Design and Research on Prefabricated Flexible Space for Response to Sudden Public Events

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ABSTRACT
The large number of temporary shelter facilities built after the disaster has brought a huge impact to the local environment. Portable house is widely used in China at present, but its accommodation experience is poor, the structural design of the house is severely homogenized, and the spatial plasticity is poor, making it unable to be used multiple times. The authors use methods such as example, comparison, and reasoning to summarize and conclude sudden public events. The authors also analyze the current situation of temporary shelter facilities after disasters both domestically and internationally. Taking the prefabricated and flexible space as the entry points, and taking post disaster emergency space as the research object, the authors design and explore design solutions that are more convenient, practical, and sustainable. They propose a modular design with a single module as the unit to meet the iteration, juxtaposition, and change of spatial functions. The authors also introduce prefabricated and elastic spaces into the design practice of emergency spaces, and verify and practice the design scheme proposed in the article.

Keywords: *Sudden public events, Prefabricated style, Flexible space, Modular design, Space design.*

1. INTRODUCTION

This study is based on the current issue of frequent occurrence of sudden public events. Explore the multifunctional design of emergency spaces to meet the multifunctional and humanized requirements after sudden public events occur.

1.1 Research Significance and Background

In recent years, the epidemic has erupted, and natural disasters such as floods and earthquakes have occurred frequently in various regions. In the face of post disaster resettlement and reconstruction, the primary task is to build emergency relief spaces. With the increasing urgency and complexity of sudden public events, higher requirements have been put forward for the performance of emergency spaces. The actual use effect of temporary prefabricated houses nowadays is not ideal, and the current situation cannot meet the demand. Therefore, there is a need for a new type of emergency space that can provide high performance, comfort, and applicability.

In response to unexpected public events, the temporary application of prefabricated building plays a key role. The research on flexible space is reflected in its flexible and diverse application forms, meeting different needs in different environments. Therefore, the study of prefabricated flexible space is of great significance for responding to sudden public events.

1.2 Research Content and Methods

Based on the above background, the research direction and content were determined, and the following four research methods were summarized based on the research content

1.2.1 Research Content

Based on the environment of sudden public events, taking the basic functions of prefabricated space as a reference, and according to their functional and humanized needs, it is aimed to study and design a set of prefabricated flexible space to respond to sudden public events, and carry out description through the following four parts: The first part defines the research scope, explains the relevant concepts of prefabricated space and flexible space, and describes the current situation in China and foreign countries. The second part analyzes the spatial needs of sudden public events, understands what needs exist in specific situations, and proposes design principles for spatial design. The third part is based on the principles outlined in the previous chapter for spatial requirements, combined with prefabrication, to elaborate on modular spatial design and combination issues. The fourth part summarizes the entire article, explains the shortcomings in the research, and points out future research directions.

1.2.2 Research Methods

Literature research method: through extensive review and summary of domestic and foreign journals and papers on prefabricated emergency houses, modular design of buildings, new materials for prefabricated building and other aspects, people can understand the current research progress, obtain relevant theoretical and methodological achievements, and provide a solid foundation for research.

Case analysis method: By analyzing different cases, the authors study different types of post disaster emergency spaces and systematically analyze their structure, materials, functions, and environmental factors, as well as analyzing the pros and cons of bringing existing emergency spaces into different disaster contexts.

Investigation and research method: By investigating the current prefabricated space and analyzing the existing prefabricated space, research is conducted from its functional structure, function, materials, and other aspects. The authors conduct on-site inspections, organize research materials, and make summaries.

Comparative method: By comparing and analyzing the construction methods, functional allocation, material utilization, and combining the structural design characteristics of key nodes of prefabricated spaces through previous literature and journal research, the advantages and disadvantages of different schemes are analyzed, providing effective reference and selection for the design of prefabricated flexible space.

2. LITERATURE REVIEW

Sudden public events cover a wide range, and it is necessary to define the research scope and explain the relevant concepts of the research object. Secondly, it is also necessary to sort out and summarize existing cases in China and foreign countries.

2.1 Definition of Research Scope

This design summarizes the classification of sudden public events ("Figure 1"), and conducts design and research on this basis.

