the needs for health facility beds.

A promising solution to these issues is modular buildings, which includes prefabricating constructing parts offsite and putting them collectively on site. In comparison to standard building techniques, the modular approach has some benefits, including quicker set up, reduced expenses, and greater design and format flexibility. From residential and business systems to academic and scientific establishments, modular construction has been utilized in an extensive range of applications.

The utilization of modular construction for emergency hospital rooms during the COVID-19 epidemic is the field of investigation for this thesis. It addresses the use of modular hospital rooms that may be quickly built in response to an increase in patient volume. The objective of this study is to set design standards for modular hospital rooms that can be used in future emergencies as well as to assess how well modular construction works as a solution for emergency healthcare facilities.

The thesis begins with a review of the literature on modular construction and its use in healthcare facilities. After that, a selection of examples of modular hospital rooms used during the COVID-19 epidemic is presented. The case study gives an overview of the planning and building phases and evaluates how well the room performed in terms of patient care and safety. The thesis is completed with a series of design recommendations for emergency-useable modular hospital rooms.

Overall, this thesis argues that emergency healthcare facilities could benefit from modular construction, and that modular hospital room designs can be improved for patient care and security. This research aims to contribute to the development of more resilient and adaptable healthcare systems that can better respond to future emergencies by investigating the use of modular construction in response to the COVID-19 pandemic.

Contents

Chapter 1

Challenges and Solutions in Healthcare Infrastructure during the COVID-19 Pandemic

1.1 Italy's Struggle with COVID-19: A Shortage of Hospital Beds

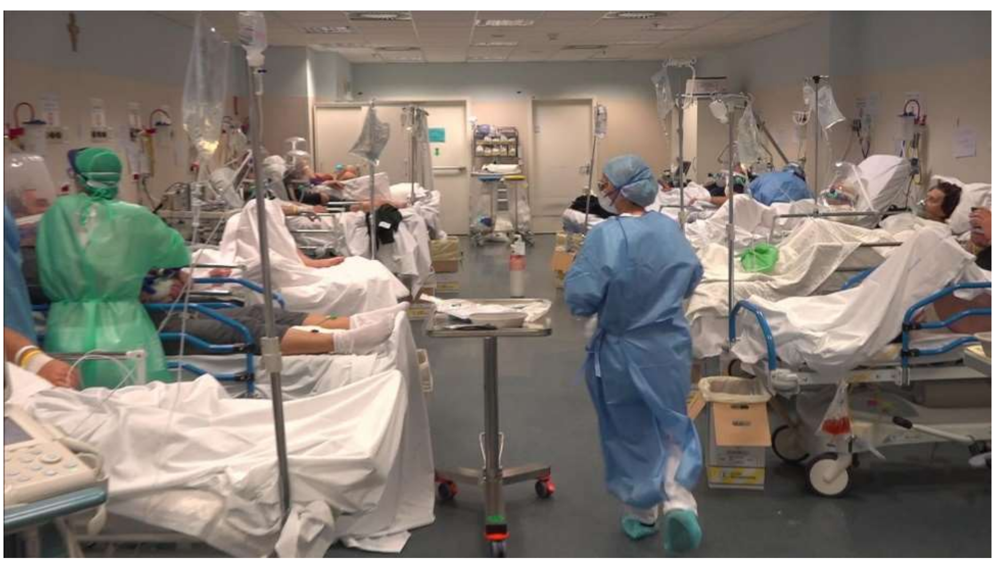
The COVID-19 pandemic in 2020 had a catastrophic impact on Italy, experiencing one of the highest numbers of cases and deaths internationally. One of the maximum substantial demanding situations that Italy confronted for the duration of the pandemic turned into a shortage of hospital beds (de Belvis, et al., 2022). As the quantity of COVID-19 cases surged, hospitals were rapidly overwhelmed, with many patients not able to get entry to the care they needed (Armocida, Formenti, Ussai, Palestra, & Missoni, 2020).

Before the COVID-19 pandemic, Italy's healthcare system was already under pressure (Boccia, Riccardi, & Ioannidis, 2020). The country had an exceedingly high quantity of hospital beds per capita, but lots of those beds had been in older, smaller hospitals that have been poorly ready to deal with a surge in patients (Armocida, Formenti, Ussai, Palestra, &

Missoni, 2020). In addition, Italy's healthcare system changed into heavily reliant on care physicians, who frequently acted as gatekeepers to medical institutional care. This intended that patients with complicated medical needs had struggled to get right of entry to the professional care they needed (Remuzzi & Remuzzi, 2020).

When the COVID-19 pandemic hit Italy in February 2020, the country was caught off guard. Within weeks, the quantity of cases started out to surge, and hospitals fast have become overwhelmed (Boccia, Riccardi, & Ioannidis, 2020). Regional differences emerged. In Lombardy, the worst affected region, hospitals had been compelled to turn away patients because of a lack of beds, with a few patients having to look ahead to days in ambulances outdoor hospitals (Remuzzi & Remuzzi, 2020).

The shortage of medical institution beds became not only a hassle in Lombardy. Across the country, hospitals were suffering to cope with the influx of COVID-19 patients. In a few areas, hospitals were pressured to transform non-medical facilities into COVID-19 wards, and in a few cases, patients needed to be transferred to hospitals in different regions (Boccia, Riccardi, & Ioannidis, 2020).



Bergamo is at the epicenter of the epidemic. Source: https://news.sky.com/story/coronavirus-they-call-it-the-apocalypse-inside-italys-hardest-hit-hospital-11960597 Last accessed: 27.06.2023

Several reasons explain why Italy experienced a scarcity of hospital beds throughout the pandemic. One of the main reasons was the lack of investment inside the healthcare in the years leading before the pandemic (de Belvis, et al., 2022). Italy's healthcare system had been underfunded and understaffed for years, with many hospitals in need of renovation and modernization. As a result, whilst the pandemic hit, the healthcare system became ill-organized to cope with the surge in patients (Remuzzi & Remuzzi, 2020).

There was also a severe shortage of medical staff. The high patient influx, infection risks among healthcare workers, fatigue and burnout, and recruitment challenges contributed to the scarcity. This shortage had significant implications for patient care and highlighted the need for measures to strengthen the healthcare workforce (de Belvis, et al., 2022).

1.2 China's Struggle with COVID-19: Overwhelmed Healthcare Infrastructure

China similarly to Italy, had significant challenges during the COVID-19 pandemic, with a high number of infected patients and the need to expand healthcare capacity. As the number of COVID-19 cases were rising, hospitals faced great pressure and struggled to meet the everyday growing demand for medical care (Cao, Li, Chen, Miao, & Yang, 2020).

Before the pandemic, China's healthcare system had made significant progress, but it still had limitations in some areas. While the country had a high number of hospital beds per capita, more of these beds were in the urban areas and the bigger cities (Sun, et al., 2021). This meant that when the outbreak hit, the hospitals in less-developed regions were not ready to handle the sudden flow of patients. Moreover, healthcare relied on the primary care facilities, which had challenges in giving specialized care to patients with complex medical needs (Sun, et al., 2021).

When COVID-19 hit in Wuhan in late 2019, China had difficulties in managing the outbreak (Cao, Li, Chen, Miao, & Yang, 2020). The rapid spread of the virus caught the country off guard, and hospitals quickly became overwhelmed with infected patients (Chen & Zhao, 2020). In Wuhan, temporary hospitals were quickly constructed to accommodate the growing number of patients, but even then, there were struggles in providing care for all patients (Chen L.-k. , et al., 2021).

The strain on healthcare infrastructure extended beyond Wuhan, affecting various regions across the country. Some hospitals faced difficulties in accommodating COVID-19 patients, leading to the conversion of non-medical facilities into temporary treatment centers (Sun, et al., 2021). Additionally, the challenges of coordinating responses and sharing resources between different regions became evident, highlighting the need for improved communication and cooperation among healthcare systems nationwide (Chen & Zhao, 2020).

Nurse pushing a bed outside a fever clinic at a hospital as coronavirus disease (COVID-19) outbreaks continue in Beijing
Source: https://www.pbs.org/newshour/world/after-abrupt-reopening-china-faces-covid-19-spiral
Last accessed: 27.06.2023

Several factors contributed to the overwhelmed healthcare infrastructure in China. The sudden surge in COVID-19 cases exposed the need for increased investment in healthcare infrastructure, including the renovation and modernization of hospitals to meet the demands of future emergencies (Sun, et al., 2021). Furthermore, the shortage of medical staff and the risks they faced in dealing with the pandemic added to the strain on the system, emphasizing the importance of strengthening the healthcare workforce (Sun, et al., 2021).

China encountered significant challenges with its healthcare infrastructure during the COVID-19 pandemic. The pandemic highlighted the need for improved coordination, investment, and preparedness in the healthcare system to be able to manage large-scale emergencies (Sun, et al., 2021). The experience of the COVID-19 pandemic will undoubtedly contribute to strengthening not only China's healthcare system, but worldwide and be prepared to respond to future health crises (Chen & Zhao, 2020).

Chapter 2

Advancing Healthcare Infrastructure: The Role of Modular and Prefabricated Buildings

2.1 Modular Construction Characteristics and Types

Compared to other traditional construction techniques, modular construction is a unique manner of building. The fundamental volumetric component of modular structures, modules, are manufactured off-site and then transported to the construction site for assembly and connecting services. Additionally, the method combines different manufacturing technologies for quick construction. Modular buildings are more durable than traditional buildings thanks to the independent engineering done in a factory (L.-k. Chen, et al. 2021). Fig. 1 depicts the main phases of modular construction, including the assembly of a module in a factory, the completion of a volumetric module, and the completion of a typical modular building on location. Wall, floor, and ceiling panels are the building blocks of modular volumetric units, along with any necessary bracing. Hollow sections or hot-rolled steel angles are frequently used as corner posts (Gatheeshgar, et al. 2021).

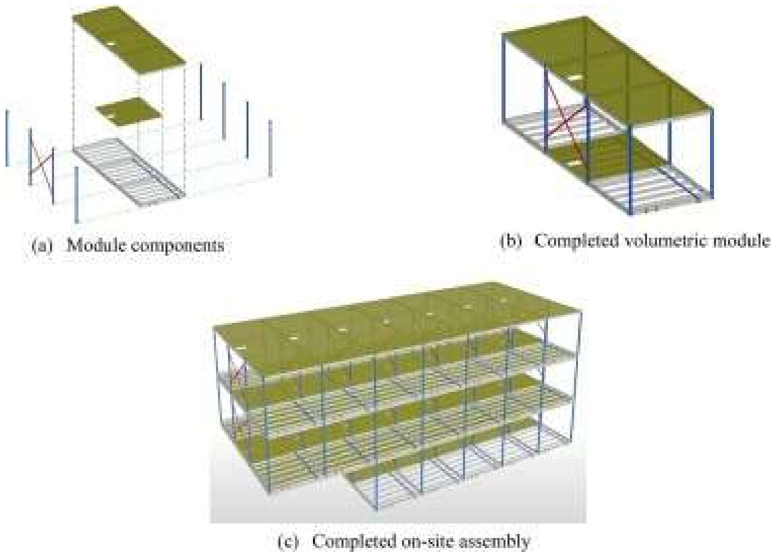


Fig. 1. Modular construction: Module assembly to completed modular building

In general, modules can be divided into two types based on the load path. The two generic forms of modules are corner post supported modules and load bearing wall modules, and both types are used in actual construction (Smolova and Smolova 2021). Fig. 2 shows examples of these two different sorts of modules. While the load is transferred to the foundation of load-bearing wall modules through the walls, it is transferred to the foundation of corner post modules through corner posts and frequently intermediate posts as well. Wall studs are typically set at 300 mm or 600 mm intervals in a load-bearing steel module. Additionally, the modular industry employs a variety of module shapes, including slope end, stepped, faceted, and tapered modules. The rectangular shape module, however, continues to be popular in buildings. It should be noted that while corner supported modules are unlikely to be used, wall supported modules are compatible with any shapes. For structures where more open space is required, corner post modules are helpful. As shown in Fig. 3, modules can be stacked one on top of the other, side by side, to create a wide range of architectural layouts. All these features enable the assembly of modular units vertically up to 25 stories while gaining the stability of a core made of steel or concrete. (Gatheeshgar, et al. 2021)

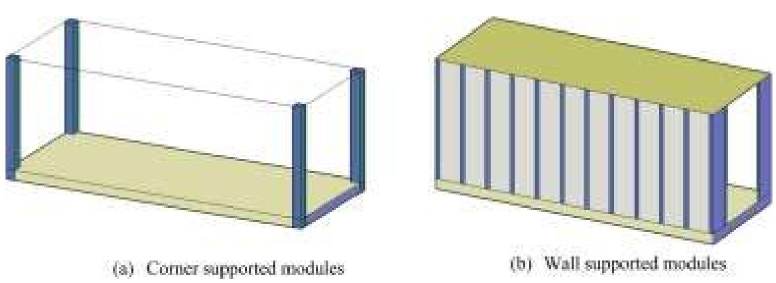


Fig. 2. Generic types of modules

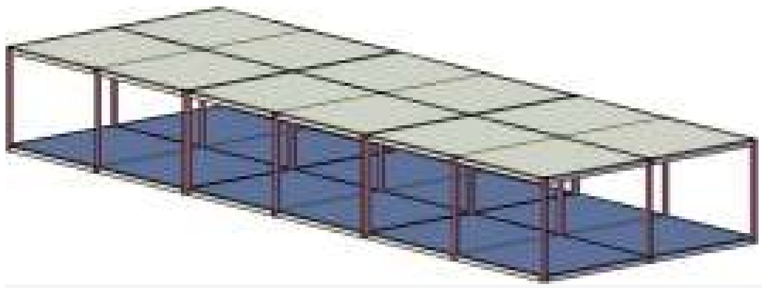


Fig. 3. Corner post modules arranged horizontally to form wider open space

The choice of modular structure depends on several factors, including the desired height of the building, load transfer mechanism, material preferences, and project requirements (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019). For low-rise buildings, self-supporting load-bearing modules are commonly used, as they transfer loads through the side walls (Gatheeshgar, et al., 2021). These modules are suitable for buildings with heights typically ranging from four to eight floors. On the other hand, frame-supported modules transfer loads through edge beams connected to corner posts, which require high resistance to compression. Frame-supported modules are used when greater heights or specific load requirements need to be met (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019).

Additionally, the materials used in modular construction, such as timber, steel, and concrete, have their own advantages and limitations (Gatheeshgar, et al., 2021). Timber modules, such as glue-laminated timber (glulam) or cross-laminated timber (CLT), are known for their architectural versatility, speed of construction, and reduced environmental impacts. Steel modules offer high load-bearing capacity with minimal weight, allowing for large spans between columns. Concrete modules provide strength and can be combined with other materials like timber or steel to achieve specific structural requirements, also known as Hybrid buildings (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019).

The choice of modular structure and materials may also be influenced by local regulations, availability of construction materials, climate conditions, and cultural preferences. Different regions or countries may have specific requirements and construction practices that influence the selection of modular structures. For example, certain regions may prefer timber-based modules due to their sustainability benefits, while others may prioritize steel or concrete modules for their specific structural requirements (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019).

In summary, the context, including factors such as building height, load requirements, local regulations, availability of materials, and regional preferences, can play a significant role in determining the most suitable modular structure for a specific project. It is essential to consider these contextual factors when making decisions about modular construction methods and materials (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019).

