Reshaping Dormitory by Modular Steel Structure

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Abstract: Modular steel structure with a 100% assembly rate, is one of significant methods to realize building industrialization. It has an extensive application prospect due to the short construction cycle and small impact on the surrounding environment. Based on the characteristics of modular architecture, this paper takes the work of the 2018 Chinese College Students Steel Structure Innovation Competition as an example to discuss the design possibilities of student dormitories. However, due to production mode and transportation conditions, modular building also has some limitations for application. Through research on design, this paper makes the breakthroughs in the design limitations of modular building.

1. Introduction

Different from the traditional construction method, modular building is prefabricated in factory, and only the assembly work is done on site, which greatly shortens the construction period. In addition, it can be reused to improve efficiency and save energy [1]. But the structure system and connection mode of modular building is different from traditional buildings. Therefore, it is of great significance for scholars to study all aspects of modular building.

J. Y. R. Liew, R. M. Lawson et al. studied the modular construction of high-rise buildings, tested the connection modes and relevant reliability, and applied them to engineering practice,[2-3] In recent years the study of modular buildings rise gradually in China. Z. H. Chen, F. Wang, P. F. Zhang et al. conducted experiments to analyze the mechanical properties of the structure system of modular building, also studied the key technologies of envelope system and on-site installation, and the results were applied to related engineering projects such as the dormitory in Jinghai district, Tianjin City.[4-5] W. J. Zhu, Z. H. Ren et al. explored the space organization and aesthetic design of modular building, and propose effective strategy for the modular building to break the monotony of space and appearance.[6-7]

The student team of Tongji University participated in the 2018 National College Student Steel Structure Innovation Competition sponsored by China Steel Construction Society. The work "Sifang House" built a multi-storey dormitory with modular steel structure for 1500 college students, and won the special prize. By this modular dormitory design, we try to tap the potential of modular system to facilitate various requirements regarded as favorable architectural functions and space.
2. Competition task
The China Steel Construction Society regularly holds the National College Student Steel Structure Innovation Competition to stimulate students’ enthusiasm for structural innovation. Each year, the current advanced structural system and innovative node structure can be seen from the competition works. The competition requirement in 2018 is to build a university dormitory for 1,500 students with prefabricated steel structure. Moreover, some basic conditions are given, such as site type, earthquake resistance type, ground roughness, basic wind pressure, basic snow pressure, structural design conditions, and so on, without specific site restriction. According to the functional requirements of students’ dormitory, the buildings should adapt to most regions in the country with the structural system innovation.

3. Design of competition works
This design uses modules that are self-stacking to form four square yards with retreat places that are connected by a common functional ring to meet functional needs and competition requirements. (figure 1). The name “Sifang House” of this work also has multiple meanings, as follows.

1. The university students are from all over the country, this is a dormitory where the students from all over the world. 2. The four square yards in the design meet the dormitory requirement, so this is a four-square dormitory. 3. Because the module building can be quickly disassembled and used in another place, thus this is a mobile dormitory.

Therefore, this dormitory is the harbor for students from all over the world and also can be moved where they are needed. Simultaneously, it can increase or decrease with the number of students increasing or decreasing. Namely, when the number of students decreases, some modules can be removed and transported to another place, but when the number of students increases, some modules would be increased.(figure 2).

Figure 1. Overall aerial view of the dormitory.

Figure 2. Modular dormitory increases or decreases with the number of students.

The process of design is based on the beginning of a traditional dormitory. 1. In order to improve the living quality, the traditional inner corridor dormitory is transferred into a square yard composed of four outer corridors dormitories. 2. If the square yard is the north-south layout, it is difficult to avoid the problem of sunning the east and west on the left and right sides. Then, the yard is rotated by 45° so that each side of the yard has southern sunshine. 3. Construct a retreat platform at the corner of the yard, which can not only enrich the architectural space, but also most intuitively reflect the features of the module architecture. 4. With calculation, four courtyards are a suitable layout to meet the living requirements of 1,500 students. 5. A public function ring is introduced to connect the four residential
courtyards as a whole, thus creating more public activity space for students. (figure 3) From the process of design generation, it can be seen that the name of the work is not only romantic but also the result of rational analysis based on functional requirements.

4. Design strategies

4.1 Multi-level public space
The introduction of the public function ring is a highlight in the design, furthermore, the public space of the whole program is multi-level. The most important public space at the first level is the function ring in the middle, in which some study rooms and activity rooms can be set up to provide indoor activities for students. The second level of public space is the five courtyards enclosed by the building, which is a foyer for students to enter the indoor space and good outdoor activity space for students. The third level is our retreat platform. These retreat platforms are not empty but also formed by the splicing of framed modules, which can provide students semi-outdoor activity space. The fourth level is to extract several modules to form semi-outdoor activity space between floors. (figure 4).