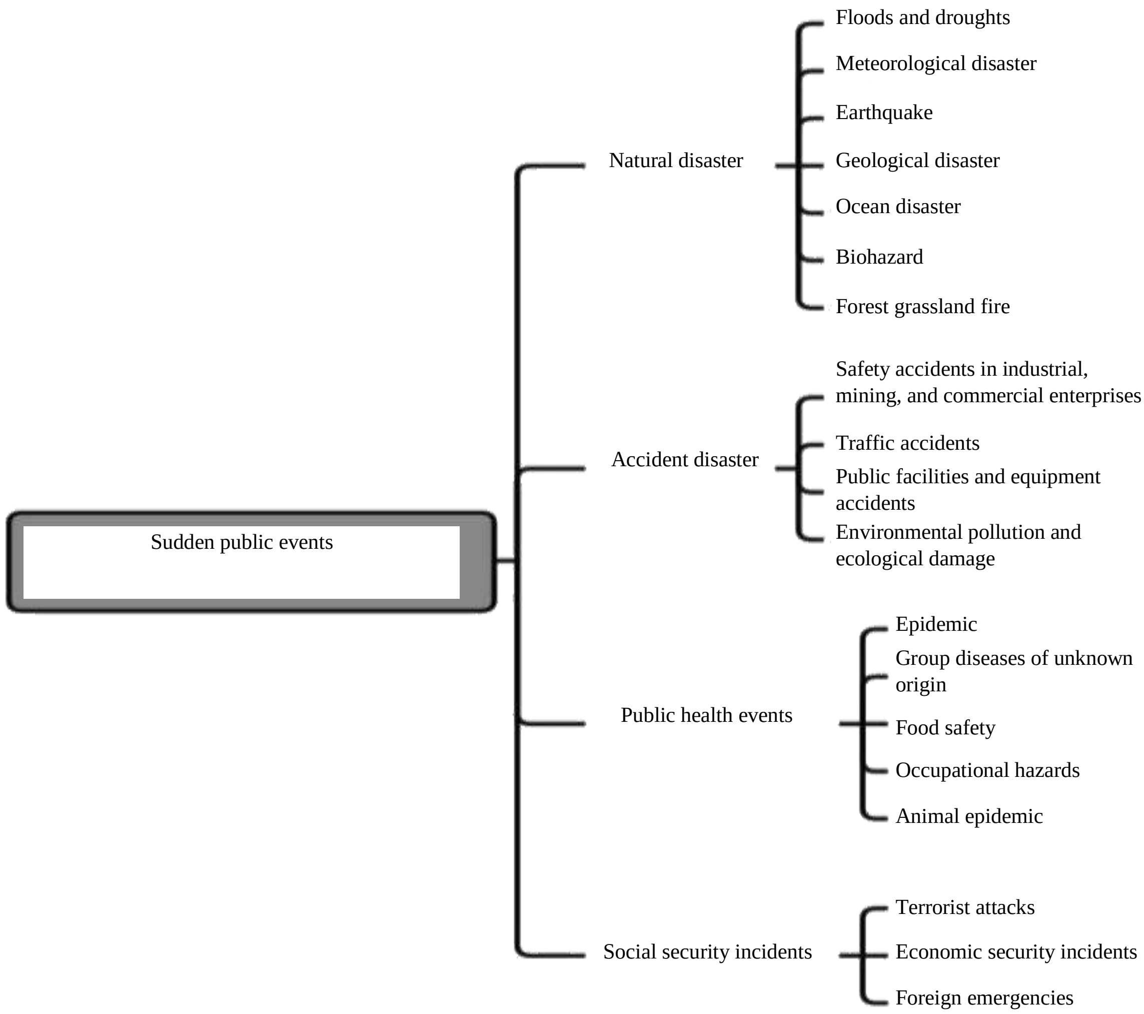


Figure 1 Classification of sudden public events (organized by the authors).

Taking the recent epidemic as an example, although the epidemic has ended, it still faces more unknown tests in the future. Therefore, a set of emergency space is designed to respond to various sudden public events. Temporary emergency buildings will adopt prefabricated technology, which transfers traditional on-site construction work to factory prefabrication for completion. Various components such as wall panels, floors, stairs, balconies, etc. will be transported to the site and installed on site through special connection processing. [1] In particular cases, compared with general prefabricated building, prefabricated space is positioned as a low rise building, focusing on short-term temporary buildings, building detachable space for multiple uses, which has high spatial plasticity. At the same time, the use of new building materials makes the building more capable of coping with and adapting to harsh conditions.