Picture on the left: Prefabricated modules with cross-laminated timber (Puukuokka apartment building, Finland) source: https://www.archdaily.com/614915/puukuokka-housing-block-oopeaa Last accessed: 08.07.2023

Picture on the right: Hybrid building (Linea Nova building, Rotterdam, The Netherlands) source: https://www.skyscrapercenter.com/building/de-karel-doorman/5562 Last accessed: 08.07.2023

2.2 Exploring the Construction Process and Benefits of Modular Buildings

Modular buildings have emerged as a revolutionary approach to construction and offer a flexible and efficient solution to meet the demands of various industries. Unlike traditional construction methods, modular buildings are constructed off-site in factory-controlled environments and then assembled on location (Torre, 1994). Modular construction has gained attention in the construction industry due to its advantages over traditional construction methods. The advantages are faster and safer construction processes, more correct predictability in completion time, superior quality, reduced on-site labor, less resource wastage, and less environmental impact (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019). This chapter aims to explore modular buildings and explain their construction process.

Design and Planning: The process of constructing modular buildings begins with meticulous design and planning, the first design points taken into consideration are crane capacity, transportation and site accessibility (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019) . Architects and engineers collaborate to create detailed plans, considering the client's requirements and the site conditions (Torre, 1994). During this phase, factors such as the layout, dimensions, materials, and specifications of the modules are determined. Design considerations also include the integration of mechanical, electrical, and plumbing systems within the modules (Kamali & Hewage, 2016). The design is translated into modular units, which are individual sections of the building that can be transported and assembled later (Torre 1994). Additionally, site-specific factors such as foundation requirements and transportation logistics are taken into account. Effective coordination among stakeholders, including owners, engineers, designers, suppliers, and contractors, is essential to ensure a successful design and planning process (Kamali & Hewage, 2016).

Factory Fabrication: Once the design is finalized, the construction of modular buildings takes place in a controlled factory setting (Torre, 1994). Factory fabrication is a key component of modular construction. In this phase, the individual modules of the building are manufactured and assembled in a controlled factory environment. The fabrication process involves precise cutting, shaping, and assembly of the module components according to the design specifications (Kamali & Hewage, 2016). Skilled workers, including carpenters, electricians, plumbers, and technicians, collaborate to fabricate the modular units (Torre, 1994), also automated machinery is employed to ensure high-quality construction. Quality control measures are implemented to verify that the modules meet the required standards. The factory fabrication phase enables efficient and standardized production, as well as the optimization of material usage and waste reduction (Kamali & Hewage, 2016).

Module Construction: The construction of modular units involves various stages (Torre, 1994). Module construction refers to the assembly of the fabricated modules to form the modular building. During this phase, the completed modules are transported from the factory to the construction site (Kamali & Hewage, 2016). Structural components such as walls, floors, and roofs are assembled using high-quality materials. Plumbing and electrical systems are installed, and insulation and finishing touches are added. Each module undergoes rigorous quality checks to ensure it meets the required standards (Torre 1994). The module construction phase aims to streamline the assembly process, minimize on-site work, and ensure the structural integrity and functionality of the building (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019).

Transportation and Assembly: Transportation and assembly play a crucial role in modular construction. (Kamali & Hewage, 2016) After the modular units are constructed, they are transported to the site. (Torre, 1994) This phase involves the logistics of transporting the fabricated modules from the factory to the construction site. Specialized vehicles and equipment are utilized to safely deliver the modules to the site. (Kamali & Hewage, 2016) The transportation method depends on the size and distance, with options including trucks, trains, or even ships (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019). Upon arrival, the modules are carefully lifted and positioned onto the permanent foundation or supports. Accurate alignment and connection of the modules are carried out to ensure a seamless integration. Transportation and assembly require coordination among various stakeholders, including transportation providers, crane operators, and construction crews. (Kamali & Hewage, 2016)

Integration and Finishing: Once the modules are in place, the process of integration and finishing commences. Plumbing and electrical systems are connected, and the necessary adjustments are made to ensure the modules fit together seamlessly. Interior finishes, such as painting, flooring, and fixtures, are installed to transform the modules into functional spaces (Torre 1994). The modules are then lifted, placed, and connected to each other according to the predetermined design. Proper alignment, leveling, and sealing of the modules are essential to ensure structural integrity and weatherproofing. Skilled labor and specialized equipment are employed to carry out the module construction phase efficiently (Kamali & Hewage, 2016).

Site-Specific Considerations: Modular buildings are versatile and can be customized to suit different site conditions and requirements. Site-specific considerations, such as access, terrain, and utilities, are considered during the planning and assembly stages (Torre, 1994). Site-specific considerations address the unique aspects and challenges of the construction site. This phase involves evaluating the site conditions, such as soil stability, access, utilities, and environmental factors (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019). The adaptability of modular construction allows modular buildings to be deployed in various locations, including remote areas or sites with limited space (Torre 1994). Site-specific considerations also include compliance with local building codes and regulations, obtaining necessary permits, and managing any site-specific risks or constraints. This chapter explores how modular construction can adapt to different site conditions and discusses strategies for overcoming site-specific challenges (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019).

Modular buildings have gained popularity due to their numerous advantages, including shorter construction times, cost-effectiveness, and reduced environmental impact. Understanding the mechanics of modular buildings highlights their unique construction process, from design and factory fabrication to transportation, assembly, and finishing. As the demand for flexible and efficient building solutions continues to grow, modular construction stands as a promising option to meet the needs of various industries and sectors. (Torre 1994) But despite the advantages, the private sector still heavily relies on traditional on-site construction methods. The reasons for this slow adoption of modular construction in the private sector are not fully understood (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019).

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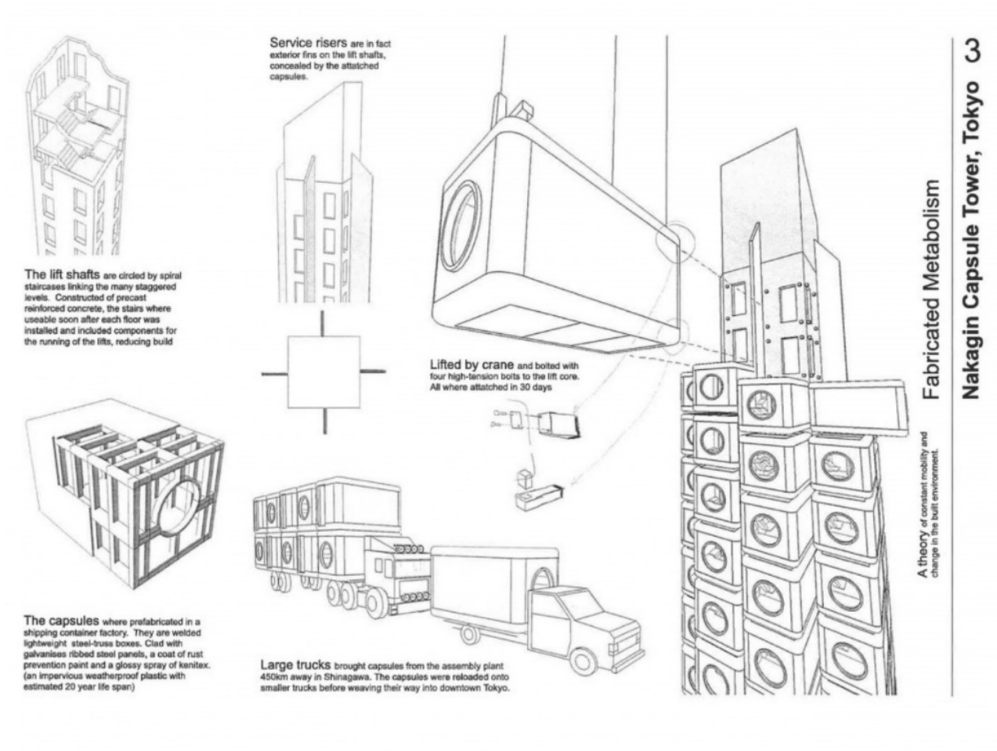
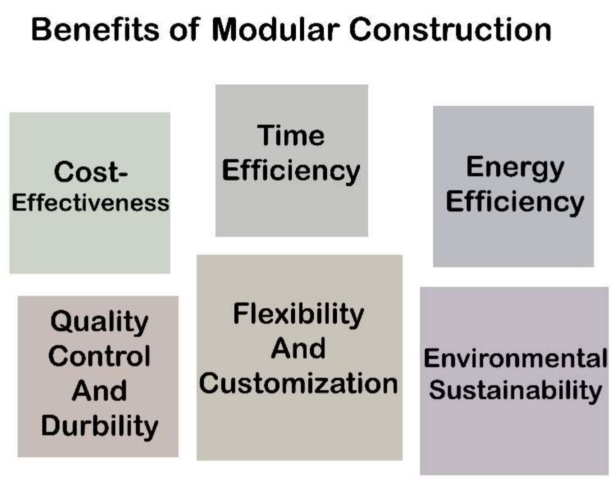


Example of a modular high-rise stabilized by concrete core; Nakagin Capsule Tower, Tokyo 1969-1972 by Kisho Kurosawa. Source: https://www.metalocus.es/en/news/nakagin-capsule-tower-tokyo-1969-72-kisho-kurokawa# Last accessed: 05.07.2023

2.3 Modular and prefabricated buildings in hospital use

Modular and prefabricated buildings have also become solutions in the healthcare industry, providing numerous benefits and addressing the specific needs of hospitals and medical facilities. This chapter explores the importance of modular and prefabricated buildings in the context of healthcare, highlighting their advantages and contributions to enhancing patient care and medical operations.



Speed and Efficiency: Speed is of utmost importance in the healthcare sector, especially during emergencies or when there is a pressing need for additional medical facilities. Modular and prefabricated buildings offer unparalleled speed and efficiency in construction. Off-site fabrication and parallel construction processes significantly reduce construction timelines, enabling hospitals to be operational in a fraction of the time required for traditional construction. (Torre 1994) This rapid deployment is crucial for accommodating patient overflow, setting up temporary clinics, or expanding existing facilities swiftly. (Smolova and Smolova 2021)

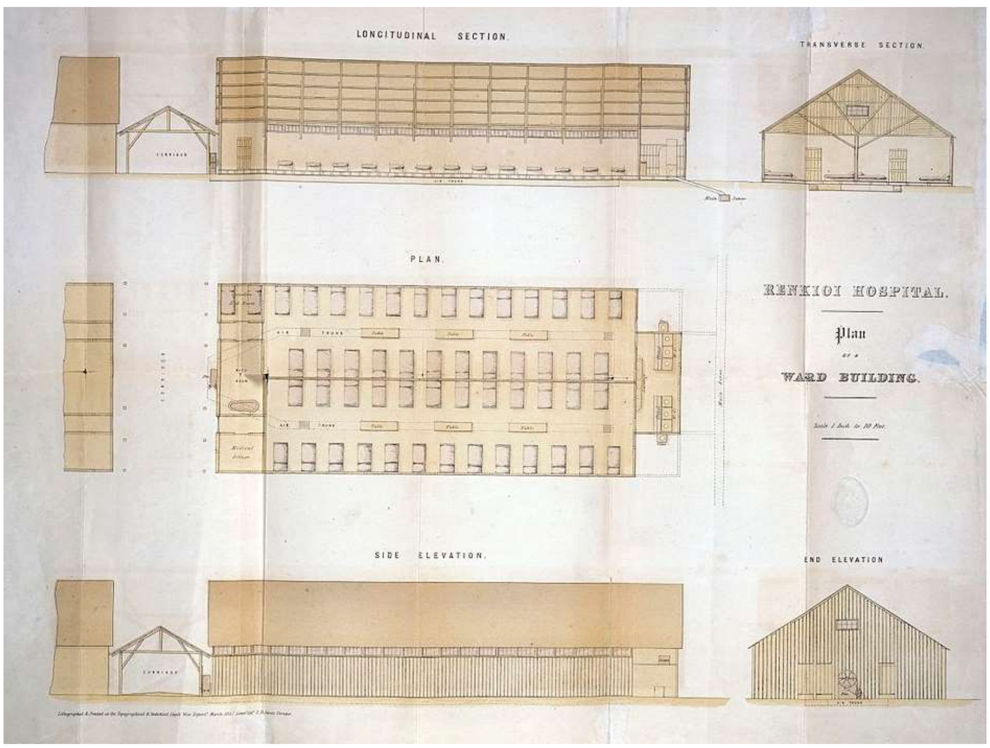
Flexibility and Scalability: Healthcare needs are dynamic and can vary based on regional demand, seasonal fluctuations, or unforeseen circumstances such as disease outbreaks or natural disasters. (Smolova and Smolova 2021) Modular and prefabricated buildings provide inherent flexibility and scalability to adapt to these changing demands. Modules can be easily added, removed, or reconfigured to create custom spaces, ensuring hospitals can quickly adjust their capacity and accommodate evolving patient requirements. (Torre 1994) This agility allows healthcare facilities to efficiently manage resources and optimize patient care delivery. (Smolova and Smolova 2021)

Cost-Effectiveness: Controlling costs is a crucial aspect of healthcare management. Modular and prefabricated buildings offer cost-effective alternatives to traditional construction methods. Factory-controlled construction reduces material wastage and enhances efficiency, resulting in overall cost savings. (Torre 1994) Hospitals can allocate their budgets more efficiently towards medical equipment, patient care, and staffing, thereby improving the quality of healthcare services.

Quality Control and Standardization: The controlled factory environment of modular and prefabricated building construction ensures stringent quality control measures are implemented at every stage of fabrication. Skilled workers, following standardized processes, produce modules that adhere to rigorous quality standards. This standardized approach minimizes variations and defects, resulting in consistent and reliable building components. The reliability of modular buildings in terms of structural integrity, insulation, and utility systems enhances patient safety and satisfaction. (Torre 1994)

Infection Control and Environmental Considerations: Maintaining a sterile and infection-free environment is crucial in healthcare settings. (Taylor 2020) Modular and prefabricated buildings can be designed with infection control in mind. (Smolova and Smolova 2021) The controlled factory environment reduces the risk of contamination during construction. Additionally, the use of antimicrobial materials and advanced ventilation systems helps create clean and hygienic spaces, minimizing the spread of infections. (Taylor 2020) Moreover, modular construction often incorporates sustainable practices, such as energy-efficient designs and the use of eco-friendly materials, aligning with the growing emphasis on environmental responsibility in healthcare. (Smolova and Smolova 2021)

Modular and prefabricated buildings play a vital role in the hospital and medical sector, offering invaluable advantages that align with the unique requirements of healthcare facilities. (Smolova and Smolova 2021) The speed, flexibility, cost-effectiveness, quality control, and infection control measures associated with these construction methods (Torre 1994) contribute to improved patient care, efficient resource utilization, and enhanced operational capabilities. (Taylor 2020) As the healthcare industry continues to evolve, modular and prefabricated buildings will remain instrumental in addressing the ever-changing demands and challenges faced by hospitals and medical facilities. (Smolova and Smolova 2021)



A plan of Renkioi Hospital, a prefabricated hospital from 1855, used during Crimean War. Source: https://www.worldhistory.org/Renkioi_Hospital/ Last accessed: 05.07.2023

2.4 Temporary emergency mode for requisitioning and transforming existing hospitals.

In Hubei, Xiaogan and Huanggang are the cities that have been hit the hardest, aside from Wuhan. Around 3,000 confirmed cases have been reported, which is 500 more than the number of SARS patients in Beijing in 2003. However, Xiaogan and Huanggang are cities with significantly lower levels of healthcare than Beijing (Cao, Fang and Xiao 2019). Wuhan had a small number of beds for the treatment of infectious diseases, which lowered the chances of successfully combating the emergency epidemic. (Zhihu 2020)

The primary actions conducted by Xiaogan and Huanggang involve fast modernising and transforming existing hospitals. As an illustration, Huanggang requisitioned the Dabie Mountain Regional Medical Center to serve as a single location for fever sufferers to receive care. In the early stages, Xiaogan requisitioned and renovated 4 existing hospitals, adding 990 additional treatment beds. (Zhihu 2020)

There are specific challenges when developing Xiaotangshan Hospital in a hurry during an epidemic or a large-scale infectious disease hospital in a city. An effective emergency strategy is to renovate existing hospitals (Zhihu 2020).

