Investigation on Architectural Adaptability for a New Kind of Column-Supported Modular Steel Buildings

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***Abstract*—In recent years, building industry in China is experiencing upgrade and industrialized building becomes a hot issue. Modular steel building, as one of the most promising types of prefabricated structures, can save construction time, improve quality, and reduce resources and waste. It can be expected that modular steel building will have vast potential for future development in China. Firstly, this research proposes the size selection method of column-supported modular steel building based on the architectural requirements and the transportation limits. The dimensions for individual module are selected as 6 meters for length, 2.4 meters for width and 3 meters for height. Furthermore, the architectural adaptability of column-supported modular steel building is studied with respect to dormitory building, office building, school building and residential building. The results indicate that the column-supported modules with selected dimensions have acceptable applicability with respect to the four types of buildings.**

***Index Terms*—prefabricated structures, column-supported modular steel buildings, size selection, architectural adaptability,**

I. Introduction

Modular steel building, as prefabricated room-sized volumetric units, are always fully fitted at the manufacturing stage and are installed on site as load-bearing ‘building blocks’. A modular steel building is a collection of modular components connected together to form a self-supported and load-bearing structure. It differs from temporary or mobile buildings in terms of structural design and quality requirements [1]. The design and construction of modular steel buildings have to conform to relevant specifications in building codes. There are two generic forms of modular components. One is wall-supported modular component where vertical loads are transferred through walls, and the other is column-supported modular component where vertical loads are transferred through columns, which is shown Fig. 1. This study focuses on the column-supported modular component [2].

As a new structural system, researches on modular steel buildings in China are few [3]. In order to promote its applications, it is necessary to determine the dimensions of individual modular component and study its architectural adaptability based on the Chinese codes [3].

A typical column-supported steel modular component is shown in Fig. 1. The modular component consists of four channel section floor beams, four channel section ceiling beams and four Rectangular hollow section (RHS) columns [4]. The beams and columns are welded together to form an integrated modular component under a controlled manufacturing environment [5]. To avoid the local buckling of the column wall, inner stiffeners are placed inside the RHS columns correspond to the locations of the beam flanges [6].

Typical connections which connects modular components on its channel section beams instead of the RHS columns are shown in Fig. 2.

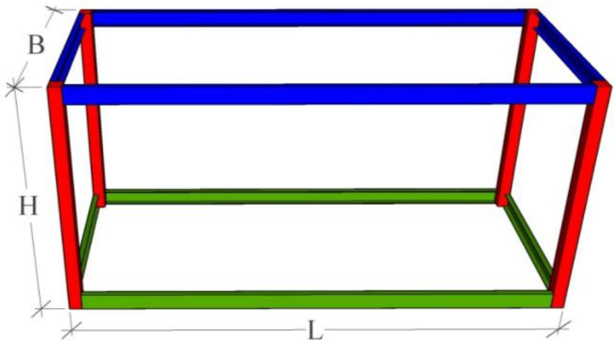

Figure 1. Column-supported steel modular component

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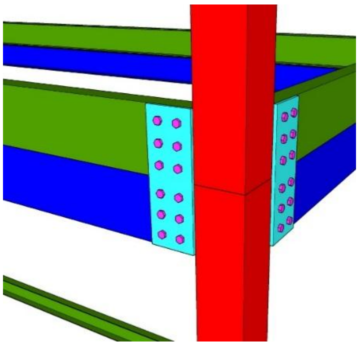
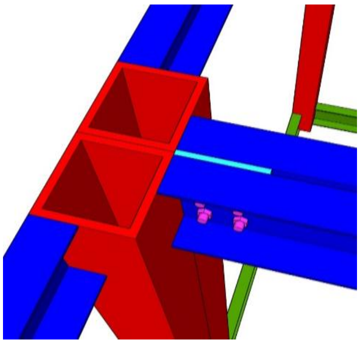


(a) Connections with two modular components in adjacent store



(b) Connections with two modular components in same story

Figure 2. Connections with two modular components

II. Size Selection

The size selection for individual column-supported modular component is to determine its outside dimension, which is L, H and B in Fig. 1. The size selection method presented in this paper is based on the architectural requirements and the transportation limits in China [7].

The basic module adopted in China is M=100mm. In the architecture design, the basic module or its multiple value are used as the architecture module [8]. Generally, in Chinese codes, the architecture modules are a series of numbers arranged according to 3M [9].

If the outside dimension of modular component is less than the inside dimension of standard container, there is no need to consider its transportation problem as it can be transport in the standard container. However, the inside dimension of the standard container is no the architecture modules in China, and the height of the standard container is 2350 mm, which is too small for the architectural requirements of clear height [10].

The common transportation methods for modular component are highway transport, rail transport and water transport. In China, the dimension limits of cargo with respect to highway transport are 12160 mm for length, 2500 mm for width and 3050 mm for height; The dimension limits of cargo with respect to railway transport are 13020 mm for length, 2600 mm for width and 4750 mm for height; The dimension limits of cargo with respect to water transport are 32200 mm for length, 10500 mm for width and 5390 mm for height. In conclusion, the outside dimension limits for modular component are 121M for height, 25M for width and 30M for height.