2.2 *Explanation of Relevant Concepts*

Based on the definition of the research scope, there is a need to explain the relevant concepts of resilient space that can be assembled to respond to sudden public events.

2.2.1 Prefabricated Space

Prefabricated building is a major innovation of the traditional architectural style, and this concept has been explained above. Prefabricated building is a typical representative of modern industrial production mode, which is dominated by standardization, industrialization, informatization and intelligent management mode, and reflected in design, parts prefabrication and component assembly.

2.2.2 Flexible Space

Yang Yang and Hu Weiping once elaborated on the basic concept of flexible space, which is the combination design of multiple functions in the same space to maximize the utilization of space, reduce the proportion of immutable elements in the spatial structure as much as possible, permeate new elastic components and products into the space in all directions, and carry out reconstruction design, blurring the functional boundaries of the space and changing with demand.

2.3 Current Research Status in China and Foreign Countries

Many scholars in China have proposed the construction of emergency housing after disasters. Kuang Hong [2] also believes that post disaster reconstruction houses should have a higher construction speed, a simpler construction method, and a more intuitive explanation of the three elements of construction guidance, reducing the range of components used and achieving diversified post disaster emergency housing construction with less standardization. Jin Zhixiang [3] believes that in order to improve design efficiency, it is necessary to expand the combination of standard units and obtain different functional spaces. At the same time, emergency spaces should adopt more convenient and simple construction techniques, and use high-performance and environmentally friendly building materials. Lu Juncong [4] from Guangzhou University summarized six common emergency space systems, explained the advantages and disadvantages of six different structural systems in emergency space, and analyzed their advantages and disadvantages. On the basis of theoretical comparison, people can use computer algorithm programs to generate a system model for post disaster emergency space. Peng Ze from Xi'an University of Architecture and Technology [5] conducted research on the design principles and methods of emergency temporary buildings, outlining site selection, material selection, structural selection, standardization, and other design principles. He summarized and analyzed the construction measures for rapid construction of the line of sight, construction organization methods, and various methods of dismantling and recycling. Han Yuncong from Shandong Jianzhu University [6] conducted a survey and research on the size of various functional spaces in the lower level residential buildings, forming a modular residential system with strong applicability.

In foreign countries, D'Orazio and Marco [7] believe that emergency spaces will affect users' living time in these buildings based on their physiological, psychological, and other factors. Therefore, in the design, not only should it be designed for short-term living, but it should also provide residents with sufficient indoor comfort. Naomi Morishita, Salah Haj Ismail et al. [8] believe that after suffering from the torment of war and the impact of disasters, people become physically and mentally unstable, and there is a stricter demand for indoor comfort. Therefore, compared to conventional buildings, transitional resettlement houses after disasters consume more energy to make people feel comfortable in the room. Rita Thapa, Hom Bahadur Rijal et al. [9] respectively elaborated on the indoor temperature range of emergency spaces in winter and summer, and emphasized that the use of mechanical equipment can maintain room temperature at a certain comfortable temperature, and the affected population needs a more demanding environment compared to the local unaffected population. Hui Yu, Ge Bai et al. [10] proposed a detachable personal emergency housing scheme based on the post disaster resettlement function. The house can be split and folded into several panel components, and when needed, it can be assembled by two to three people within three hours, with a high degree of industrialization of the components.

2.4 Brief Summary

This chapter systematically sorts out the scope and classification of public emergencies, and elaborates on the meaning of prefabricated space in the professional field and the specific meaning of article emergencies. It also explains the concepts of prefabricated space and flexible space. In addition, through the above combing of the current situation of prefabricated building in emergencies at home and abroad, the research mainly focuses on the use of relatively simple and convenient construction methods, and the use of green and environmentally friendly building materials to reduce the design phase time, improve the design efficiency, meet the basic functions of the house, and give residents enough indoor comfort.