However, balancing the care of COVID-19 patients and regular patients is the major challenge in expropriation and reform. Hospital wards have been temporarily converted into hospitals for the treatment of infectious diseases during the epidemic era. Consideration must be given to both the accommodation and relocation of many regular patients as well as the effective management of critically sick patients. (He, et al. n.d.)

The newly built Dabie Mountains Medical Center, transformed and equipped with 1,000 beds, functioned as the largest coronavirus hospital in Huanggang. Source: http://p.china.org.cn/2020-07/09/content_76254766.htm Last accessed: 27.06.2023.

2.5 Modular buildings as quick actions.

The rapid and widespread spread of the pandemic has created an urgent need for the construction of temporary emergency facilities in various locations. These facilities serve critical purposes such as testing and treatment centers, critical care or first aid facilities, command centers, administrative offices, washrooms, distribution centers for essential services, mobile training facilities, and storage for medical supplies and equipment (Cheng, et al. 2021).

In response to this urgent demand, modular structures have emerged as a practical and efficient solution, not only in the healthcare industry but also in other sectors such as commercial, hotel, and education (L.-K. Chen, et al. 2021). The health industry has recognized the benefits of modular construction, with healthcare providers and investors increasingly viewing prefabrication and modular construction as the most viable and practical choice (Smolova and Smolova 2021).

Modular construction offers several advantages that make it well-suited for emergency situations like the COVID-19 pandemic. The ability to quickly manufacture and assemble modular units allows for rapid deployment of essential facilities in response to evolving needs. The controlled factory environment ensures efficient production and quality control, leading to consistent and reliable structures (Smolova and Smolova 2021).

Moreover, the versatility of modular units enables customization and adaptation to different functions and requirements. Whether it is an isolation ward, testing center, or administrative office, modular buildings can be designed and configured to meet specific needs. This adaptability makes modular construction an ideal solution for future emergencies that may require similar efforts (L.-k. Chen, et al. 2021).

The images on the page depict examples of modular units specifically designed and constructed to address the urgent demands posed by the COVID-19 pandemic. These units showcase the diverse applications and configurations possible within the modular construction framework. They highlight the flexibility and scalability of modular buildings in providing the necessary infrastructure to support healthcare services and emergency response efforts.

The first unit of CURA, sponsored by UniCredit, is built and installed at the OGR temporary hospital in Turin, Italy
Source: https://carloratti.com/project/cura/ last accessed: 23.06.2023.

Constructing the hospital in Wuhan. Source: [https://emag.archiexpo.com/qa-behind-the-scenes-of chinas-prefab-hospitals-against-coronavirus/](https://emag.archiexpo.com/qa-behind-the-scenes-of-chinas-prefab-hospitals-against-coronavirus/) last accessed: 23.06.2023

As the world continues to navigate through the challenges of the pandemic and future unforeseen crises, the development and utilization of modular buildings are poised to play a significant role. The efficiency, speed, and adaptability of modular construction make it an asset for healthcare providers, governments, and emergency response organizations, enabling them to swiftly respond to changing circumstances and ensure the provision of essential services in times of need.

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2.6 Equipment needed and electricity use of a single hospital room equipped for COVID-19

One COVID-19 hospital room will require about 1,000 and 2,000 watts of energy to run all the necessary systems; however, this variety can change based at the precise equipment used within the room. (Squire, Munsamy, Lin, Telukdarie, & Igusa, 2021)

The ventilator, IV pump, and heart monitor are regularly the three devices that consume the most power in a COVID-19 hospital room. They can every use hundred watts of strength, which means that they can contribute notably to the room's average energy call for. (Squire, Munsamy, Lin, Telukdarie, & Igusa, 2021)

The lighting fixtures, the air conditioning, and the medical gases are additional gadgets which can increase the amount of energy utilized in a

COVID-19 health center room. Fluorescent lights, which may additionally expend loads of power, are often utilized in hospital rooms. The air conditioning is important for retaining the climate chilly, that could assist in preventing the infection from spreading. In COVID-19 patients, gases such oxygen and nitrous oxide are also used, and those gases may also need a compressor, which also uses power. (Squire, Munsamy, Lin, Telukdarie, & Igusa, 2021)

Physicians and nurses wear personal protective equipment while they attend to a COVID-19 patient in the ICU at Providence Cedars-Sinai Tarzana Medical Center in Tarzana, Calif. on December 18, 2020. Source: https://www.capradio.org/news/npr/story/?storyi

The equipment in the room as well as the number of patients inside can influence how much electricity is used. For example, more power could be used while two patients share a room than when simply one affected person is there. (Squire, Munsamy, Lin, Telukdarie, & Igusa, 2021)

The type of medical equipment needed in a COVID-19 room will vary depending on the severity of the patient's condition, but common items include:

Oxygen therapy: This is important for patients who are having problems with their respiratory system. Oxygen may be added via a nasal cannula, a face mask, or a ventilator.

Intravenous fluids: These are used to maintain patients hydrated and to deliver drugs.

Pulse oximeter: This device measures the oxygen in the blood.

Electrocardiogram (EKG): This device records the electrical activity of the patient's heart.

Suction machine: This is used to dispose secretions from the airways.

Nebulizer: This tool offers medication in a mist form.

Personal protective equipment (PPE): This includes gowns, gloves, mask, and eye safety. (Cheng, HHsu, Weng, Liu, & Tsai, 2021)

In addition to those essential objects, some COVID-19 rooms may moreover have extra specialized device, which include:

Negative pressure room: This form of room has an air filtration machine that gets rid of viruses and microorganisms from the air.

Ventilator: This system allows patients to breathe if they're now not capable of respiring on their own.

Intensive care unit (ICU) bed: This form of mattress is ready with video display units and exclusive gadgets which could assist in keeping patients alive.

The precise clinical tool desired in a COVID-19 room may be determined through the affected person's individual needs. However, the objects indexed above are some of the maximum common gadgets which might be found in these rooms. (Cheng, HHsu, Weng, Liu, & Tsai, 2021)

Chapter 3

Revolutionizing Pandemic Healthcare Infrastructure: Examples of Innovative Approaches and Transformative Solutions

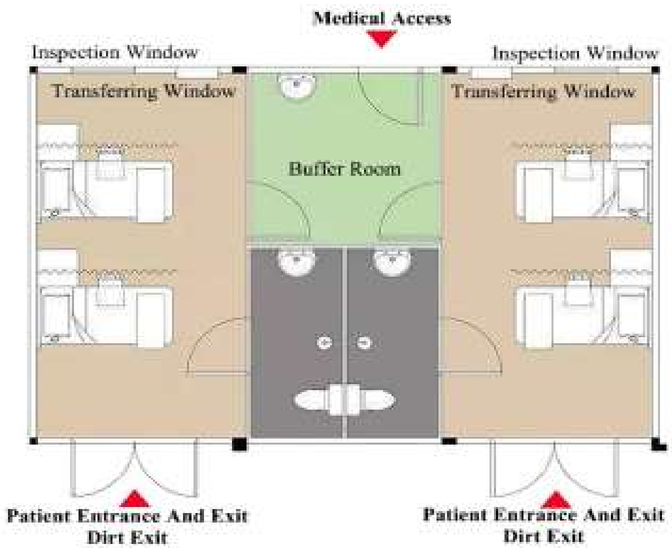
3.1 Application of modular buildings across the world for COVID-19 pandemic.

Given that conventional construction methods using brick, timber, and concrete structures cannot be used for fast-tracking construction, modular architecture is a viable answer to key difficulties in the health sector. In this situation, modular technology may be able to help. Therefore, it is anticipated that many nations will use modular buildings to create quarantine facilities, isolation wards, testing labs, resting spaces for medical staff, and so forth. Therefore, the healthcare system in a crisis has a special benefit from a modular solution (Chen L.-K. , et al., 2021).

The architect Carlo Ratti and his associates designed the CURA project, also known as "Connected Units for Respiratory Ailments," developed modular intensive care units (ICUs) made from repurposed shipping containers. The first prototype was installed at a hospital in Turin, Italy, to expand emergency facilities during the COVID-19 pandemic. CURA pods are designed to be quickly deployed and provide a safe working environment with comprehensive biocontainment equipment. The project was a collaborative effort involving architects, engineers, and medical technology companies. Each 20-foot container is equipped with negative pressure systems, glass windows for monitoring patients, and autonomous functionality for easy transportation. The initial installation in Turin served as an ICU for the hospital, housing medical equipment for two patients. The modular design allows for multiple configurations, either as an extension of existing hospitals or as standalone field hospitals. (Ratti, 2020)

China provides a fantastic illustration of how modular architecture can be used to quickly build hospitals. Following the Covid-19 epidemic in 2020, the number of patients in dire need of hospitalization and treatment increased significantly, which presented the Chinese authorities with a challenge (Zhihu, 2020). Early in February, Wuhan, China—the core of the coronavirus outbreak—used the modular building construction approach to establish a temporary hospital with 1,000 beds to solve this problem. The erection of the facility has taken only 10 days, which is a ground-breaking achievement in the history of modular building construction. The before and after pictures of Wuhan's Huoshenshan Hospital's construction are shown in the pictures below. Three days later, China opened Leishenshan, a hospital with 1600 beds, in the city. These two hospitals, which make up a significant portion of China's effort to combat the coronavirus, were built using steel modular components set on concrete foundations, which allowed construction to be completed in record time (Chen L.-K. , et al., 2021).

These actual cases have demonstrated the ability of modular construction to meet the urgent demand for medical infrastructure. It is important to remember that the modern world needs to be ready for any potential pandemics. Therefore, it is still necessary to develop modular units with improved overall performance in both structural and non-structural areas.



One patient room module in the Houshenshan hospital Source: https://www.sciencedirect.com/science/article/pii/S0926580521000066 Last accessed: 19.05.2023

Before (left) and after image (right) of the Huoshenshan Hospital in Wuhan, China Source: https://www.stuff.co.nz/world/asia/119139230/coronavirus-outbreak-china-to-complete-1000bed-hospital-in-under-a-week Last accessed: 20.05.2023

3.2 Flexible Healthcare Solutions: Adaptable Structure Types for Pandemic Response

Type 1: Temporary and Adaptive Structures

- The structures listed under Type 1 are designed to be temporary and adaptable to different situations.
- The structures can be quickly assembled and disassembled as per the needs of the situation.
- They are primarily meant to serve as emergency triage or testing centers during pandemics or other emergencies.
- Examples of Type 1 structures include the "pop-up" testing and triage centers in Hong Kong and the "COVID-19 Mobile Unit" modular testing unit developed in the United States.

Type 2: Hospital Extensions and Conversions

- Type 2 structures involve the conversion or extension of existing hospitals to accommodate increased patient load during pandemics.
- These structures are designed to be integrated with existing hospital infrastructure to provide a seamless healthcare experience.
- Examples of Type 2 structures include the temporary intensive care unit at the Royal Berkshire Hospital in the UK and the rapid conversion of a convention center in Wuhan, China, into a temporary hospital during the COVID-19 pandemic.

Type 3: Dedicated Pandemic Hospitals

- Type 3 structures are dedicated pandemic hospitals that are designed from the ground up to specifically deal with infectious diseases.
- These structures have advanced infection control systems and are designed to handle large numbers of patients.
- Examples of Type 3 structures include the Huoshenshan Hospital and Leishenshan Hospital in Wuhan, China, which were constructed specifically to deal with the COVID-19 pandemic.

Type 4: Retrofitting Existing Infrastructure

- Type 4 structures involve retrofitting existing infrastructure, such as hotels, into healthcare facilities during pandemics.
- These structures are designed to be quickly repurposed to handle the increased patient load during pandemics.
- Examples of Type 4 structures include the retrofitting of a hotel in the Philippines into a COVID-19 isolation facility and the use of university dormitories in the United States to house COVID-19 patients.

In summary, the four types of structures listed represent different approaches to providing healthcare infrastructure during pandemics. Type 1 structures are temporary and adaptable, Type 2 structures involve the expansion or conversion of existing infrastructure, Type 3 structures are dedicated pandemic hospitals, and Type 4 structures involve retrofitting existing infrastructure for healthcare purposes. Each type of structure has its unique advantages and limitations, and the choice of structure depends on various factors such as the severity of the pandemic, available resources, and the needs of the community.

3.3 Unveiling Architectural Inspiration: From Mobile Units to Containerized Hospitals, Shaping Innovative COVID-19 Facilities

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3.3.1 *TYPE 1: Pop-up COVID-19 testing and immunization units.*

COVID-19 MOBILE UNIT

Architects: Studio M-Rad, Santa Monica, CA, USA

Room Setup: The modular unit features three testing stations with windows and ring-shaped pass-through portals. A panel that projects outward provide privacy and infection prevention measures. The unit is designed for COVID-19 nasal swab tests and includes a portable elevator for wheelchair accessibility.

Spatial Organization: The rooms are organized within the trailer, with each testing station equipped with the necessary equipment and space for nurses to perform tests. The layout ensures efficient workflow and convenience for patients.

Construction and Transportation: The modular unit is designed as a trailer that can be easily transported by being drawn by another car. It can be taken to various locations for testing purposes, showcasing its mobility and flexibility.

Construction Time: One unit is produced, delivered and ready to operate in 21 days.

Materials: The unit is made of lightweight steel and can be customized with designs and texture on the outside panels. The specific panel used for this project is copper, which has antipathogenic properties. The virus dies within 4 hours on a copper surface.

Visual renderings of the COVID-19 mobile unit by M-Rad architects Source: https://www.dezeen.com/2020/05/07/m-rad-covid-19-testing-unit-copper-design/ last accessed 28.04.2023

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3.3.2 *TYPE 2: COVID-19 vehicular nomad units*

MODULAR TESTING UNIT

Architects: Perkins and Will with Schmidt Hammer Lassen Architects and Arup Group

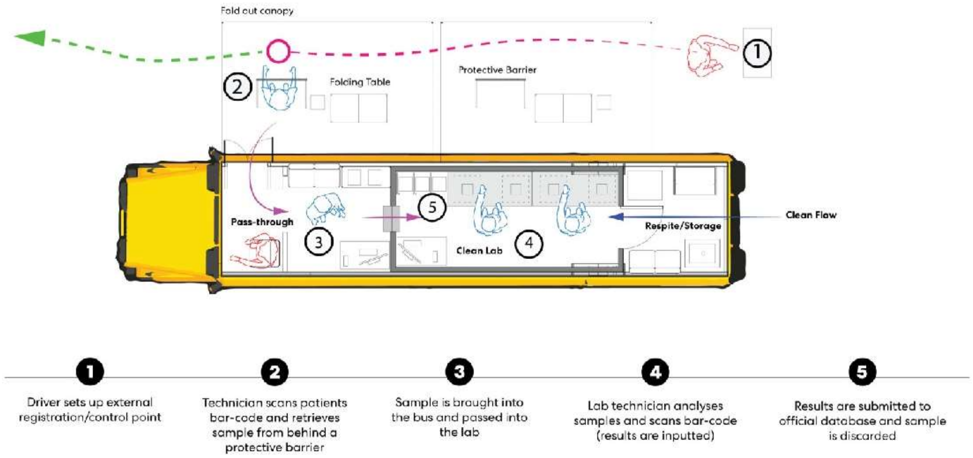
Room Setup: The interior of the converted school bus is divided into three sections - the staff work/PPE storage zone, the lab, and the administration/registration/testing area. Each section is organized to efficiently carry out the testing and vaccination procedures.

