The application and research progress of steel structures in construction industrialization

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Abstract. Building industrialization is the trend for future building industry. The development prospect is promising because of the many advantages of fabricated steel structure. This paper presents an introduction to the fabricated steel structures, including its concept, advantage and main forms in domestic and overseas areas. Besides, the latest researches on the fabricated steel structures were reviewed. Typical cases of assembled buildings with steel-structure were also introduced. The questions and difficulties concerning this issue are also discussed in this paper.

1. Introduction
Building energy consumption has become a large part of the total energy consumption and a heavy burden of the national economy in China. According to related data, the building energy consumption accounts for 30% of the total energy consumption. The number can reach 46~47% considering the consumption for producing the building materials. Compared with developed countries, China’s construction industry is still dominated by on-site construction with low level of industrialization, leading to the low efficiency and high consumption in whole industry. The energy consumption is about three times as many as that in developed countries. Nowadays, the serious problems faced the building industry are high energy consumption, severe wasting of resources, big disturbance to the environment and varied quality. All these problems could be solved with the development of building industrialization [1].

The concept of architectural industrialization came into being with the western industrial revolution. Its core idea is “building houses like manufacturing cars”. The basic processes are building standardization, components pre-production, mechanization of construction and scientific management. Besides, new achievements of modern science and technology will be adopted gradually to improve labor productivity, to speed up construction, and to reduce engineering cost and improve the quality of project.

As the growing trend of building industrialization, new-type building industrialization refers to adopting intelligent building system under the control of digital information technology. It will complete mass customized production in order to achieve personalized ordering and personalized architecture.

Prefabricated building refers to the building of which the major components and parts are manufactured in the factory, transported to the site and mechanized installed to form a building that meets predetermined functional requirements. The advantages of this type of building include less
limitation by climatic conditions, time and labor saving and quality improving. The development of fabricated building is a key point of building industrialization and also the final path of realizing it.

2. Fabricated steel structures

Fabricated buildings are generally divided by structural materials into prefabricated concrete structures, fabricated steel structures, and fabricated hybrid structures. Steel structures have many advantages such as good machining performance, easy to be assembled, lightweight and high-strength. Therefore, steel is suitable for the fabricated structures, and steel structures can help to achieve the modularization, standardization, industrialization, assemblage and informatization of buildings, which is in accordance with the concept of innovation, coordination, green, openness and sharing coordinating.

2.1. Fabricated steel structures abroad

The steel structure industrialization abroad mainly focuses on the low-rise prefabricated steel structure [2]. Cold-formed thin-walled light steel structure system is widely used in Australian. This system has the advantages of environmental friendly, high-speed construction, good seismic performance et al. BSAIS industrial building system in Italy is suitable for the construction of steel structure flat. They have novel shape, reasonable structure, and good seismic performance. They also have the advantage of high-speed construction. There are a large number of applications in Europe, Africa, and the Middle East. Sweden is one of the leading countries in building industrialization in the world, with 95% components of the light steel structures are prefabricated.

Besides, the representative structure system of foreign prefabricated multi-storey steel structure buildings is the Kaiser Bolted Bracket and Con Xtech Con X system specified in American code "steel structure seismic design specification" [3]. Another is the high-rise mega steel structure building system proposed by Japan [4,5], which separates the structural components from the building composition of each room.

2.2. Fabricated steel structures in China

Generally, the domestic steel structure systems can be divided into three categories.

2.2.1. Structures with enclosure system innovation

In the design stage, the collaborative design of the three major systems of structure, enclosure and interior decoration should be considered. The design should take the architectural function as the core, take the frame as the unit for the main body, and try to unify the size of the column network. They are supported by industrial enclosure and interior decoration. The interior decoration design can hide the beams, columns and supports to ensure safety, durability, fire resistance, heat preservation and sound insulation.

2.2.2. Modular steel structures

The modular building system can achieve full factory production [6,7]. The typical systems include disassembly mobile house and modular box house. The disassembly mobile house uses light steel structure as the skeleton, color steel sandwich board as the enclosure material, and standard modulus for space combination. The main components use bolt connection, making the structures can be assembled and disassembled easily and quickly. While the second type, modular box house, take the box as the basic unit. The main frame of the box is made of section steel or thin-wall section steel, and the enclosure materials are all non-combustible materials to ensure the fire safety. The interior and exterior decoration of the box house are all processed in the factory, with no need for secondary decoration. Figure.1 shows the typical box modular steel structures.
The prefabrication rate of such steel structure systems can reach 90%, including the structure, external walls, doors and windows, to internal decoration, mechanical and electrical. The factory steel structure adopts the quality management system of the manufacturing industry. All products are finalized after the factory test and verification.

2.2.3. Industrial residential building system. Some domestic enterprises and research institutes have developed some special residential steel structure system suitable for residential buildings, aiming to solve the problems for the traditional residential steel structures. Typical example of such new systems are steel tube bundle composite structure system and box steel plate shear wall structure system, which have been applied in practice.

3. Development of fabricated steel structures
In terms of modular research, Annan studied the main and secondary beam joints of the column load-bearing box modular steel structure [8] and the seismic performance of the structure [9-11]. Hong and Cho studied the hysteretic behavior of a type of column-supported modular steel buildings with double-skin steel wall.

Li and Mao [12,13] studied the problems of splice joints between adjacent box modules of column-supported modular steel buildings, and proposed a new type of vertical splice joint between adjacent box modules. The tensile strength, shear strength and corresponding failure modes of the new connection proposed were investigated through experiments.

Cao [7] proposed the calculation method of joint stiffness and length coefficient for column-supported modular steel buildings. Vertical monotone loading test and horizontal monotone loading test on the double-layer single-span full-length box modular steel structure were conducted in the research, and its bearing capacity, lateral stiffness and failure mode were analyzed.

Chen [6,14] developed a composite special-shaped column structure system, which is suitable for multi-high-rise residential buildings. The proposed system has a larger usable floor area of rooms and has good seismic performance.

Hao [15] proposed a new type of steel plate shear wall suitable for the residential system. The shear wall is light weight and has good seismic behavior. When the steel plate shear wall is being used, the structural layout is more flexible with larger use space. The horizontal stiffness of the structure increased and the steel consumption can be reduced. The shear walls can be used to replace the steel support in the residential structure to achieve better architecture effect and to improve the structural safety. He also proposed the MCFTS (multi-core Concrete Filled Steel Tube System) for high-rise steel residential structures. In this system, multi-cavity concrete-filled steel tube-support structure system and composite multi-cavity concrete-filled steel tube special-shaped column-support structure system are used. The seismic performance of the proposed system is studied by experiments.
There are also some new types proposed and used by building companies. Yuanda Group proposed a steel frame structure system with joint diagonal brace. Diagonal braces are used between the beams and columns to strengthen the connection.

Chen [16] proposed a new type of assembled beam-column bolt joint named assembled beam-column flange bolt joint. This assembly joint can avoid the problems caused by on-site welding, and improve the installation efficiency of construction site.

4. Further development

The use of sections to divide the text of the paper is optional and left as a decision for the author. Where the author wishes to divide the paper into sections the formatting shown in table 2 should be used.

- The architects can use the advantage of steel to create new design for steel structures.
- Unified standardized module system and standards are needed in this field to achieve architectural industrialization.
- Enclosure structures and supporting construction equipment (water, heating, electricity, air conditioning system) should be improved to form a complete prefabricated system.
- Fabricated building construction techniques should be developed to improve the construction quality.

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