3. ANALYSIS OF SPATIAL NEEDS IN RESPONSE TO EMERGENCIES

The authors design and analyze the space for unexpected events based on the above content, and summarize the design principles of prefabricated elastic spaces by comparing the advantages and disadvantages of various emergency spaces

3.1 Design Analysis of Temporary Residential Spaces After Disasters

Human survival cannot be separated from architecture. In terms of the basic living conditions of people, such as clothing, food, housing, and transportation, "living" provides living space for people. Disasters often cause significant damage to buildings, therefore, research on emergency spaces after disasters is particularly important.

3.1.1 Comparative Analysis of Products of the Same Type

After extensive data review and sorting, the following four common types of emergency facilities were summarized, and the advantages and disadvantages of different types of emergency facilities were analyzed. ("Table 1")

Table 1. Analysis of the advantages and disadvantages of different types of emergency facilities (summarized by the authors)

Category	Advantages	Disadvantages	Legend
Portable house	Low cost Can be built on a large scale Easy to split Good thermal performance	1. Components that are easily damaged during disassembly 2. Poor insulation performance 3. Materials are difficult to degrade 4. Difficult to recycle	
Disaster relief tents	Convenient transportation Low construction cost Small storage volume Reusable	Single spatial form Poor resistance to harsh environments Poor insulation performance Not capable of building performance	
Container residential	Take and use as needed Furniture integration Overall storage	High transportation costs Simple spatial form Difficult to disassemble components High coste spatial form	
Mobile houses	Strong fluidity Furniture integration High space utilization	Not applicable for family sharing High cost of construction Low safety factor High transportation costs	

3.1.2 Specific Situation Analysis

Specific situations are divided into the following four categories: the first category is natural disasters such as earthquakes, floods, fires, and mudslides; the second category is infectious diseases, group diseases of unknown causes, and other public health events; the third category is transportation accidents, public facilities and equipment accidents, etc.; the forth category is temporary workplaces such as construction temporary buildings, border guards stationed, and work spaces. From this, it can be inferred that post disaster temporary residential spaces need to possess the following characteristics: temporary, malleable, sustainable, and simple.

3.2 Design Principles for Temporary Residential Facilities After Disasters

Based on the design analysis of temporary residential spaces after disasters, design principles are proposed in terms of functionality, structure, and materials.

3.2.1 Functional Design Principles

To meet the behavioral needs of users, it is first necessary to meet basic living conditions and provide living space, including kitchen and bathroom space, rest space, etc. Secondly, to meet the needs of more users, it is a necessity to include transportation space, office space, medical space, etc. Finally, in order to provide additional value for the space while meeting basic living standards, organic plant fusion can be appropriately combined to reduce carbon emissions, purify the environment, and improve the quality of life of residents.

3.2.2 Structural Design Principles

As an emergency space, the design of the structure also needs to meet the requirements of convenient construction, firm structure, and convenient transportation and rapid construction in case of sudden public events.

3.2.3 Material Design Principles

Due to frequent changes in material standards in China in recent years and the unique nature of the research object, the tolerance of its facilities is different from that of ordinary temporary facilities. While meeting material usage standards, it is also necessary to meet various performance indicators. ("Table 2")

Table 2. Analysis of the advantages and disadvantages of different types of emergency facilities (summarized by the authors)

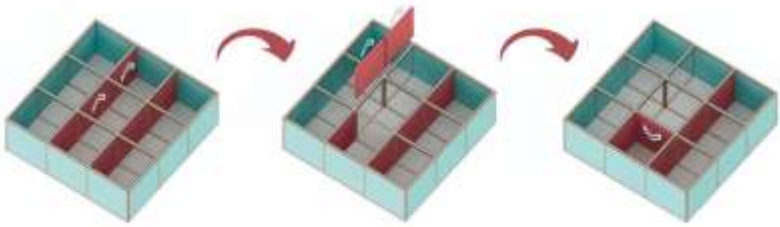
Performance classification	Detailed description
High strength	It has certain properties such as high strength, fire resistance, anti explosion, anti ice-explosion, and resistance to chemical corrosion.
High durability	It has certain anti-corrosion, waterproof and other properties, which can prevent corrosive substances from penetrating into the interior and accelerate the aging of facility components.
Sustainability	It can solve environmental issues, effectively reduce construction costs, while reducing life cycle costs, maintenance costs, labor costs, and mold costs.
Aesthetics	It has a certain aesthetic value and can change the texture and color of materials according to the usage needs of the facility.
Convenience	It can reduce transportation and installation costs, be able to quickly transport to the site, reduce installation difficulty and improve construction efficiency.