Spatial Organization: The bus is designed to accommodate different areas, including a waiting space under a pull-out canvas tent, where patients can sit and undergo screenings and immunizations. The layout ensures smooth workflow and privacy for patients.

Construction and Transportation: The mobile COVID-19 testing, and vaccination unit is created by repurposing standard school buses. It can be easily deployed to medically disadvantaged areas, such as schools and other facilities in remote regions. The unit is self-powered and can be transported to various locations as needed.

Construction Time: The information provided does not specify the exact time required to retrofit a school bus into the mobile unit.

Materials Used: The bus is retrofitted with necessary equipment and amenities for testing and vaccination purposes. The materials used for the interior setup, including the the lab equipment, seating, and protective barriers, are not mentioned in the provided details.

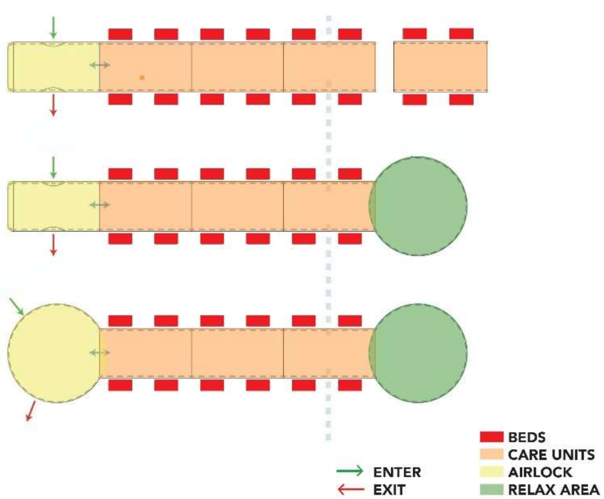


A plan of the Mobile testing center bus Source: https://www.archdaily.com/942023/3-major-architecture-firms-propose-school-buses-and-shipping-containers-for-accessible-testing-labs last accessed: 05.25.2023

3.3.3 *TYPE 3: COVID-19 Pop-ups in repurposed host structures.*

PPS (Personal Protective Space) for Caregivers

Architects/Designers: plastique fantastique Art Group, Berlin, Germany



Redrawn plan from author.

Room Setup: The original concept envisioned patients staying in clear Plexiglas capsules within a high-tech mega-hospital. The capsules were made of transparent plastic shells and were moved using a rail network suspended from the ceiling.

Spatial Organization: The patient rooms in the proposed system are capsule-shaped and made of polyethylene. In the PPS for Caregivers, staff members have their own soft plastic pneumatic bubble. The exhibit showcases multiple bubble-tubes placed in renovated host buildings.

Construction and Transportation: The proposed system requires the construction of a rail network suspended from the ceiling to transport the patient capsules. The PPS for Caregivers involves renovating host buildings to accommodate the bubble-tubes.

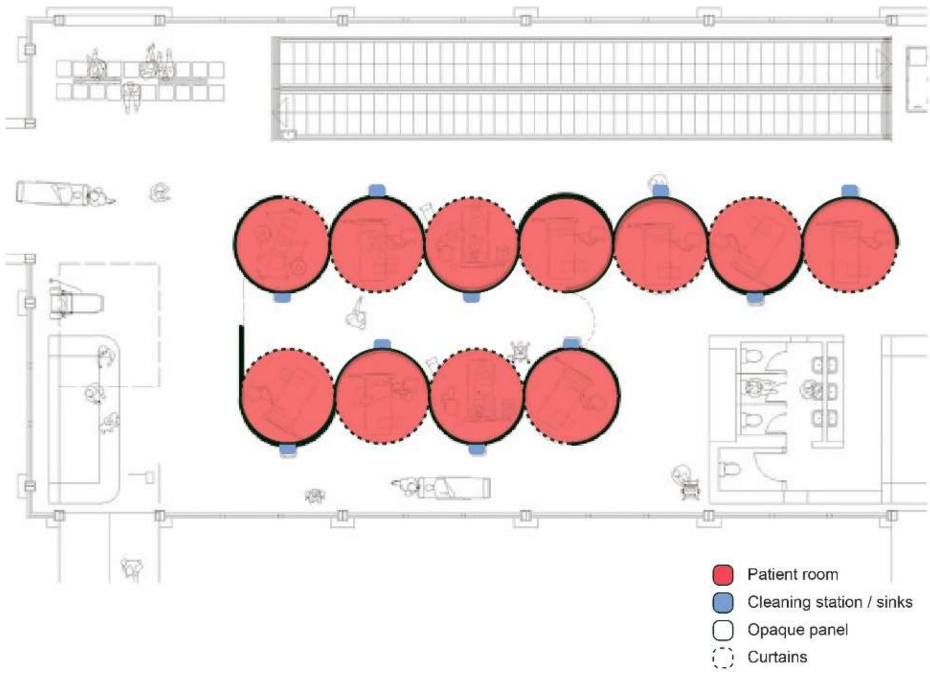
Construction Time: No information was available that specifies the amount of time needed for the construction of this module.

Materials Used: The capsules in the original concept were made of clear Plexiglas, while the patient rooms in the PPS for Caregivers were made of transparent plastic shells and polyethylene. A soft plastic pneumatic bubble is used for the staff members.

A nurse using the protective Capsule to make a swab test. Source: https://plastique-fantastique.de/Mobile-PPS-for-Doctors Last accessed: 12.05.2023

COVID-19 Superhospital

Designers: Opposite Office, Munich, Germany



Redrawn plan from author.

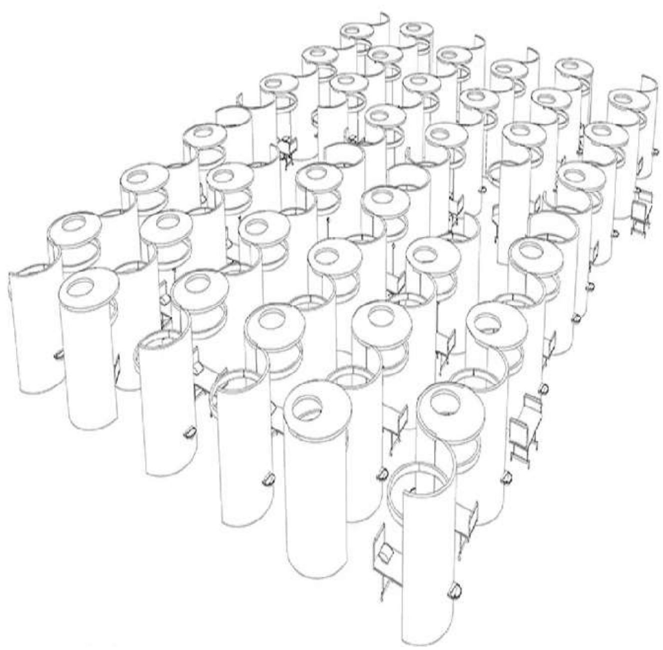
Room setup: The plan involves equipping medical personnel with modular cabins that include single beds, tray tables, hospital monitoring, and sinks. Steel frames and planks would be used to build the cabins.

Spatial organization: The plan suggests constructing rows of hospital bays by swapping out airport sitting spaces for rounded modular cabins. Each bay's curved shape offers a protected and tranquil setting for healing.

Construction and Transportation: To eliminate the need for substantial transportation, the concept offers erecting the modular cabins on-site using the airport's existing building structure.

Construction Time: Following the lead of the Wuhan Huoshenshan Hospital in China, the project stresses quick construction with the goal of opening the Superhospital in a matter of days.

Materials used: The modular cabins are built using steel frames and planking, and fabric curtains.



Renderings and views of the Covid-19 Super hospital. Source: https://www.dezeen.com/2020/04/01/opposite-office-proposes-berlin-brandenburg-airport-superhospital/ Last accessed: 15.05.2023

3.3.4 *TYPE 4*: *COVID-19 Lift-pack and containerized surge field hospitals and quarantine units.*

Huoshenshan Hospital

Investor: Government of China, Wuhan, China

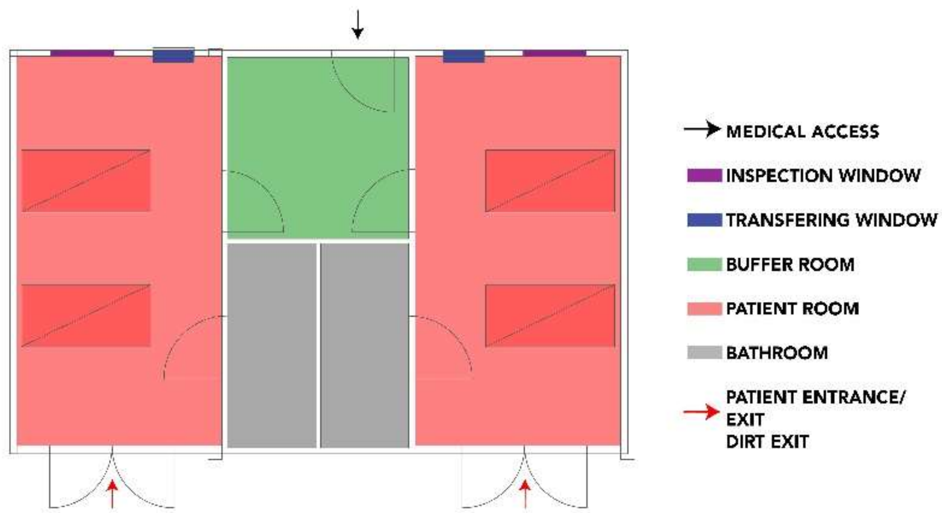
Room Setup: The rooms in the COVID-19 field hospital in Wuhan were set up using modular and prefabricated construction. Each module, measuring 10 by 10 meters, accommodated two beds and was designed to be negatively pressured throughout. The interior areas of the hospital were sparsely furnished, lacking windows that allowed occupants to see the outside.

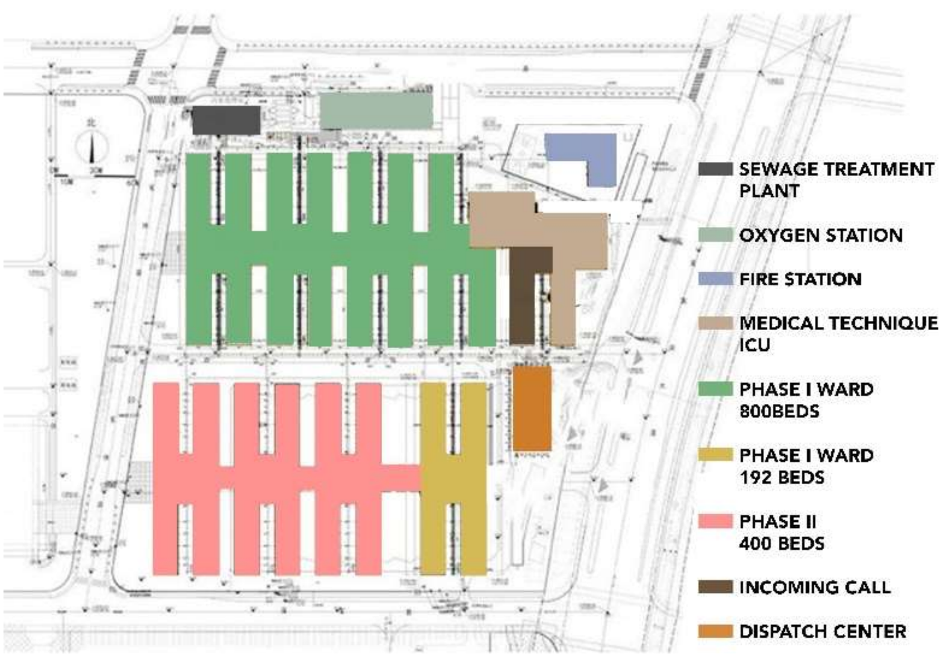
Space Organization: The hospital in Wuhan was constructed with two levels housing thirty intensive care units, nursing and medical support, and multi-bed quarantine units. The modular design allowed for efficient organization and utilization of space within the facility.

On-site Construction and Transportation: The COVID-19 field hospital in Wuhan was built on-site in a rapid timeframe of under 14 days. The construction process involved a large workforce of up to 7,000 workers working in three shifts. Earth movers were used to prepare the location, and the foundation of the hospital was built with concrete layers alternated with fiber insulation. The construction did not require special transportation as it took place on the designated site.

Time Required to Build: The field hospital in Wuhan was constructed in under 14 days, showcasing an impressive feat of rapid construction to address the urgent need during the COVID-19 outbreak.

Materials Used: The hospital's foundation was built using concrete layers alternated with fiber insulation. The modular construction of the hospital utilized prefabricated components.





Redrawn plans from authors images.

CURA Pod

Architects: CRA—Carlo Ratti Associati with Italo Rota, Turin, Italy

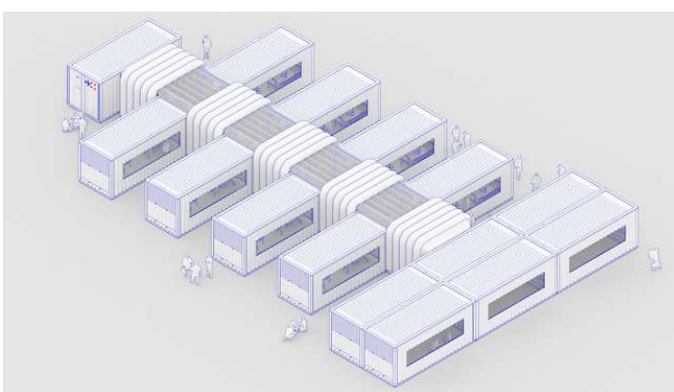
Room Setup: The CURA Pods are constructed from standard intermodal shipping containers, measuring 6.1 meters in length. Each pod is equipped with two beds and necessary medical supplies. Ozone filters and specially installed glass windows ensure pressurization control and visibility.

Spatial Organization: The CURA Pods can operate individually or be connected to a circulation spine covered with fabric, allowing for larger-scale installations. The container's sides feature small glass windows that offer views outside and enable workers and relatives to see inside.

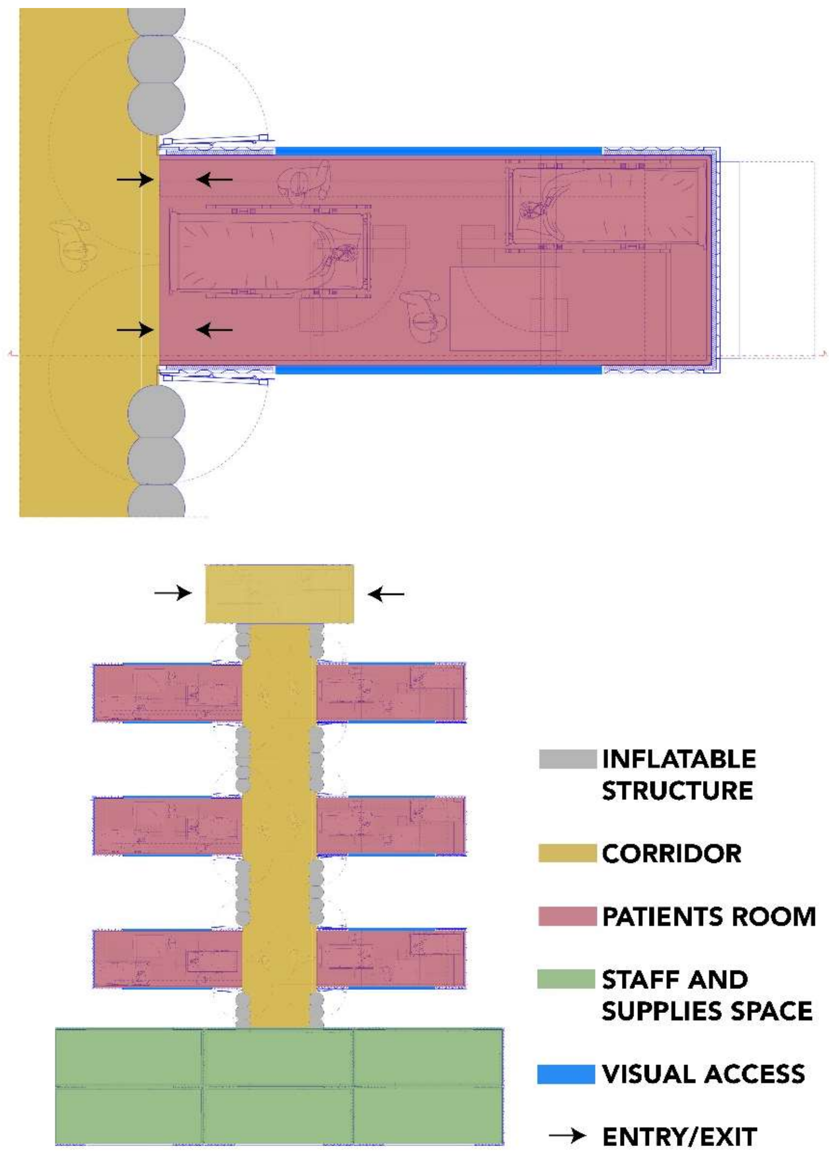
Construction and Transportation: The modular design of the CURA Pods allows for quick assembly and deployment. Being based on shipping containers, they can be easily transported and set up on-site at hospitals or emergency facilities.