4.2 Module type control
Based on the classification of building functions, the modules used in the entire work can be divided into six types as shown in table 1. Except for the size of the 4 and 5 modules are slightly longer, all other modules' size are the same, which is convenient for production, transportation and installation. (figure 5).

| Module type         | Module number | Function of the module                                      |
|---------------------|---------------|------------------------------------------------------------|
| 1 Barrier-free module | 45            | Barrier-free dormitory with barrier-free toilet and balcony |
| 2 Standard module   | 680           | Basic dormitory module with a toilet and the balcony       |
| 3 Terrace module    | 22            | Terrace for rest and better view                           |
| 4 Service module    | 96            | Activity room for public activities such as coffee bar     |
| 5 Steel framed module | 48          | Only have structure frame, playing a structural support role |
| 6 Transportation module | 116       | Containing stairs and elevators                          |
4.3 Structure system features

In the architectural construction, this work adopts the light steel keel structure system. With the advantages of light weight, convenient construction as well as rapid construction and installation. The specific construction measures focus on equipment pipeline integration and module connection, and the equipment pipelines are laid in the toilet and walkway to facilitate production and maintenance of equipment. The joint parts between modules should be installed by sealant or patchwork plate on site so as to realize the sealing and the integrity of the building.

The innovation of structural system is also the focus of this competition. Based on the architectural design, the structure adopts the modules’ self-stacking way. Simultaneously, the main innovations are the positioning anti-shear double function key and energy dissipation technology. The positioning anti-shear double function key designed in the connection provides locating function during installation to improve the speed and accuracy as well as transfers shear force between modules in service to ensure structural safety. The corrugated steel plate shear wall in the system is smaller than the general steel bracing, not affecting the use of indoor space, moreover, it has the function of energy dissipation and shock absorption. (figure 6)

In addition, the structural design not only considers the mechanical properties of the building, but also fully calculates the lifting conditions of each module unit. [8]

The modular building is greatly suitable for the function and scale requirements of the dormitory, in addition to the design of the public space and the innovation of the structural nodes, the design has achieved good results. However, there are still some restrictions which are caused by the characteristics of modules worth to think how to break through.

Figure 5. Modular design

Figure 6. The corrugated steel plate shear wall
5. Limitations of module building

Although modular buildings have many advantages, currently the costs of construction in most areas are higher than those of traditional construction methods. The combination of modules forms a whole, which could lead to double walls in the whole building interior. Each module structure is independent, the lower module also bear the upper load, the structural steel content would be more than the traditional column and beam system building. There are also some conflicts between the wall structure of the steel structure and the traditional living habits, such as not being able to place the brackets on the wall at will. The most important limitation of modular building is that the size of a single module is limited, which results in difficulty in forming a large space in the building.

Because the production and assembly of module construction have been completed in the factory, a simple unit is transported to the destination, so it is difficult to avoid the size limitation for the transportation. In terms of conventional land transportation, the size standards for cargo transportation are as follows.

The total height is 4.2 meters, the total length is 18 meters, and the total width is 2.5 meters. After deducting the size of the truck, the cargo size is basically 3 meters high, 15 meters long and 2.5 meters wide. Each unit of the modular building is a independent “box” in structure. The columns and beams in the unit not only support its structural integrity but also take into account the other loads in the building as a whole as well as their integrity during transportation and hoisting. Therefore, it is difficult to eliminate some beams and columns of the single unit. The size limitation of each "box" makes it difficult to directly use the modular building to realize the requirements of a large internal space such as a large span and a high height.

6. Limitations break through of modular architecture through design

It is hard to avoid some limitations of modular building, and some can be broken through by design. The height problem of module can be solved, that is, the length of the module can be regarded as a height, which can effectively increase the building height. However, the opening and depth of the building are only about 3 meters, and the module units with such a installation mode should meet the structural stability during transportation and after installation, the structural cost would be further increased.

When the two layers of modules are superimposed, the top plate of the next layer can be removed, and the bottom plate of the upper layer can be appropriately raised, so that the height of the lower building can be appropriately increased. However, the height increase in this way is limited, and the height of the upper module could also be reduced, which makes the modular unit difficult to meet the requirements of large range of height increase. It is still a feasible method to increase the height in a small range to improve the interest of space.

It can be combined with an assembled steel structure system. For example, a hotel building can be constructed with a prefabricated steel structure system on the first floor to meet the needs of the building opening and floor height. The second floor and above use the modular unit to build the room. It is also possible to build a full-height space with fabricated steel structure between two rows of module units to obtain a relatively large space.(figure 7) Such a combination of structural form can well solve the special space requirements, and it is also an ideal way to break through the size limit.

It is possible to meet high space requirements by means of modular unit splicing. The first layer of the public function ring of this competition work has a large entrance space of 6.6 meters wide, 6.6 meters high and 9 meters deep through the stacking of units. The horizontal superposition of the 13.2-meter long modules above the two superimposed modules on the first and second floors is equivalent to the extraction of the following four superimposed modules so as to increase the space size. (figure 8)There should be many similar methods to enlarge the space size and break through the limitation of module unit.
This article discusses the potential to establish feasibility to accommodate the diversified requirements functionally, socially and aesthetically via modular dormitory design. Though the limited module size places restrictions on the pursuit for large space to some extent, delicate engagement and combination of restricted module types and thorough consideration of transportation and installation conditions are thought to contribute to relatively satisfactory feasibility.

8. References
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