From all above, the outside dimension of modular component is determined as L=6000 mm, B=2400 mm, H=3000 mm. The presented outside dimension meets both the requirements of architecture codes and transportation limits.

The architectural adaptability of modular steel building can be investigated based on the presented outside dimension. This section will study its architectural adaptability with respect to dormitory building, office building, school building and residential building.

III. Architectural Adaptability

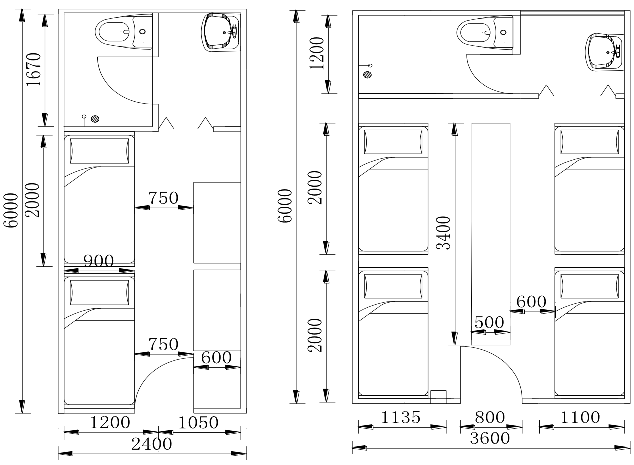
Architectural adaptability here means that how many kind of buildings with different architectural functions the presented modular structures can adapt to [11]. The architectural adaptability of column-supported modular steel building will be studied with respect to dormitory building, office building, school building and residential building in this section and the basic architectural layout program are put forward.

A. *Dormitory Building*

Dormitory building belong to residential buildings, but it is a special category. Compared with other residential buildings, the layout of dormitory buildings is much more regular and neatly arranged. Therefore, dormitory building is one of the most suitable forms of column-supported modular steel buildings.

A two-person dormitory room which is formed by one module is shown in Fig. 3 (a); A four-person dormitory room which is formed by one and a half modules (which means three modules can form tow rooms) is shown in Fig. 3 (b). The stair room formed by one module is shown in Fig. 4; The stair and elevator room formed by two modules are shown in Fig. 5. The layout program of a typical dormitory building which is formed by modules is shown in Fig. 6.

The investigation shows that column-supported modular steel buildings can be well applied in dormitory buildings and has good architectural adaptability.



