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Research on the Design Strategy of Chinese Emergency Hospital Construction Based on the Concepts of Prefabricated Construction and Modularity——The Example of Huoshenshan Hospital in Wuhan, China

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Abstract: *During the spread of COVID-19 in 2020, the construction of emergency hospitals for infectious diseases reached its peak, but there is still a lack of theoretical support and technical advice. This paper applies the technical theory of Prefabricated construction and modularity to analyse and summarise the architectural design strategy implemented for Huoshenshan Hospital in Wuhan, China, in order to provide some references, and guidance for similar projects in the future.*

Keywords: *Prefabrication; modularization; emergency hospital; architectural design*

1. Introduction

Prefabricated architecture as defined by GB/ T5119-2017 in China's"Evaluation Standards for prefabricated Buildings", defined as a building in which prefabricated components are assembled on site according to the system basis method to create its main load-bearing structure as well as the fully decorated non-masonry components and walls of the enclosure and partition walls[1]. This mainly includes prefabricated buildings made out of materials such as concrete steel and wood.

The earliest research on "modularity" originates from Herbert Alexander Simon, a master of decision-making management in American economic organizations. Modularity refers to the process of breaking down a complex system or problem into multiple modules, each of which have specific sub-functions and are combined in specific ways to form a set. This approach provides a ways of thinking about how to achieve the entire system's desired function.

In the book Module Era: The Nature of New Industrial Structure, Japanese academic Masahiko Aoki defines'module'as a semi-autonomous subsystem that is capable of forming a system has some independent functions, and may form a more complex system based on a standardized interface structure along with other subsystems in accordance with certain contact methods. Tong Shizhong, a Chinese academic, defines this term in the book Design Methods and Applications of Modularity Principles: A module is an independent universal unit that can be combined into a system and that has specific functions and structures in relation to the interface[2].

When modularity is applied to architecture a building is separated into modules and units, with independent functions. Lastly, these are combined in specific ways to create the entire building.

An emergency hospital is a non-permanent medical facility established in response to a large-scale pandemic to temporarily care for infected patients.

2. The Development History of The Prefabricated Buildings and The Modularization

The concept of the "Domino" model was advanced by modernist master Le Corbusier in 1914. The main structural element of the building is the reinforced concrete slab - column, which is the first time in history that the construction of standardized mass production has been advanced. And derived from this in addition to the use of the "living machine". It has the connotation of using different combinations of

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functional modules to suit people's varied needs for architecture[3].

In the 1930s, architect Buckminster Fuller proposed the "Dymaxion House" The Flexible Housing Experiment, which marked the appearance of the first modular living quarters, featured a highly advanced prefabricated bathroom module used by the US military during World War II. But the experiment never got off the ground due to lack of funding. He then moved on to other projects as well. This later practice evolved into THE Winslow Ames House. It was made up of several bathroom, kitchen and equipment system modules. The system was operated in a temporary residential neighborhood constructed by the U.S. government. After World War II the idea of modularity building spread rapidly to other regions[4].

In the 1950s Lustron and Gunnison homes were built from prefabricated steel frames, where certain facilities could be customized, such as kitchens, doors and Windows, garage facilities, and the like. Though only a portion of the custom modular design was used in the home, the modular concept of prefabricated building was introduced to the wider public[5].

The concept of modularity rose to a new level in the early 1960s with Archigram's "plug city" project in 1964, who introduced the concept of interchangeable cities in architecture and foresaw a dystopian Cold War future. Habitat67, a 1967 Montreal exhibition project designed by Moshe Safdie, is a modular precast mega structure[6].

The world has moved into the information economy era since the 1990s. The use of information-integrated construction technology and diversified smart technology has made buildings increasingly complex. The architecture began to shift from analog control to parameter control, in an effort to meet more diverse needs.

Research on prefabrication and modularity in China began relatively late compared to that in foreign countries. Research on the modular in China since the 1990s has focused primarily on box buildings, and the content of the research is relatively straightforward. As the nation began to vigorously promote prefabricated buildings, more and more designers began to pay attention to modular design thinking, which was very intensive. He Jingtang, Academician of South China University of Technology, was an academic who applied modular design thinking in his Shenzhen Science Museum project. It took the traditional octagonal tower as its building motif, combined with the demands of new materials and technology, and made an entirely new combination of buildings. In 2004 CIMC began to explore modular design for prefabricated buildings. Representative projects include Casuarina Student Housing. At the end of the two sessions in 2016, the Chinese government proposed to vigorously promote the development of prefabricated buildings and to improve the quality and efficiency of the construction of engineering projects[7].