This chapter summarizes common sudden public events and compares different types of emergency facilities. Through analysis of specific situations, it summarizes the characteristics that this facility needs to have, such as temporality, plasticity, sustainability, and simplicity. It also proposes corresponding design principles for post disaster temporary indoor space design and post disaster temporary residential facilities.

4. MODULAR DESIGN OF PREFABRICATED FLEXIBLE SPACE

Modular design is formed through the establishment of elastic spaces in prefabricated elastic spaces. ("Table 3")

Table 3. Four flexible graphs (summarized by the authors)

Space type	Space schematic
Module elasticity	
Spatial elasticity	
Molding elasticity	
Environmental elasticity	

4.1 Constructing Flexible Space

Although most temporary shelter facilities after disasters are built with prefabricated components, their spatial form and function are relatively simple. Therefore, the concept of "Raumplan" [1] is introduced into the construction of post disaster emergency spaces, resulting in diversified spatial forms of functions, achieving the maximum integration of functions and space, and it is called the flexible space. Flexible space can be mainly divided into the following four categories: ("Table 3")

4.2 Building Modular Units

Based on the explanation of flexible space, provide a specific description of the concept and composition of modular units.

4.2.1 Modular Unit Concept

Module units are divided into spatial units and component units. The modularization of post disaster emergency space includes modular

1. Space design is a three-dimensional construction activity that should be flexibly organized according to different functional characteristics, and different height values can appear in the same plane.

component units and modular space units. By splicing different types of modular components, modular spatial units with different functions are formed. Then combine different modular spatial units to form a complete modular system.("Figure 2")

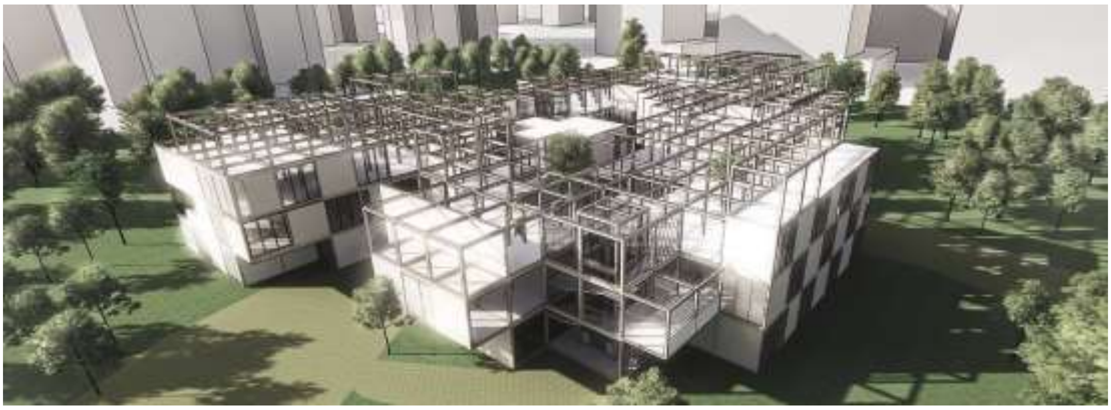


Figure 2 Conceptual rendering of prefabricated flexible space.

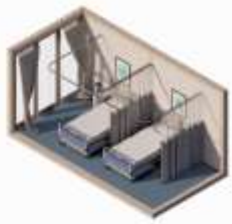
4.2.2 Combined Modular Component Units

Compared with traditional on-site construction, factory prefabrication production method can ensure the quality balance and standardization of various components, shorten construction time, reduce environmental pollution and land space occupation. The modular component system is an integrated spatial unit composed of external support structures, maintenance structures, internal facilities, and other components. The modular component unit system meets the standardized prefabrication production, testing, adjustment, and storage requirements of the factory. After a disaster occurs, it is directly transported to the site for assembly, which can effectively solve the problem of emergency resettlement after a disaster.("Figure 3" "Table 4")

Figure 3 Conceptual rendering of prefabricated flexible space.