Construction Time: The design and production process of the CURA Pod lasted 4 weeks, as a result of the joined effort of an international task force.

Materials Used: The primary material used in the CURA Pods is intermodal shipping containers, which provide a sturdy and adaptable structure. Other materials, such as fabric for the circulation spine and glass windows, are also used to enhance functionality and aesthetics.



Hospital made of CURA pods. Source:https://www.archisearch.gr/architecture/connected-units-for-respiratory-ailments-cura-for-emergency-coronavirus-treatment-by-carlo-ratti-and-italo-rota-architets/ Last accessed: 03.07.2023



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STAAT Mod

Architects: HGA+The Boldt Company, USA

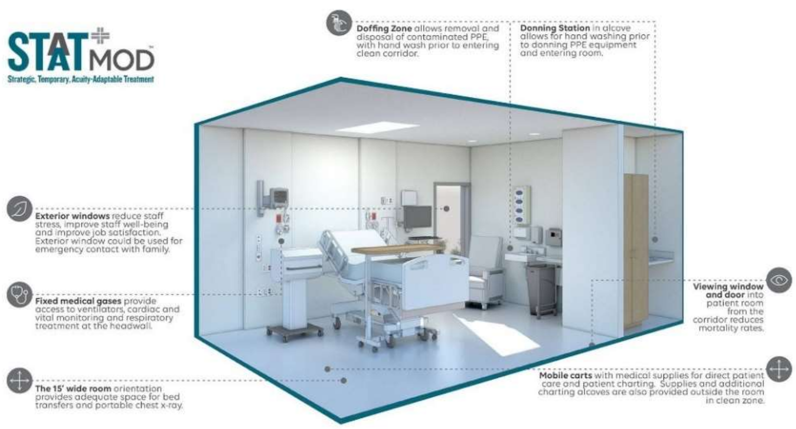
Room Setup: The STAAT Mod system offers various module configurations, including two-room modules for interior installations, eight-bed ICU modules, and 12-bed modules with negatively pressured open bays. The dimensions of each module are 12.5 by 40 by 10 feet (3.8m by 12m by 3m).

Spatial Organization: The modules are designed to be adaptable and allow for module additions and deletions without compromising functionality. The layout follows a spine-and-finger arrangement, reminiscent of Nightingale hospitals, with modest windows in the patient housing module.

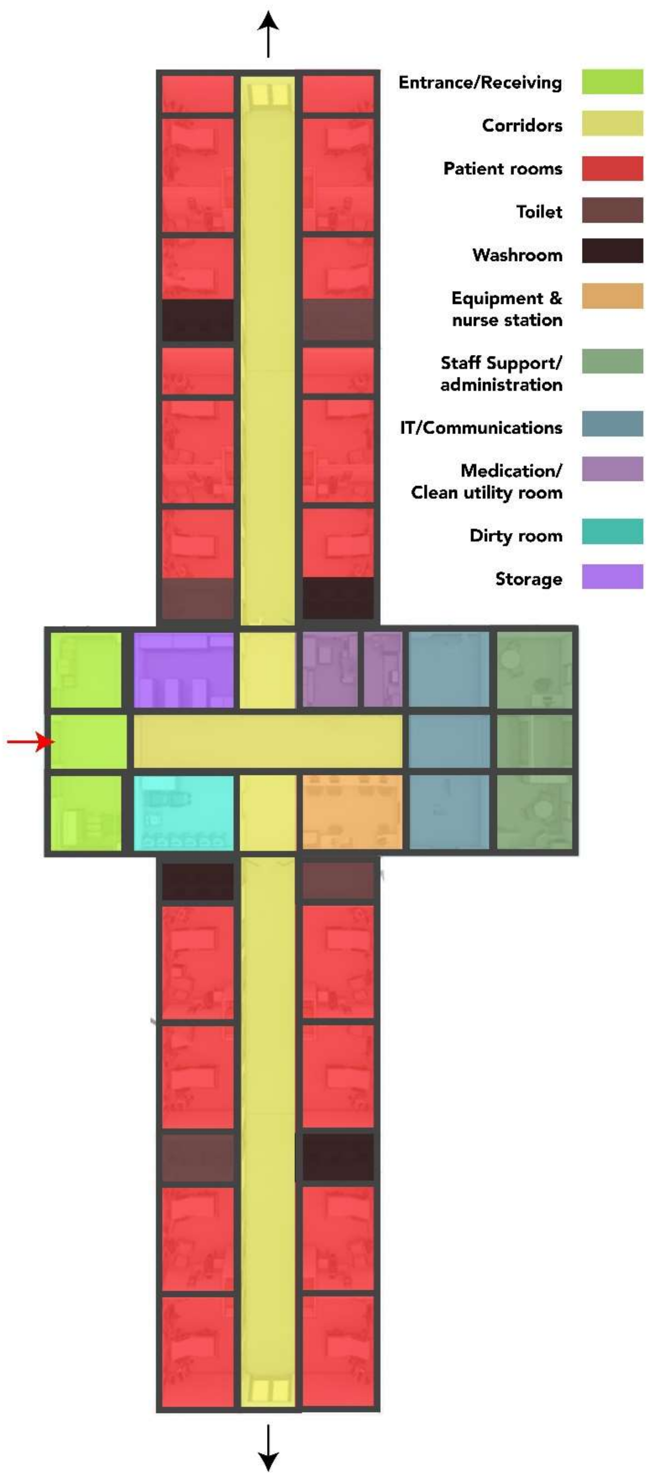
Construction and Transportation: The STAAT Mod system can be installed indoors or as a freestanding medical facility adjacent to an acute care center. It utilizes a prefab modular system, which may require special transportation depending on the location and setup requirements.

Construction Time: From start to finish, a module can be completed in less than 10 days.

Materials Used: Various materials. Specific information not provided.



STAAT MOD modular room, interior view. Source: https://hga.com/meeting-healthcare-challenges-through-prefabricated-modular-solutions-and-engineering/ Last accessed: 06.05.2023



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3.4 Inspired by Revolutionary Pandemic Healthcare Infrastructure: Innovative Approaches and Transformative Solutions

The examples of modular buildings and flexible healthcare solutions presented in this chapter have a profound impact on design thinking and approach. The CURA project's innovative use of repurposed shipping containers to create modular intensive care units is truly impressive. The ability to rapidly deploy these units and provide a safe working environment with comprehensive biocontainment equipment showcases the potential of repurposing unconventional materials and structures. This inspires exploration of their advantages in terms of speed, sustainability, and adaptability.

Moreover, the construction of temporary hospitals in Wuhan, China, using modular components highlights the importance of efficiency and adaptability in emergency healthcare infrastructure. The capability to quickly assemble and disassemble these structures to accommodate the increasing patient load during a pandemic is a game-changer. It motivates the focus on designing facilities that can be rapidly deployed, effectively responding to the urgent demands of healthcare infrastructure during challenging times.

These examples also spark interest in exploring the potential of flexible spatial organization. The modular design of the CURA pods and the adaptability of the temporary hospitals in Wuhan demonstrate how space can be optimized to meet the specific needs of a pandemic. This inspires the creation of designs that allow for seamless scalability and efficient workflow, ensuring facilities can easily adapt to changing circumstances and accommodate different healthcare requirements.

Furthermore, the use of innovative materials and technologies in these examples, such as antipathogenic copper panels and advanced infection control systems, piques curiosity about incorporating cutting-edge solutions into designs. Exploring how the latest advancements in materials science and healthcare technology can be integrated into infrastructure to enhance patient care, safety, and overall performance becomes an exciting endeavor.

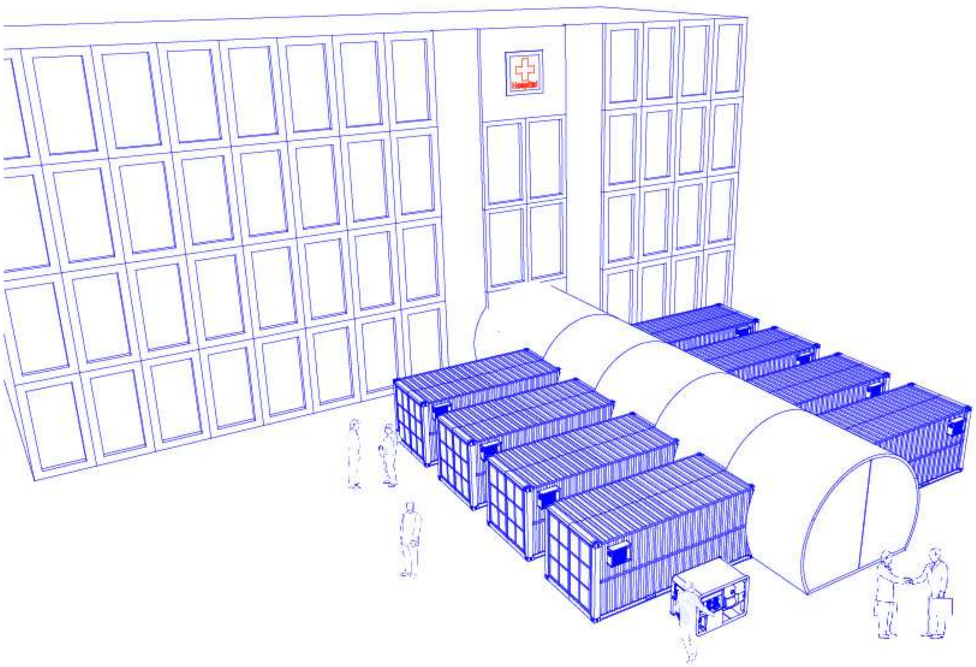
In summary, these examples serve as a significant source of inspiration and provide valuable insights into the potential of modular design, adaptability, and innovative solutions in revolutionizing pandemic healthcare infrastructure. They lay the foundation for designing healthcare facilities that are responsive, efficient, and capable of addressing the urgent healthcare needs of the future.

Chapter 4

Revolutionizing Pandemic Healthcare Infrastructure: A Concept of Innovative Approach and Transformative Solution

4.1 Design Concept

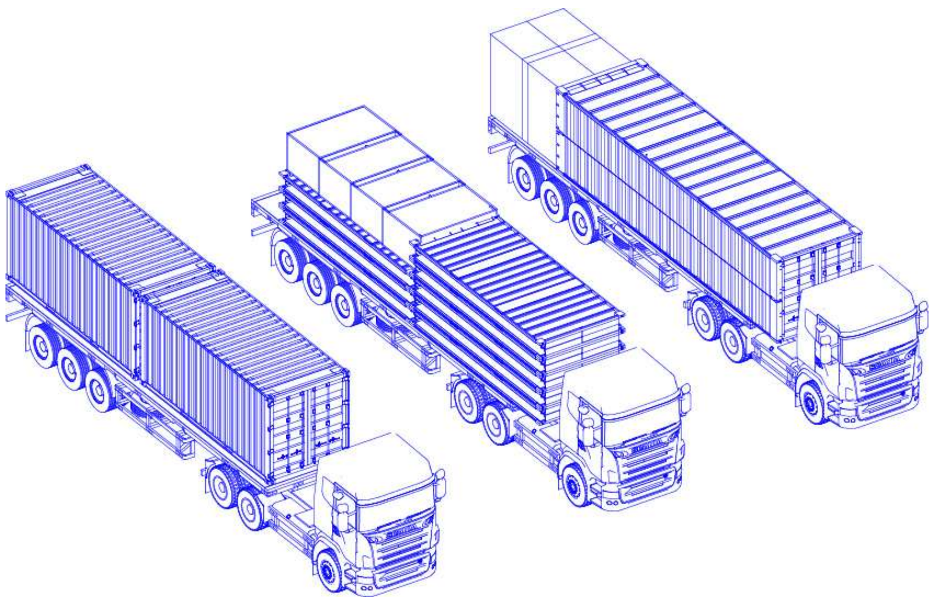
In light of the critical need for additional hospital beds during emergencies, particularly the COVID-19 pandemic, we have embarked on the task of designing a modular hospital room. The primary goal of this project is to address the scarcity of hospital beds by providing a solution that is flexible, efficient, and capable of creating a safe and comfortable environment for patients in need of medical care. This research delves into the architectural aspects of an innovative modular hospital room, which can seamlessly integrate into existing healthcare facilities.



Drawn: A view of one Modular Hospital created with 8 modular rooms.

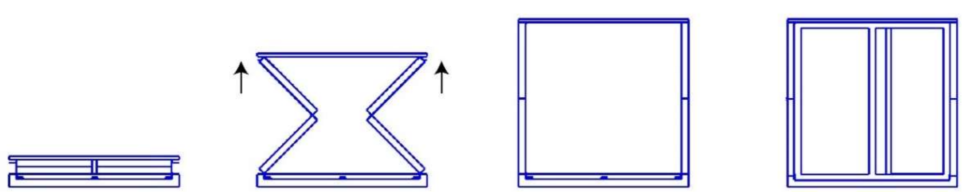
The modular hospital room developed aims to overcome the challenge of limited space within hospitals by utilizing parking lots as an optimal location. By repurposing these areas, we can maximize available resources and accommodate a larger number of patients. To ensure a secure connection to the main hospital building, the modular room is connected through an inflatable structure, allowing uninterrupted access to vital medical services and supplies. Between the connection of the main hospital building and the inflatable structure, we have a safety barrier; filter space to ensure the safety of the main hospital building.

Moreover, an outstanding benefit of the modular hospital room design is its exceptional transportability. It is truly remarkable that a mere three trucks can transport a complete set of eight fully equipped patient rooms to any desired location. This efficient utilization of transportation resources exemplifies the practicality and cost-effectiveness inherent in the modular approach. By optimizing the capacity of each transport, healthcare facilities can rapidly and efficiently enhance their capabilities, thereby offering critical care to a significantly larger number of patients during emergency situations.