The modular design theory of China's prefabricated buildings is based on the results of the build-up and development of the prefabricated buildings in China over the years, primarily from the summary of experts and researchers, who have done a great deal of exploration and reflection on modular design methods and theories. In the book "Modular Design", for example, Jia Yanlin discusses the use of combining modules to satisfy different product requirements; In the article "Research on the Development of Modular Building Space Design", Qu Yuanyuan investigated the logic of construction and the design form of modular buildings, and discussed the combination of modules, space, materials and other issues, striving to create infinite possibilities ina limited space. Luo Yinglu, in his article "Development Analysis of Modular Building Space Design", discusses the relationship between modular building components, systems, and materials, as well as analyzing the problems and difficulties in the space of modular buildings.

3. Classification and Advantages of Prefabricated Architecture and Modularity

3.1. Classification and Characteristics of Modular Prefabricated Buildings

Based on the combination of module units and a variety of structural systems it can be summarised into the following categories.

A complete system of modular structures: Buildings are composed of modular units, suitable for the regular room form of buildings, such as apartments, hotels, hospitals, and other multi-story or low-rise buildings.

Modular unit and traditional frame structure combination system: the system can be arbitrarily mounted on the traditional steel frame unit module; Where the bottom structure is a traditional framework

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and the top part is a modular unit. It is suitable for large room-type buildings, the structural system is flexible and can perform module replacement.

A combination system of modular units and slab structures: the system consists of modular units as the core support, and precast load bearing wall and floor are arranged around it. The use of steel can be greatly economized by this method.

Jumbo frame and modular unit combination system: The system uses the jumbo frame as the primary support structure and houses modular units that do not carry loads within the frame. This can be used for tall because the main force is performed by an enormous frame.

Shear wall core tube and modular unit combination system: This system is a composite system of modular unit and core tube structure, with the core tube as the primary bearing structure, which can be used to construct tall buildings.

Box modules can be broken down into the following types:

Box enclosing module.

A separate building space is created by the module through four vertical panels which carry the main load across the vertical walls. The installation process involves attaching the floor slab and then attaching the wall and roof panels on top of the slab to form a unit module. Enclosed boxes are used subject to transport and installation requirements. Depending on the construction site and local environmental factors, the height of such modules can typically be limited to around six to ten stories.

Open partial box module: A series of holes are placed on the vertical wall of the closed box, in such a way as to form a partial open box module. The hole size is determined by the structural performance of the fixed-wall side girder. During the module construction process, a larger space may be formed by multiple modules, and the structural performance of the lateral beam and corner column determine the height of the building. Fully open module: load from the module structure is transferred to the corner column and to the lateral truss, and all four facades of the module are completely open, which has a high flexibility of combination. At the same time, the wall plays no supporting role because it is supported only by the corner posts of the wall. Thus, when using the module alone, the build height should not exceed three stories.

3.2. Advantages of Modular Prefabricated Buildings

Prefabricated modular buildings can be flexibly relocated in accordance with the concept of modern sustainable development; Modular construction cycles are shorter, typically half to a third shorter than the traditional construction process. ; In terms of construct scalability, modular products can be tuned based on the change in functional form, and the main body of the building may flexibly extend or reduce the area of use. In keeping with the needs for sustainable development.

3.3. The Problems of Modular Prefabricated Buildings

A suitable engineering system and building system for modular design of prefabricated buildings has yet to be formed. Currently, building products formed after prefabricated modular buildings are not scalable and cannot meet the needs of the increasingly developing design and function of the building space.

4. Design Strategy of Huoshenshan Emergency Hospital

4.1. General Layout and Site Selection

4.1.1. Site Selection Strategy

First, site selection requires convenient transportation and accessibility, and second, it requires that it has little impact on the citizenry around it, which is far from densely populated areas such as residential areas, schools, shopping centers, and office buildings and is located in the lee direction of the prevailing perennial wind direction in densely populated areas; Lastly, proximity to and use of existing municipal facilities, as well as avoidance of flammable, explosive, and harmful gas generation and storage areas. At the same time, the layout of the hospital also takes into consideration the fact that the residential building on the northern side of the area has yet to be delivered for use, and the number of users of public

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buildings on the southern side is also low, which has a small effect on the riskiness of the region.