Table 4. Functional module classification diagram (summarized by the authors)

Spatial classification	Functional classification	Modulus	Illustration
Transportation space	Accessible passage + elevatorn	4X	
	Emergency staircase	2X	
Living space	Single occupancy	1	
	First-generation household	2	
	Multiple dormitory	2	
	Second-generation household	5	
	Third-generation household	6	
	......	......	

Spatial classification	Functional classification	Modulus	Illustration
Office space	Two person office space	1	
	Four-person office space	2	
	......	......	
Medical space	Medical space	2	
	......	......	
Storing space	Storing space	2	
	......	......	
......	......	......	

4.2.3 Combined Modular Spatial Units

Modular spatial units are based on modular components, which are prefabricated in the factory and transported to the site for splicing and assembly [12]. Prefabricated in the factory with multiple standardized spatial units as the basic modules, these different functional unit modules can be combined and matched with different needs to meet diverse placement forms.("Figure 4")

Figure 4 Conceptual rendering of prefabricated flexible space.

4.3 Application and Design of Structures and Materials

Modular components are prefabricated in the factory and then transported to the site for construction. Its structure is disassembled and reassembled in a reversible splicing manner. And it can facilitate the maintenance and replacement of each build. The flexible space adopts modular component units, without the need for professional construction personnel. Generally, disaster victims and volunteers can participate in the construction work after simple learning.

4.3.1 Prefabricated Foundation

To cope with sudden public events, it is necessary to choose a foundation that can be prefabricated, has strong seismic performance, and has fast construction speed to assemble flexible space. The prefabricated foundation [13] is composed of three parts: the top reinforcement is fast, the middle reinforcement is fast, and the column body (as shown in "Figure 5"). It adopts a prefabricated design, which has the characteristics of low production and transportation costs. Moreover, compared to the construction method of cast-in-place piles, the construction method is simpler and the safety construction cost is lower. Two sets of reinforcement blocks can make the foundation structure more evenly stressed and avoid the problem of uneven settlement.

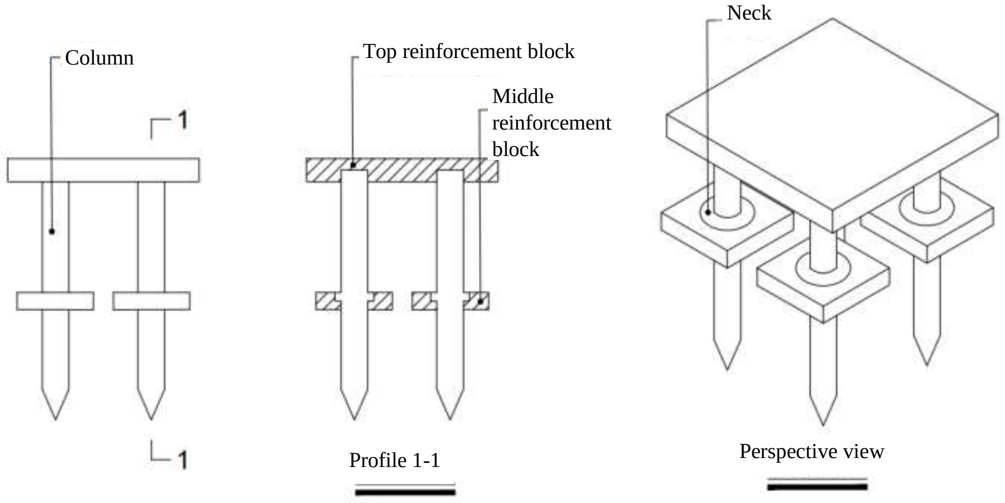


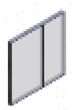
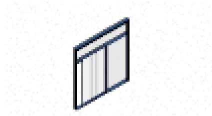
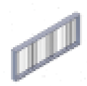
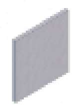
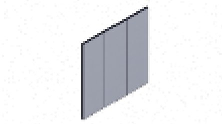
Figure 5 Schematic diagram of pile foundation (organized by the authors).

The prefabricated foundation consists of three parts: the top reinforcement block, the middle reinforcement block, and the column body.