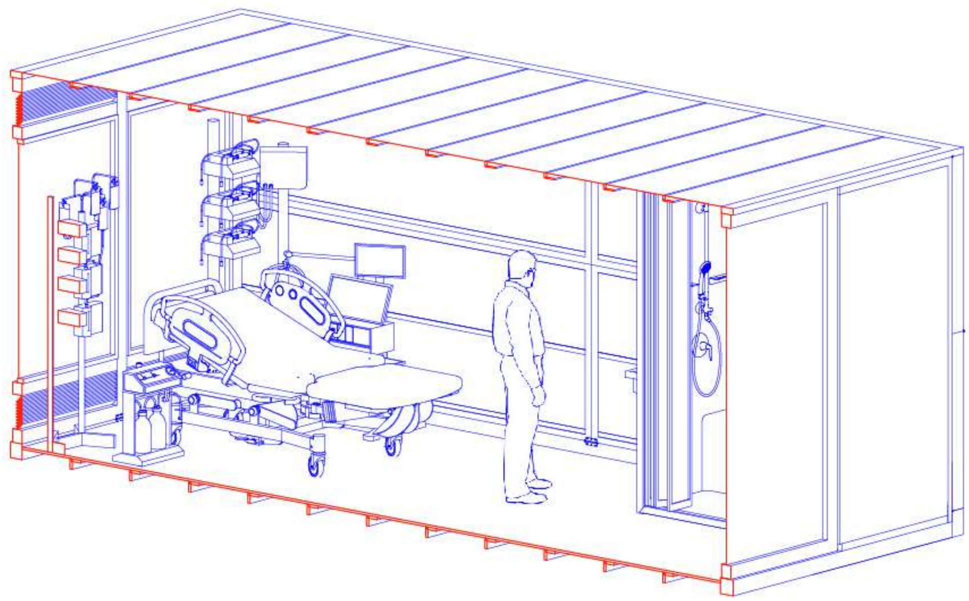


Drawn: A visual representation of the transportation methods for one modular hospital for 8 patients.

The structural design of the modular room places a strong emphasis on portability, ease of setup, and durability. To achieve these objectives, lightweight materials, such as lightweight steel, have been employed for the framework. This choice enables efficient transportation and assembly. Additionally, lightweight panels have been utilized for the walls, roof, and floor, ensuring structural integrity while minimizing overall weight. This lightweight construction enables easy transportation of the modules to different locations as the need arises.



The modular hospital room has been purposefully designed to cater specifically to patients with COVID-19, equipped with all the necessary equipment and facilities. Each module features a comfortable bed for the patient, along with essential medical equipment and monitoring systems. Furthermore, a prefabricated bathroom has been seamlessly integrated within the module to enhance convenience and maintain stringent hygiene standards. The modular nature of these rooms allows for seamless expansion, with the capability to add more modules as required. This scalability effectively enhances the healthcare infrastructure, ensuring it can adapt to the increasing demands during emergency situations.

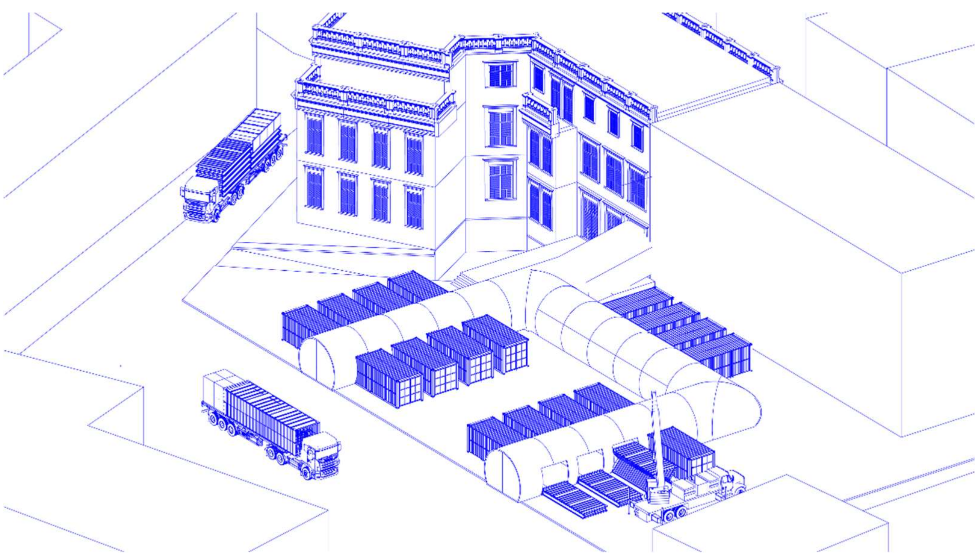


Drawn: Visual representation of the interior space in one module.

The installation process of the modular hospital room has been streamlined through the utilization of a folding mechanism. By employing a small crane, the module can be effortlessly lifted and positioned into place. The walls, roof, and floor are designed with hinges, allowing them to be opened or folded back as needed. This design feature significantly facilitates transportation, as the folded module becomes compact, occupying minimal space. Consequently, this enables cost-effective relocation and efficient storage when the modules are not in use.

The modular hospital is efficiently powered by a generator, ensuring uninterrupted electricity supply for all critical operations. This generator, equipped with advanced fuel management systems, guarantees a constant power source to support the functioning of essential medical equipment within the facility. Chapter 2, subchapter 2.7 shows many advanced medical tools, like high-tech tests, life-saving breathing machines, machines to watch patients, and special medical devices.These cutting-edge technologies are seamlessly integrated into the modular hospital's infrastructure, empowering healthcare professionals to deliver high-quality care and effectively address the healthcare needs of patients during pandemics or emergencies.

To address the scarcity of hospital beds during emergencies, particularly the COVID-19 pandemic, the development of a modular hospital room offers an innovative solution. By capitalizing on underutilized parking lots and utilizing lightweight materials, this modular design provides a flexible and scalable healthcare solution. The inclusion of essential medical equipment and a prefabricated bathroom ensures patient well-being and comfort, while the folding mechanism and simplified installation process enhance mobility and practicality. With the ability to add more modules as needed, this modular system holds significant potential in supporting healthcare systems during crises, effectively meeting the evolving needs of patients and medical professionals alike.

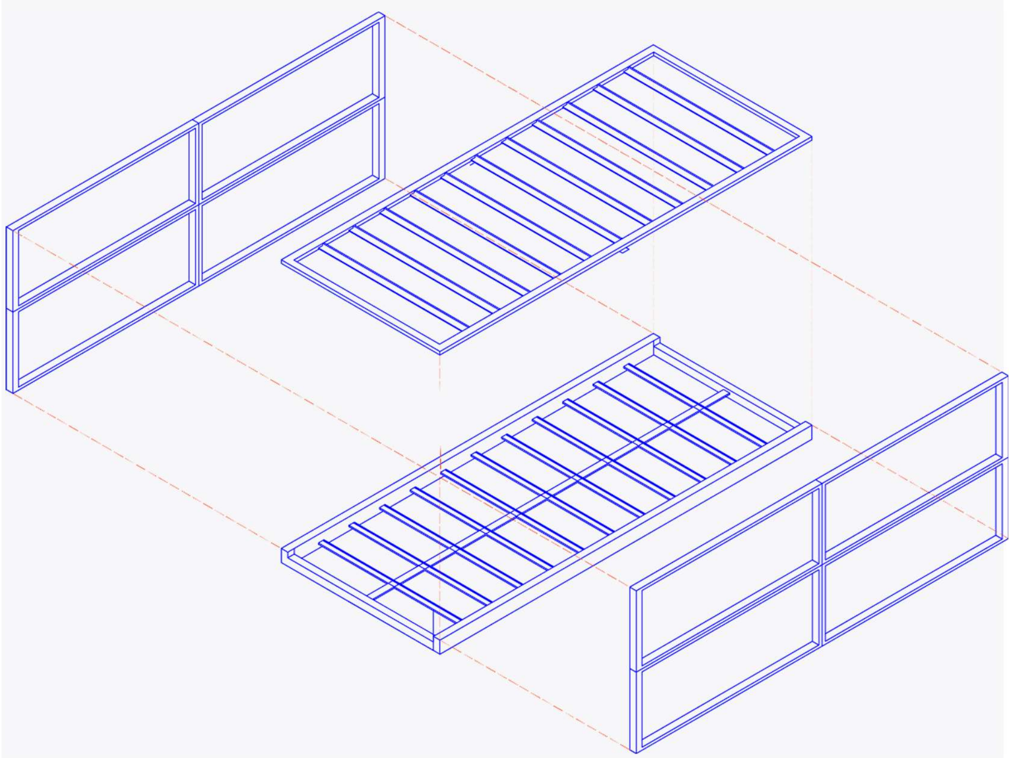


Drawn: Visual setup of one hospital in Astanteria Martini in Torino, Italy.

4.2 Structure of the modular room

In response to the need for efficient and compact emergency healthcare facilities, this chapter explores an innovative concept project: the foldable emergency hospital modular room. This concept combines a lightweight structure design and a folding mechanism, allowing for ease of transportation and setup.

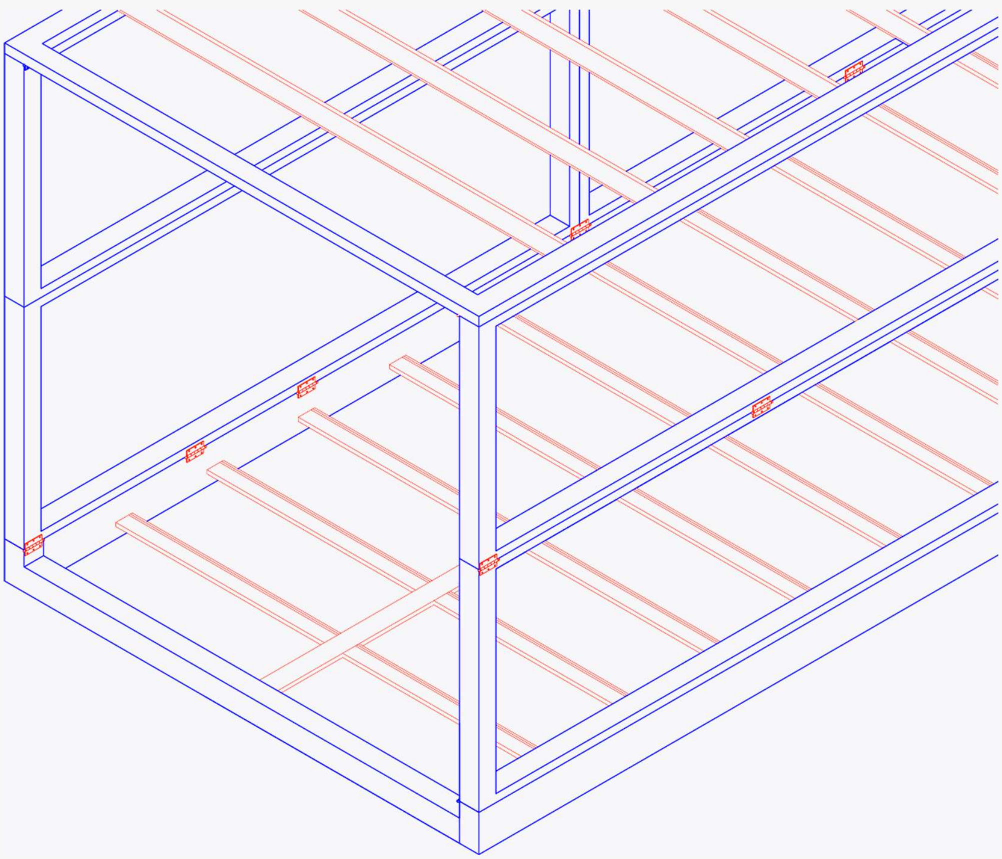
Lightweight Structure with Hollow Posts: To ensure a lightweight yet sturdy structure for the modular hospital room, the design incorporates hollow posts in every corner and in the middle of the room. These hollow posts, made of lightweight steel, reduce the overall weight of the modular unit while maintaining necessary strength and stability.



Drawn: Structural components of a module.

Folding Mechanism for Efficient Transportation: The key feature of the foldable emergency hospital modular room is its ability to fold in half. The two sides of the structure are hinged, enabling them to break in half and fold inward. This folding mechanism significantly reduces the space required for transportation, optimizing efficiency by condensing four rooms into the same space as a single repurposed shipping container.

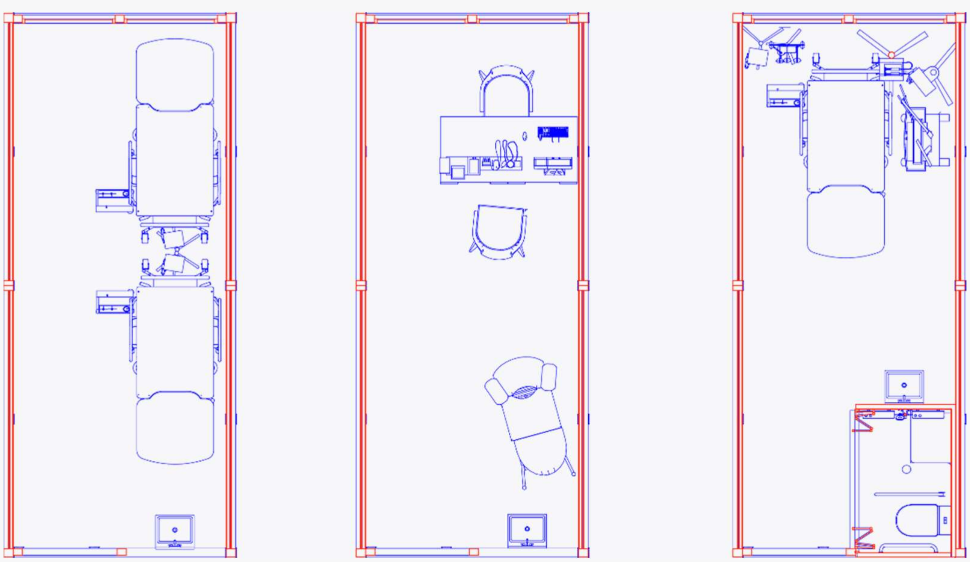
Structural Integrity and Durability: While prioritizing transportation efficiency, the foldable design does not compromise the structural integrity or durability of the emergency hospital modular room. The construction materials and techniques used ensure the necessary strength and stability for a medical environment. Although, rigorous testing and quality control measures should be implemented to ensure smooth operation of the folding mechanism and to maintain a robust and secure structure during deployment.



Drawn: A visual representation highlighting the structure and the hinges used to open the structure.

Streamlined Deployment and Setup: The deployment process of the foldable emergency hospital modular room is designed to be streamlined and time efficient. Once the room reaches its destination, it can be easily unfolded and expanded to its full size, ready for immediate use. The intuitive folding mechanism enables quick setup by trained personnel, making it particularly advantageous in emergency situations that require prompt medical intervention.

Adaptability and Customization: The foldable emergency hospital modular room concept offers adaptability and customization options to cater to specific healthcare requirements. The interior layout can be configured to accommodate various medical functions, such as examination rooms, patient wards, or isolation units. Additionally, the external aesthetics and finishes can be customized to blend with existing infrastructure or suit specific environmental conditions.



Drawn: 3 possible future configurations of one module: A) A ward; B) An examination office; C) An isolation room.