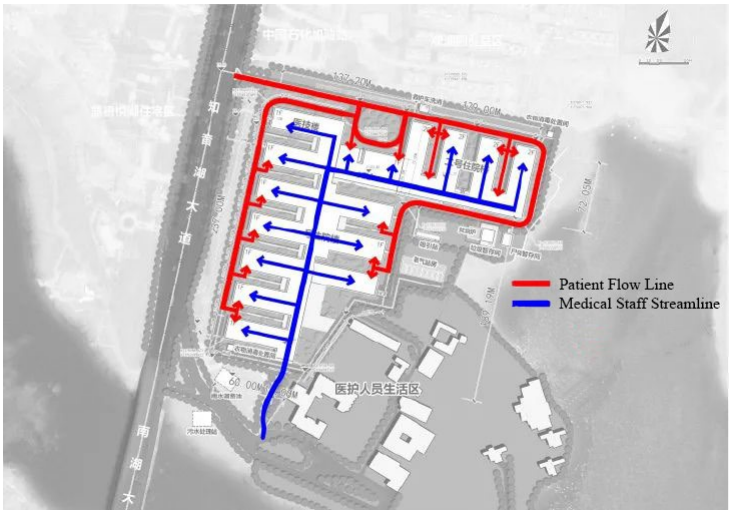
4.1.2. Geological Condition Strategy

Site selection requires flat terrain, good engineering and hydrogeologic conditions, no hydraulic connection between the groundwater and the surrounding water, or a weak hydraulic connection; The top soil layer is expected to have good engineering mechanical properties and a high bearing capacity. This method should avoid the soft soil area of the lake pond, the section with thick fill, and other adverse geologic areas.

4.1.3. General Layout

Source: http://www.jjrmyy.com/yiyuangaikuang/677187.html.

Figure 1: General Layout.



Source: http://www.jjrmyy.com/yiyuangaikuang/677187.html.

Figure 2: General Layout Streamline.

Huoshenshan Hospital has an overall L-shape and fishbone layout. The layout of the main wards is north-south with good lighting and ventilation. The No. 2 ward is laid out in an east-west direction to meet the surface of the lake, which is also suitable for ventilation. The middle section is the medical technology department, which acts as a connector; Based on meeting as many beds as possible, the hospital would have to maintain some distance from the lake to the east, with minimum distance > 30m; minimum northern distance road > 25m; The minimum distance to the western urban trunk road is > 40m; There are three entrances and exits to the site, one of which is a public road and two secondary public roads, which satisfy the requirements of the emergency infectious diseases hospital design specification.

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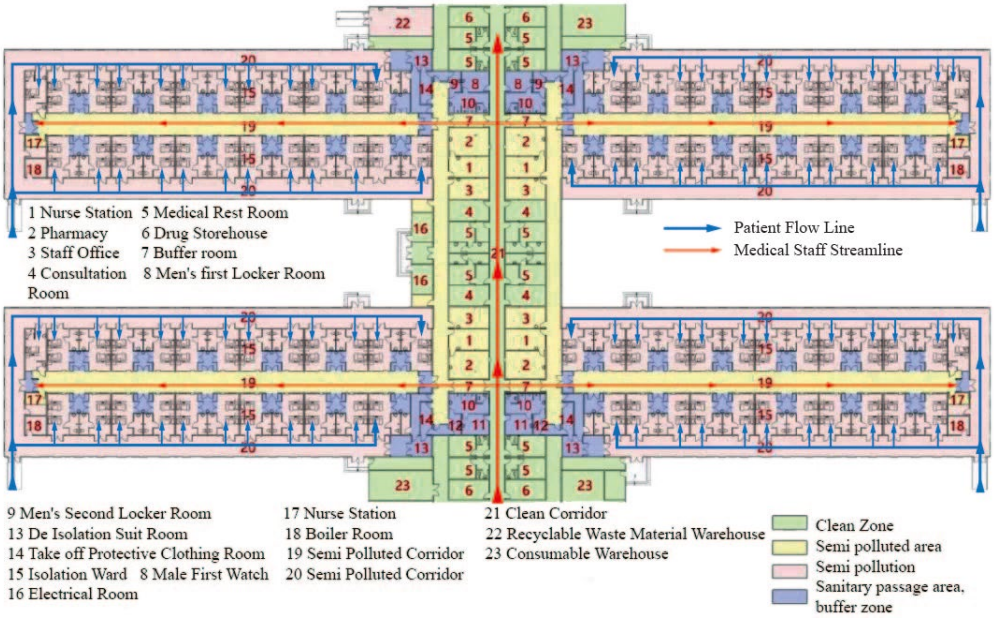
4.2. Plane Layout Strategy