4.3.2 Prefabricated Walls

Ultra High Performance Concrete (UHPC) refers to a concrete material with a compressive strength of over 150MPa, which is a cement-based composite material with high density and strong compressive performance [14].("Table 5")

Table 5. Component diagram (summarized by the authors)

Classification		M1	M2	M3
B1	Traffic maintenance construction			
B2	Optical maintenance construction			
B3	Outdoor maintenance construction			
B4	Indoor maintenance construction			

Compared to on-site pouring construction, UHPC materials are more suitable for on-site assembly and construction. On the one hand, due to the poor fluidity of UHPC, it is not suitable for on-site pouring; On the other hand, strict requirements are put forward for the later maintenance conditions of UHPC materials, which is inconvenient for on-site operations. Therefore, UHPC materials are considered to be used in combination in prefabricated building to ensure product quality and reduce production costs.

The exterior wall uses UHPC curtain walls, and the prefabricated flexible space exterior wall is the maintenance component that separates indoor and outdoor areas. It also bears some of the weight of the house and has functions such as waterproofing, fire prevention, anti-corrosion, and insulation (as shown in the top left of "Figure 7").

The interior wall is designed as a movable partition wall, which can be assembled and disassembled according to space requirements under the same functional module to temporarily divide the space.

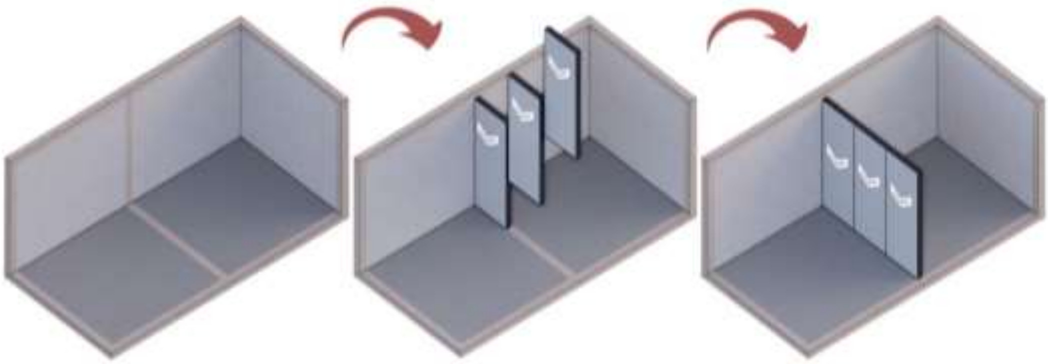


Figure 6 Schematic diagram of indoor partition wall (organized by the authors).

4.3.3 Prefabricated Support Components and Connection Methods

The prefabricated support components for building frames are mainly divided into three types of structures: clamp heads, support rods, and connectors. ("Figure 7", top right) The card head serves as the connection node for each unit body, and each surface can be connected to the support rod. At this point, the reserved punching position for the module card head connection corresponds to the reserved punching position for the support rod. Then, bolt fixation is added while considering the stability of the support rod, and multi-level design is carried out.