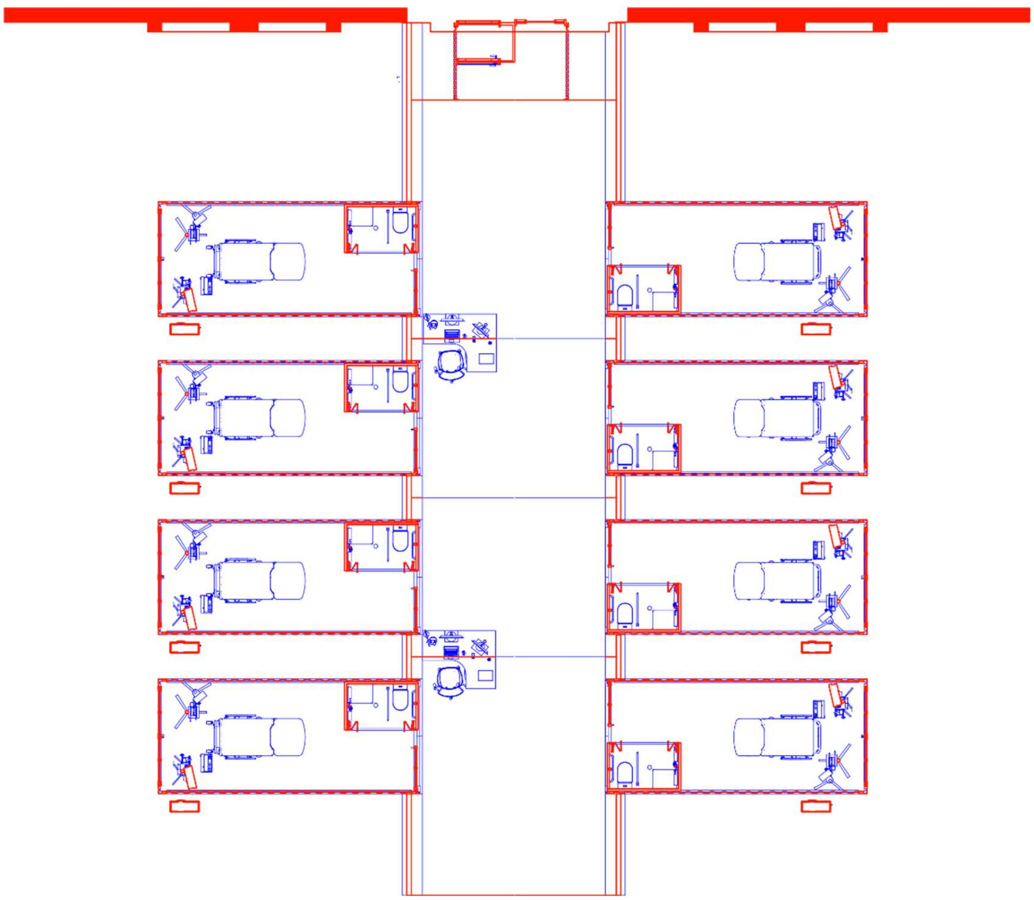
The foldable emergency hospital modular room represents a possible solution for compact and efficient emergency healthcare facilities. Its lightweight structure, folding mechanism, and optimized transportation contribute to improved efficiency and effectiveness in emergency response. With its adaptability and ease of deployment, this innovative concept holds great potential in rapidly expanding and adapting healthcare infrastructure during emergencies or critical situations.

Drawn: A visual rendering of setting up a module of 3 hospital extensions in the backyard of Astanteria Martini, Torino.

4.3 Configurations and Features of the Modular Hospital

We have devised two configurations for the expansion of the hospital, each tailored to the specific requirements dictated by the severity of the situation at hand. One configuration includes the incorporation of an airtight filter space, while the other does not. The decision regarding the inclusion of the filter space depends on the gravity of the circumstances and the level of protection deemed necessary.

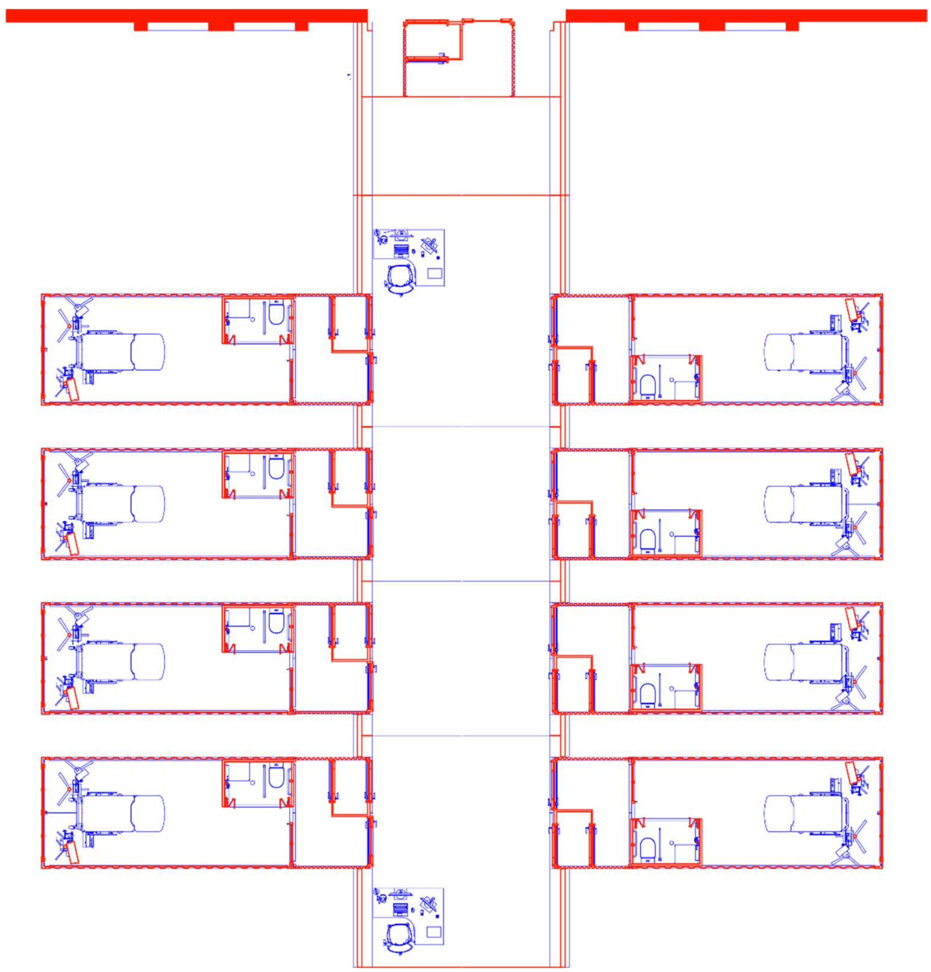
In addition to the filter space, we have implemented a filtered connection between the expansion area and the main hospital building. This connection ensures that any air circulating between the two spaces is properly filtered and purified, mitigating the risk of cross-contamination.



Drawn: Plan of the modular hospital extension without Filter Space between the inflatable structure and the rooms.

The modular hospital rooms are thoughtfully organized and interconnected through what we refer to as a "Green space" within the modular hospital facility. This Green space serves as a communal area, providing a soothing and pleasant environment for patients and staff alike.

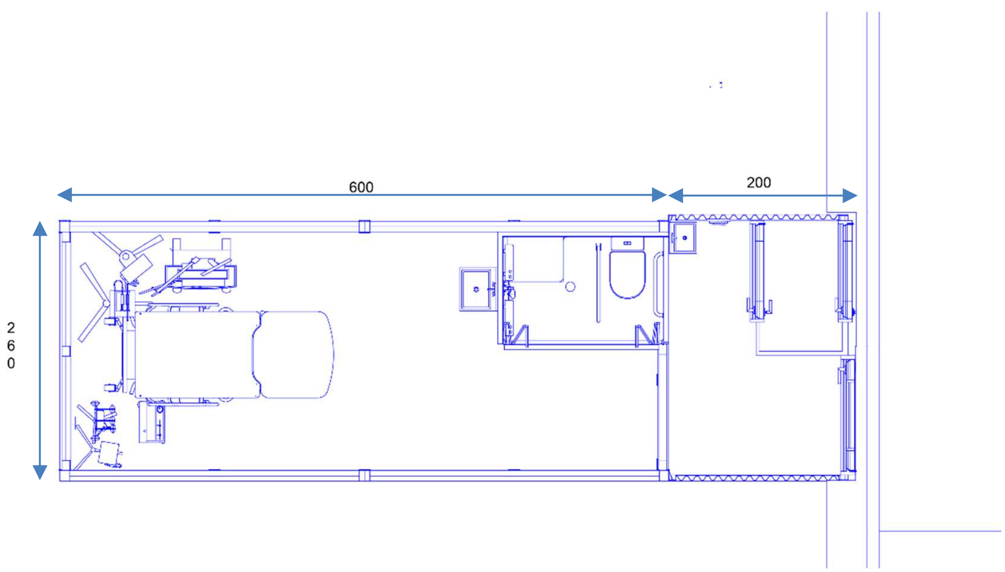
To maintain a controlled and safe atmosphere within this space, it is covered by an inflatable structure. This inflatable structure not only connects the modular hospital with the main hospital building but also acts as a barrier against external elements such as weather conditions and potential contaminants.



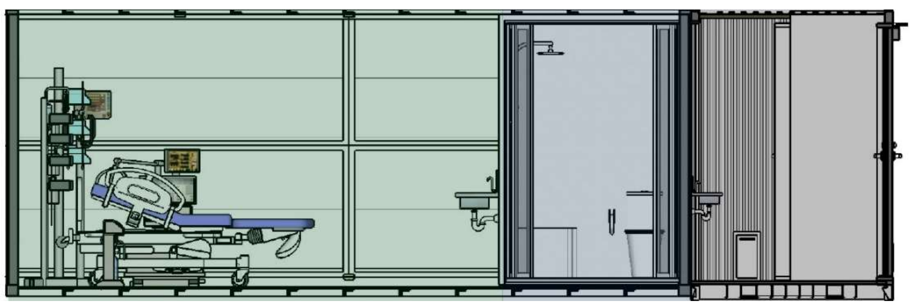
Drawn: Plan of the modular hospital extension with Filter Space between the inflatable structure and the rooms.

A single modular hospital unit consists of eight rooms, each equipped with its own bathroom. Furthermore, every room is accompanied by a dedicated filter space, ensuring a high level of air quality, and preventing the spread of infectious diseases. The inflatable structure is employed to enclose and separate the modular rooms, shielding them from the outside environment as well as safeguarding the main hospital from any potential threats. To ensure uninterrupted power supply, each modular hospital unit is equipped with a generator, guaranteeing the availability of electricity for essential medical equipment and other operational needs.

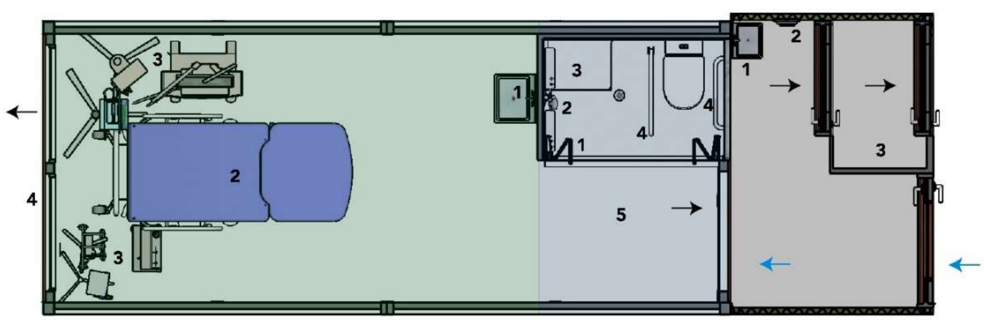
To facilitate easy transportation and setup, all the necessary components of a modular hospital unit, including the rooms, bathrooms, filter spaces, inflatable structure, generator, medical equipment for infectious diseases, and air conditioners, can be efficiently loaded onto three trucks. This modularity enables rapid deployment and swift response to urgent medical situations or emergencies.



4.4 Parts of the modular room



Section



PATIENT ROOM
1. Sink
2. Bed
3. Med. equipment
4. Window/door on the outside to ensure safety of the visitors with only visual access, also can be used in an emergency scenario to quickly remove patient

BATHROOM
1. Folding doors (open space and privacy)
2. Shower
3. Shower bench
4. Hand rails
5. Pre-space used to accomodate a patient and also help of med, staff

FILTER SPACE
1. Sink
2. Dirty/Contami-nated equipment disposal
3. Shower

← ENTRY
→ ENTRY

4.4.1 Filter Space Design; an Airtight Pressurized Room

Purpose and Function

This chapter provides a comprehensive explanation of the purpose and function of the air-tight pressurized room, emphasizing its crucial role as a barrier between clean environments such as corridors and potentially contaminated patient rooms. By maintaining positive air pressure within the pressurized room, it effectively prevents the migration of airborne contaminants and pathogens, minimizing the risk of cross-contamination and transmission of infections from patient rooms to other areas of the healthcare facility.

Contaminated Clothes Disposal Chute

The design and functionality of the specialized chute system for disposing of contaminated clothes are thoroughly discussed, highlighting its mechanism, and emphasizing the importance of easy and secure disposal to minimize the risks of contamination. The chute system provides a dedicated and efficient means of disposing of potentially contaminated clothing, ensuring that they are safely transported to a designated area, separate from clean areas, reducing the risk of cross-contamination and maintaining a hygienic environment within the facility.

Changing Area and Sink

This chapter provides in-depth details on the design considerations for the changing area and sink within the pre-entry room, emphasizing the importance of having a dedicated space where healthcare professionals can change their contaminated clothes and adhere to strict hygiene practices. The design focuses on creating an environment that promotes proper doffing and donning procedures, with well-equipped sinks for hand hygiene, ensuring that healthcare professionals can maintain optimal cleanliness and prevent the spread of contaminants as they transition between different areas of the facility.

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Shower Facility
The inclusion of a shower facility in the pre-entry area is explained, highlighting its purpose in ensuring thorough cleansing if needed after exiting the contaminated patient room. It discusses the incorporation of safety features and the use of appropriate materials to maintain hygiene standards.

4.4.2 Bathroom Design

Folding Doors for Enhanced Space and Accessibility
The use of folding doors in the bathroom design offers significant advantages in terms of increased space and accessibility. By eliminating the need for swing clearance, folding doors save valuable floor space in smaller bathrooms, making it easier for patients with mobility aids or healthcare providers to maneuver within the area. Additionally, folding doors provide a wider entryway when fully opened, allowing for smooth and unobstructed passage, particularly for individuals using wheelchairs or medical equipment.
Wheelchair Accessibility and Dimension Specifications
In designing the bathroom, careful attention is given to wheelchair accessibility features and dimension specifications to ensure it meets the necessary standards for accommodating individuals with mobility challenges. This includes incorporating features such as wider doorways, grab bars, roll-in showers, and adequate maneuvering space, all designed to promote independence, safety, and ease of use for individuals using wheelchairs or other mobility aids.
Hygienic Shower with Incorporated Seating Bench

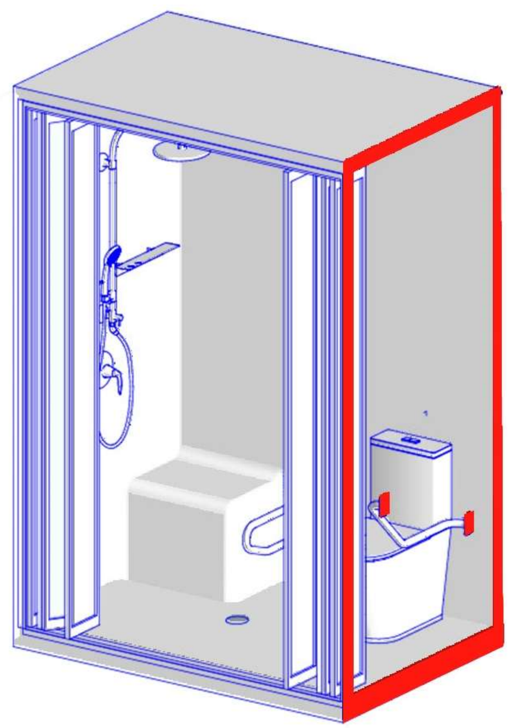
The design of the hygienic shower within the bathroom is enhanced by the incorporation of a seating bench, which serves both functional and hygienic purposes. By eliminating corners and crevices, the seating bench design reduces the potential areas for bacteria and dirt to accumulate, promoting optimal hygiene and making the shower easier to clean and maintain. Additionally, the seating bench provides a convenient and comfortable seating option for individuals with mobility limitations or those who require assistance during showering.