4.2.1. Functional Layout

Huoshenshan Emergency Hospital adopts a planform layout based on fish bones that is symmetrical in the middle based on real needs. The office space and the medical staff passageway are arranged along the central axis, with nursing units arranged on either side. There are 50 beds per nursing unit. The treatment are a consists of four nursing units. Four nursing units are responsible for each core module, with several H-shaped modules arranged to form one nursing area. Depending on the actual situation, the distance between the nursing units is set to 15m in order to meet the actual use requirements. At the end of the nursing unit are a sewer room, boiling water room, instrument room, and other functional rooms. Buffer rooms and separation service rooms are located at the junction of the nursing unit and the medical office area as an access point for the medical staff. There is a medical and nursing passageway in the middle of the nursing unit, and the wards are spread out on both sides. The patient's passageway is attached to the outermost side, and the patient enters and exits through the three inner and outer doors. The two wards and the toilet and buffer room in the middle of the ward form a standard ward unit, and the layout of the room is based on the size of the conventional container modulus of 3mx6m. The single ward consists of a double room, with transfer windows and ventilating equipment on either side of the ward, and independent toilets are equipped with toilet facilities, showers and hand basins. Between the polluted area (ward) and the semi polluted area (medical and nursing passage) there is a buffer room, which can be used as a buffer. A buffer chamber is a physical partition between different zones, which plays the role of organizing and regulating air flow, in order to avoid the direct connection between the air flow in the polluted region and the air flow in the semi polluted region after the gate is opened, leading to severe consequences of polluted air entering the semi-polluted area[8].



Source: Self drawn by the author.

Figure 3: Local Function Streamline Diagram.

4.2.2. Streamline Design

As an emergency hospital to cope with COVID-19, Huoshenshan Emergency Hospital has made a more stringent design in medical streamlining than regular hospitals.

Streamlining design principles:

The principle of streamline design is to separate people, disease, and clean up sewage, and streamlining is simple and does not intersect.

It is important that the flow of people and logistics follows the spatial order from the non clean zone to →The semi clean zone→The Clean Zone.

The Clean zone enters the polluted zone:The Clean Zone→Two times of dressing sanitary passing area→Protective clothes area→Potential pollution area→ (medical and nursing work area)→wear

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isolation clothing→buffer room→semi pollution zone (medical and nursing walkway in ward unit)→pollution zone (ward and patient walkway).

Contaminated area entering clean area:

Contaminated area→Sanitary passage room without isolation clothing→Buffer walkway→Potential contaminated area→Sanitary passage room without protective clothing →Buffer room→Dressing room→Bathroom→First locker room→Clean Zone.

Patient enters streamline:

Ambulances or transfer vehicles are used to transport the patient to each nursing unit, entering the patient channel within the nursing unit via the special patient entrance, and eventually enters the isolation ward without intersecting with any other flow lines. Since the patient channel adopts a fully enclosed mode, it is designed to exhaust air using a fan with high-efficiency filtration performance, in order to maximally prevent the spread of viruses and ensure safe hospital use.

Medical personnel streamline:

Medical staff enter the hospital through independent entrances and exits, which are different from the entrances and exits of patients. The nursing unit further subdivided the polluted area, semi polluted area and clean area, and divided the semi polluted area into potential polluted area and semi polluted area. One of these is the walkway for medical staff located in the middle of the ward unit, which is a semi polluted area, although the working area of medical staff located between the ward unit and the cleaning area is defined as an area of potential pollution. There are buffer rooms at the passageway for medical personnel to enter between the two areas, and a sanitary passageway room dedicated to the release of isolation and protective clothing is set up at the passageway for medical personnel to leave, to reinforce the isolation and protection between the ward unit and the area of potential pollution. The traditional semi polluted area was divided into two zones, which further protected the safety of the medical personnel in the work area. Medical personnel leave the ward area and enter the working area of the medical staff. First removing the most polluted isolation clothing and then entering the medical staff work area via the buffer corridor. When medical personnel leave work or enter the clean zone from the potentially contaminated zone for work, they must remove the protective clothing, the outer mask, and the protective eyewear again through the sanitary passageway room that removes the protective clothing, and then back to the sanitary passageway room in the clean zone through the buffer room[9].