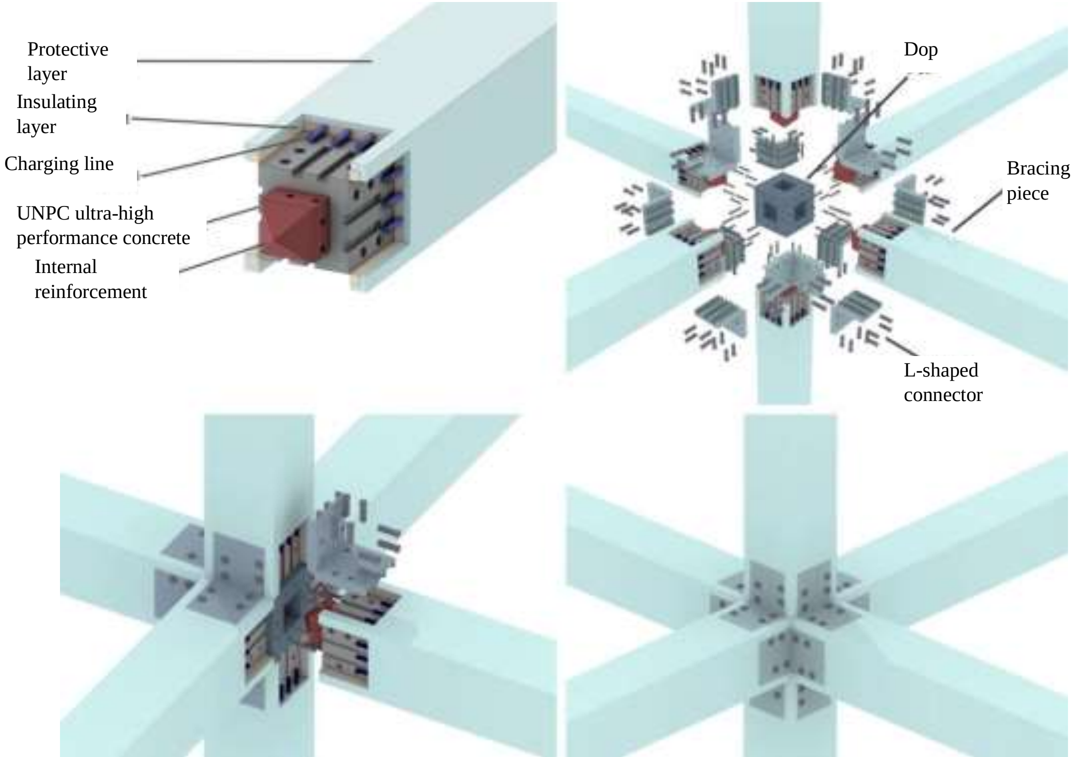


Figure 7 Construction structure and connection diagram (organized by the authors).

Finally, external connections are made using connectors, and different types of shaped connectors are used at different types of nodes — deep connections are made with high-strength bolts to the outside of the support rod. ("Figure 7", bottom left and bottom right) ("Table 6")

Table 6. Classification of connection construction (summarized by the authors)

Connection type	Style diagram	Demo diagram
L-shaped connector		
Flat L connector		
T-connector		
Cross type connector		

This chapter constructs four kinds of major flexible space, namely module elasticity, spatial elasticity, environmental elasticity, and shape elasticity, and explains modular spatial design and combination issues. This chapter also displays the classification of different module units and accessories, including the connection methods of prefabricated foundations, prefabricated walls, and prefabricated component nodes.

5. CONCLUSION

This article analyzes common sudden public events, extracts and combines the current design status of emergency spaces in China and foreign countries, and determines the design positioning of prefabricated flexible space to respond to sudden public events. Based on preliminary analysis, design and practice are conducted to obtain the following conclusions: (1) Based on research on assembly emergency spaces in China and foreign countries, a modular unit system is constructed, with a single module as the basic unit. By combining modular units, construction efficiency is improved, diversified needs for post disaster emergencies are met, and the applicability of emergency shelter spaces is improved. (2) The concept of "volume planning" is borrowed to define the four major elasticities of "flexible space": module elasticity, spatial elasticity, shape elasticity, and environmental elasticity, as well as explaining the four major elasticities separately. (3) Based on the research findings, the design requirements and principles for each component of the prefabricated flexible space are summarized. And modular components are designed, including the construction design of prefabricated foundations, prefabricated maintenance structures, prefabricated support components, and other parts. It is proposed that UHPC ultra-high performance concrete, a new type of prefabricated building construction material, can be used for many times while the properties of the house can meet the predetermined standards.

At present, there is still relatively little research on emergency spaces in China, and the author's ability is limited. There is still a lack of in-depth research on this article, and further research is needed on the specific splicing methods of support components and maintenance structures.

The country is increasingly paying attention to the post disaster resettlement of sudden public events, and the frequency and scale of emergency space use are also increasing. The standards for practicality, convenience, energy conservation, and comfort of the space are also gradually improving. Nowadays, light steel activity boards and traditional emergency spaces only consider reliability as the minimum standard, resulting in insufficient comfort and energy efficiency. At present, there is increasing emphasis on responding to unexpected events, and in this environment, there is broad development prospects for high-performance, high-quality, and efficient innovation and research in emergency spaces. At the same time, promoting more humanized functional design, adopting more environmentally friendly and high-performance building materials, and utilizing modular design and prefabricated structures that are easy to maintain, transport, build, store, and reuse provide a certain new idea for the design of future disaster emergency facilities.

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