Handrails for Enhanced Safety

The inclusion of handrails in the bathroom design is crucial for ensuring the safety and stability of patients, especially those with mobility impairments. Handrails provide a reliable support system that individuals can hold onto for balance and support while moving around the bathroom, reducing the risk of slips, falls, or accidents. They offer added confidence and independence to patients, allowing them to navigate the bathroom with greater ease and minimizing the reliance on caregiver assistance.

Materials and Construction of Bathroom Components

The materials and construction techniques used for the bathroom components, including walls, showers, and doors, are detailed. It emphasizes the selection of hygienic and durable materials to prevent the growth of harmful microorganisms. The focus of this chapter is on the materials used in bathroom construction, highlighting the use of fiberglass for durability and moisture resistance. The incorporation of an aluminum structure ensures stability.



4.4.3 Room Interior Design and Material Selection

Vinyl Flooring with Smooth Transitions

The use of vinyl flooring in the patient room is emphasized due to its numerous advantages, including cleanliness, durability, and ease of maintenance. Vinyl flooring is resistant to stains and moisture, making it easy to clean and disinfect, while its durability ensures long-term use in a healthcare setting. Additionally, smooth transitions between the floor and walls are emphasized to prevent the buildup of dirt and bacteria in hard-to-reach corners, promoting a hygienic environment that supports patient well-being and infection control efforts.

Non-Porous Wall Panels for Enhanced Hygiene

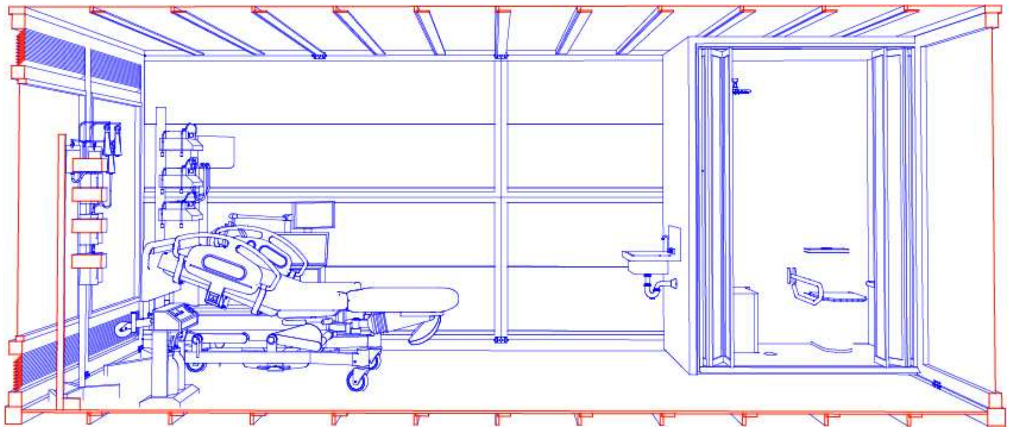
The selection of non-porous PVC wall panels for the patient room is explored in this section, emphasizing their ability to prevent the growth of harmful microorganisms. These panels act as a barrier against the development of mold, mildew, and bacteria, promoting a hygienic environment that is essential for patient health and safety. Their non-porous nature also simplifies the cleaning and disinfection process, contributing to the overall cleanliness and infection control measures within the room.

Sink Placement and Accessibility

The rationale behind placing the sink within the patient room, rather than the bathroom, is driven by the aim to enhance accessibility and convenience for patients and healthcare professionals alike. By having a sink within the patient room, individuals can easily access hand hygiene facilities without the need to leave the room, promoting infection control and saving time for healthcare providers who can conveniently wash their hands during patient care activities.

Patient Bed and Treatment Equipment Arrangement

This subsection delves into the arrangement of the patient bed and essential treatment equipment within the room, recognizing the significance of proper placement in facilitating effective care delivery and ensuring patient comfort. By strategically arranging the bed and equipment, healthcare providers can optimize their workflow, promote easy access to necessary tools, and create a conducive environment that promotes patient relaxation and well-being during their stay.



4.5 Mechanical Ventilation System

Purpose and Importance

The purpose of the mechanical ventilation system in a modular hospital room is to create a controlled and healthy indoor environment by supplying a continuous flow of clean air and removing pollutants. This system plays a vital role in maintaining optimal indoor air quality, which is crucial for the well-being and recovery of patients, as well as the health and safety of healthcare workers.

Adequate ventilation helps dilute and remove airborne contaminants, such as bacteria, viruses, allergens, and volatile organic compounds (VOCs). By continuously introducing fresh air and exhausting stale air, the ventilation system minimizes the concentration of these contaminants, reducing the risk of airborne transmission of diseases and infections within the hospital environment.

Furthermore, the mechanical ventilation system aids in temperature and humidity control, creating a comfortable and conducive environment for patients, staff, and visitors. Proper ventilation can help prevent the buildup of excessive heat, humidity, or stuffiness, which can contribute to discomfort and compromised health conditions.

Design Considerations

When designing the mechanical ventilation system for a modular hospital room, several key considerations must be considered:

Air Filtration: The system should incorporate effective air filtration mechanisms to remove particulate matter, pathogens, and other contaminants from the incoming air (Chow & Yang, 2003). High-efficiency filters, such as HEPA (High-Efficiency Particulate Air) filters, can capture a wide range of airborne particles, including bacteria and viruses, ensuring cleaner air within the room (Kumar, Kumar, & Gupta, 2008).

Ventilation Rates: The ventilation system should be designed to deliver an adequate supply of fresh air based on the room's occupancy and purpose. Ventilation rates should comply with industry standards and guidelines, taking into consideration factors such as room size, the number of occupants, and the activities taking place within the roo (Chow & Yang, 2003)m.

Pressure Differentials: In healthcare settings, maintaining appropriate pressure differentials between rooms is crucial for infection control. Negative pressure differentials in isolation rooms, for example, can prevent the spread of airborne contaminants from the room to the surrounding areas. Positive pressure differentials in operating rooms can help prevent the entry of airborne particles from outside (Kumar, Kumar, & Gupta, 2008).

System Efficiency and Robustness: The mechanical ventilation system should be energy-efficient, reliable, and capable of handling the specific demands of a healthcare setting. It should be designed to operate continuously and provide consistent air quality while minimizing energy consumption. Backup systems or redundancy measures may also be incorporated to ensure the system's reliability in case of any failures.

Noise and Vibration Control: Considerations should be given to minimizing noise and vibration generated by the ventilation system to maintain a quiet and peaceful environment conducive to patient recovery and staff productivity.

By addressing these design considerations, the mechanical ventilation system in a modular hospital room can effectively fulfill its purpose of providing a constant supply of clean air, minimizing airborne contaminants, and maintaining optimal indoor air quality for the well-being and safety of patients and healthcare personnel.

4.6 Emergency Evacuation and Safety Measures

Designing windows that open towards the outside and facilitate quick patient evacuation in emergency situations requires careful consideration of several key design factors. Firstly, the window should be designed in such a way that it can be easily opened outward without much effort. This allows patients, particularly those with limited mobility, to swiftly exit the building without the need for complicated maneuvers or excessive physical exertion.

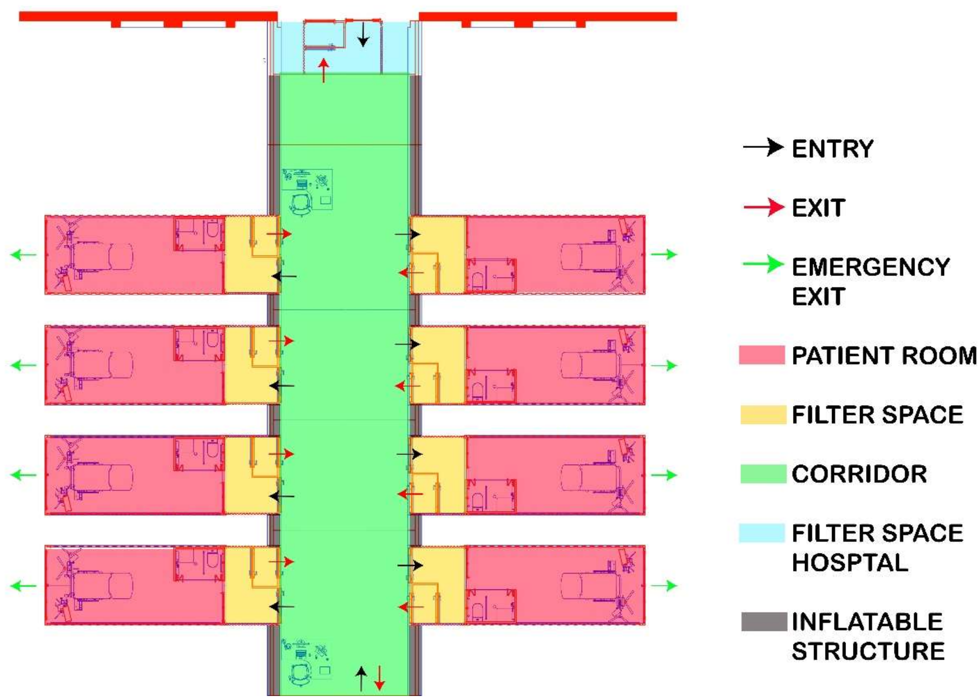
Secondly, the window frame and hinges must be robust and sturdy to ensure durability and structural integrity during an emergency evacuation. Reinforced materials and secure locking mechanisms can prevent any accidental openings or failures that may hinder the evacuation process.

In addition to the window itself, the surrounding area should be designed to support efficient evacuation. Clear and unobstructed pathways leading to the window must be maintained to enable unimpeded movement. It is crucial to ensure that objects such as furniture, curtains, or blinds do not obstruct the window or impede the line of sight to it.

Furthermore, incorporating features such as panic buttons or alarms near the window can alert emergency personnel and provide immediate assistance to evacuees. This ensures a coordinated response and helps in streamlining the evacuation process.

Considering the unpredictable nature of emergencies, the window design should also account for various environmental conditions. For example, the window should be resistant to weather elements such as rain, wind, and extreme temperatures to maintain its functionality and reliability during adverse situations.

Ultimately, an effective window design that opens towards the outside and facilitates quick patient evacuation prioritizes ease of use, structural integrity, unobstructed pathways, emergency signaling, and resilience in different environmental conditions. These considerations work together to create a safe and efficient evacuation route for patients during emergencies.



5. Implications and Future Directions

In the future, there are several important directions and implications that arise from the exploration of modular architecture and flexible healthcare solutions for pandemic healthcare infrastructure. These include:

Enhanced Emergency Response Capabilities: The adoption of modular buildings and flexible healthcare solutions enables healthcare systems to respond rapidly and effectively to emergencies. Future directions involve refining and standardizing modular designs, establishing pre-approved building codes and regulations specific to emergency healthcare structures, and fostering collaborative partnerships between healthcare organizations, architectural firms, engineering companies, and government agencies. These efforts can expedite the implementation of modular solutions and improve emergency response capabilities.

Sustainable and Cost-Effective Healthcare Infrastructure: Modular architecture offers sustainability and cost advantages over traditional construction methods. Future directions involve further exploring sustainable materials, energy-efficient systems, and renewable energy sources to enhance the environmental performance of modular healthcare facilities. By incorporating green building practices and optimizing resource utilization, healthcare systems can reduce operational costs and promote long-term sustainability.

Flexibility and Adaptability to Changing Needs: The flexibility and adaptability of modular healthcare solutions allow healthcare systems to adjust their capacity based on evolving demands. Future directions involve developing advanced modular systems that seamlessly integrate with existing infrastructure, enabling efficient expansion and conversion of healthcare facilities. Modular units can also be utilized for non-pandemic purposes, such as surge capacity during natural disasters or accommodating population growth, maximizing the utilization of healthcare infrastructure beyond emergency situations.

Technological Integration and Digital Healthcare: The future of modular healthcare solutions lies in integrating advanced technologies and digital healthcare innovations. This includes incorporating telemedicine capabilities, remote patient monitoring systems, artificial intelligence for diagnosis and treatment planning, and data analytics. The modular design allows for the integration of smart building systems, enhancing infection control, patient experience, and healthcare outcomes. Technological advancements can transform modular healthcare facilities into technologically advanced and resilient environments.

International Collaboration and Knowledge Sharing: The successful implementation of modular healthcare solutions requires international collaboration and knowledge sharing. Countries that have effectively deployed modular structures can share their experiences, best practices, and lessons learned with others. This collaboration drives innovation, accelerates the adoption of modular approaches, and fosters a global network of expertise in pandemic healthcare infrastructure.

These future directions and implications underscore the potential of modular architecture and flexible healthcare solutions to reshape the healthcare industry. By embracing these opportunities, healthcare systems can improve emergency response capabilities, enhance sustainability, adapt to changing needs, integrate advanced technologies, and foster international collaboration, ultimately creating a more resilient and effective healthcare system.

6. Conclusion

The COVID-19 pandemic has exposed significant vulnerabilities in healthcare infrastructure worldwide, emphasizing the urgent need for innovative approaches and transformative solutions. Throughout this exploration of modular architecture and flexible healthcare solutions, we have witnessed the remarkable potential of these approaches in revolutionizing pandemic healthcare infrastructure.

The examination of pandemic healthcare infrastructure across various chapters highlights the significant advancements and innovative approaches that can revolutionize healthcare systems during emergencies. By integrating technology, adopting flexible solutions, prioritizing design principles, and considering future implications, healthcare facilities can enhance their capacity, adaptability, and effectiveness in providing critical care.

The efficient management of surge capacity is crucial in pandemic healthcare infrastructure. The utilization of modular construction and repurposing of spaces provides flexible solutions to rapidly expand healthcare facilities' capacity. Modular units allow for quick deployment and integration, enabling healthcare systems to respond effectively to emergencies, optimize resource allocation, and provide essential care to a larger number of patients.

Design considerations play a vital role in creating safe and functional pandemic healthcare facilities. By employing lightweight materials, flexible room configurations, and infection control measures, healthcare facilities can ensure patient comfort, promote hygiene, and facilitate efficient workflows for healthcare professionals. Additionally, incorporating accessibility features, such as wheelchair-friendly designs and enhanced patient mobility, promotes inclusivity and ensures that individuals with diverse needs receive adequate care.

The future implications of pandemic healthcare infrastructure are promising. Embracing sustainability practices, integrating advanced technologies, and fostering international collaboration can further enhance healthcare systems' resilience and effectiveness. The adoption of green building practices, energy-efficient systems, telemedicine capabilities, and data-driven decision-making can transform healthcare facilities into technologically advanced and environmentally conscious spaces, improving patient outcomes and reducing healthcare disparities.

However, it is crucial to acknowledge the importance of continuous research and development in the field of modular architecture. As highlighted in Chapter 3, improvements in both structural and non-structural aspects of modular units are necessary to enhance their overall performance. Rigorous testing, quality control measures, and adherence to healthcare standards are essential to ensure the safety and functionality of modular healthcare facilities.

In conclusion, the exploration of pandemic healthcare infrastructure underscores the importance of innovation, adaptability, and collaboration in shaping the future of healthcare. By embracing technology, implementing flexible solutions, prioritizing design principles, and planning for future challenges, healthcare systems can respond more effectively to emergencies, provide critical care, and improve patient outcomes. The evolution of pandemic healthcare infrastructure holds immense potential to reshape the healthcare industry, creating a more resilient, patient-centered, and effective healthcare system that addresses the needs of individuals and communities in times of crisis.

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