Item streamline design:

In the Huoshen Mountain Emergency Hospital, the clean and dirty flow lines are fixed independently and do not cross each other. It is not possible to open goods warehouse doors to different areas at the same time.

Cleanliness streamlines: clean items enter the item warehouse from the special entry through the medical hallway of the cleaning room. The article storage room has two doors. Gate 1 opens to the cleaning zone and gate 2 opens to the semi polluted zone. You can't open them at the same time. Dirt flow line: after the sewer in the ward is packed, it is carried out of the ward via the special corridor for patients and the sewer outlet.

Meal delivery streamlines:

Huoshen Mountain Emergency Hospital food court enters the clean zone medical hallway through the entrance of medical personnel and items. Once buffered in the transfer room, it enters the semi polluted area and is sent to the ward area via the transfer window by the medical personnel. It is not possible to open the windows on both sides of the transfer window at the same time.

4.3. Modular Design

4.3.1. Modular Design Strategy

The design and construction of Huoshenshan Emergency Hospital must be completed in the fastest time, the modular design concept was therefore adopted in the schema design phase. With the close cooperation of the construction team, after investigating a variety of factors including the timing of the materials, combustion performance, air tightness, construction performance, waterproof performance, thermal performance, and other indicators, it is determined that the structural board room (container) of the box type is the primary material for the construction of the ward; The large function space is achieved by using the lightweight steel structure+standard steel composite plate assembly type board house, which

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is practical for modular construction.

6m for the standard unit × 3m × The box-like plank house is pre-fabricated and then sent to the site to be assembled. A nursing unit at Huoshen Mountain Emergency Hospital can be assembled in 1 to 2 days, proving the speed and reliability of the modular design concept. The design and construction of Huoshenshan Emergency Hospital must be completed in the fastest time, the modular design concept was therefore adopted in the schema design phase. With the close cooperation of the construction team, after investigating a variety of factors including the timing of the materials, combustion performance, air tightness, construction performance, waterproof performance, thermal performance, and other indicators, it is determined that the structural board room (container) of the box type is the primary material for the construction of the ward; The large function space is achieved by using the lightweight steel structure+standard steel composite plate assembly type board house, which is practical for modular construction.

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4.3.2. Rapid Construction

Construction of the assembly type was determined by Huoshenshan Hospital early in the design. Containers are used to assemble ward buildings into medical units. Due to special functional requirements × 1.8m module, lightweight steel structure, the length of the medical technology department and ICU is 1.8m. The designed ward building container has a standardized modulus of 3m × 6m, but due to time constraints, thousands of containers at the construction site have large size differences, and the facility is not able to meet the design accuracy requirements. Given this, the designer and builder classified containers and arranged them for use in the same space. At the same time, the original strip foundation design was adjusted to square steel and steel I-foundation instead of concrete foundation, and the foundation was extended to. At container joints, details of nodes with different joint widths are also considered in order to deal with box differences and build errors. With these design measures with predictability, construction can be quickly implemented as planned.

Meanwhile, on the foundation of the raft, the steel base is laid out on the short side depending on the size of the container, and the container is then placed on top of the steel base for overhead treatment to avoid the impact of water build-up on the ward during extreme weather conditions; Simultaneously, the overhead layer can rapidly install the horizontal rainwater and wastewater drain pipe, preventing entrenchment of the pipeline within the raft foundation, and improving the convenience of construction. The design of the outdoor site increases the number of rainwater inputs, reducing the hidden danger of water build-up at the site.

5. Conclusion

5.1. Conclusion

Wuhan Huoshenshan Hospital was a successful case based on its assembly type, modular design and construction. It implements synchronized design and construction, resolves many problems, and successfully completes the design task. The plan includes numerous innovative features:

It expands the traditional‘three districts and two passageways’layout of infectious diseases hospitals to‘four districts and three passageways’by adding an additional corridor for medical staff;

Its design process implements the concepts of assembly type and modular construction. This maximizes the project goals of modularization, industrialization, complete assembly, and fast progress.

5.2. Insights for Future Emergency Hospital Projects

First, emergency hospitals should be constructed on open, square, and flat land with convenient transportation located near the ground floor and with robust infrastructure in the surrounding area; Secondly, user requirements should be clarified at an early pre-design stage to prioritize readily available and easily purchasable construction materials; In conclusion, a skilled and experienced design team is important for ensuring poject efficiency and overall quality; They can select the best type of assembly modular design and construction to enhance their ability to efficiently and rapidly complete their task.

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