(a) Two-person dormitory room

(b) Four-person dormitory room

Figure 3. Dormitory room

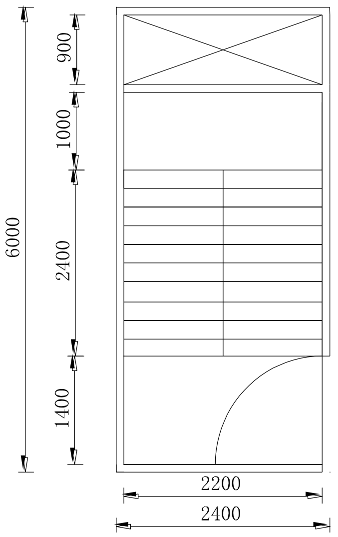


Figure 4. Stair room

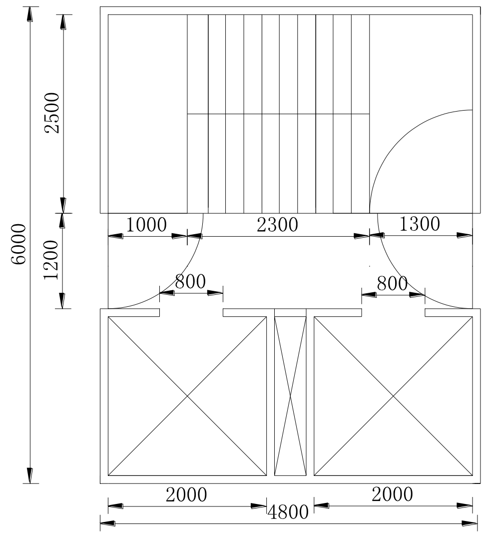


Figure 5. Stair and elevator room

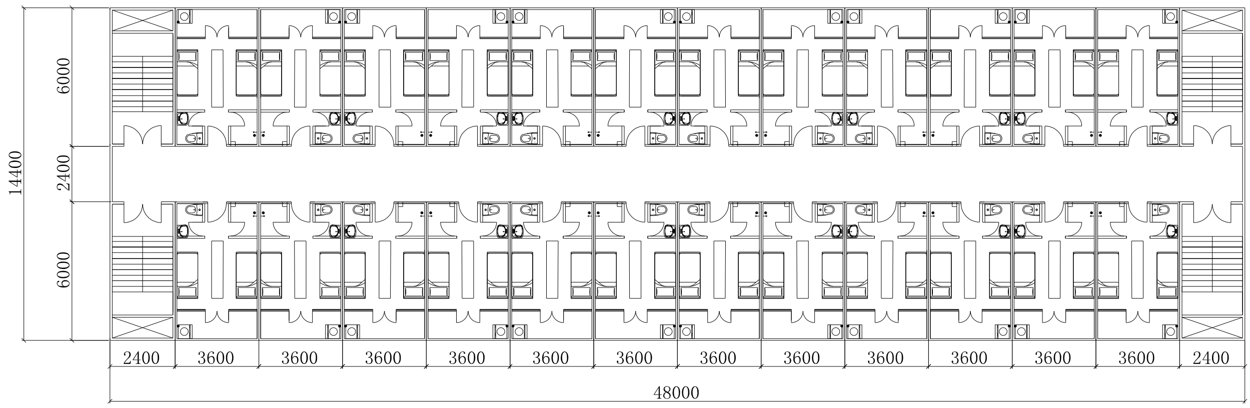


Figure 6. Layout program of a typical dormitory building

B. Office Building

In Chinese building code, the common size of individual office is depicted in Table Ⅰ. Two office rooms which are formed by three modules are shown in Fig. 7. The width, depth and height of the each office room is 3.6m, 6.0m and 3.0m, respectively. The size of the office room fits the building code well. The stair and elevator room formed by two modules are shown in Fig. 8. The washroom formed by three modules are shown in Fig. 9 (a). The layout program of a project case designed with the proposed rooms are shown in Fig. 9 (b).

The investigation shows that column-supported modular steel buildings can be suitable for different kinds of office buildings and has considerable architectural adaptability.

TABLE I. COMMON SIZE OF INDIVIDUAL OFFICE

	common size(mm)
width	3000、3300、3600、6000、6600、7200
depth	4800、5400、6000、6600
floor height	3000、3300、3400、3600

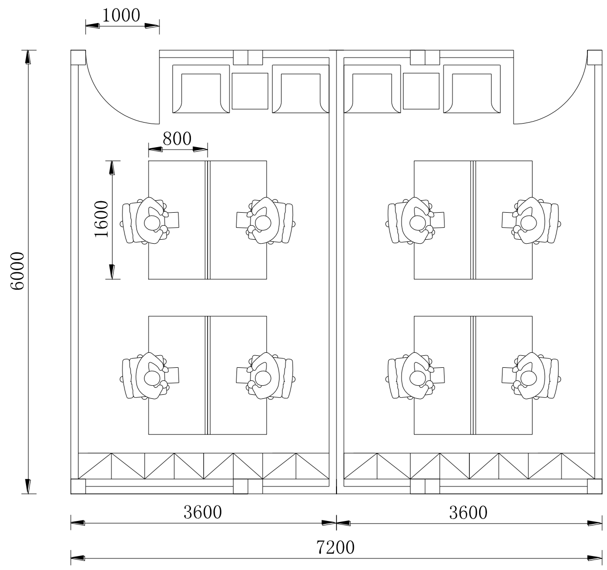


Figure 7. Office rooms

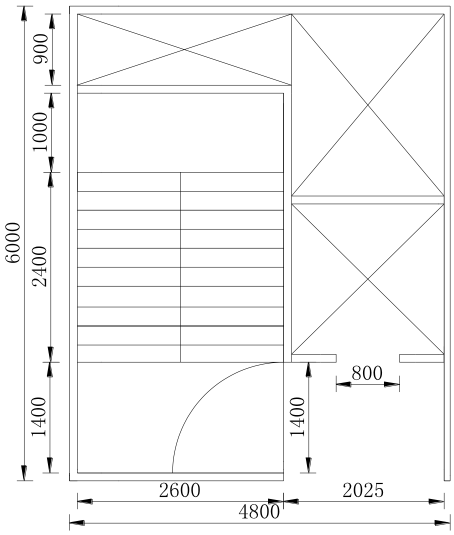


Figure 8. Washroom

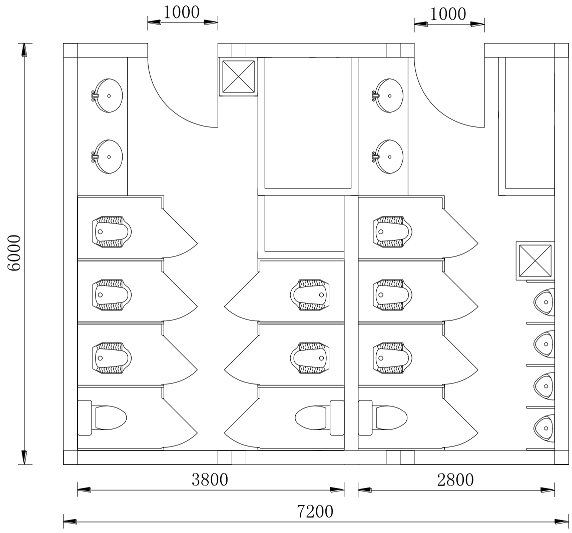


Figure 9. (a). Washroom

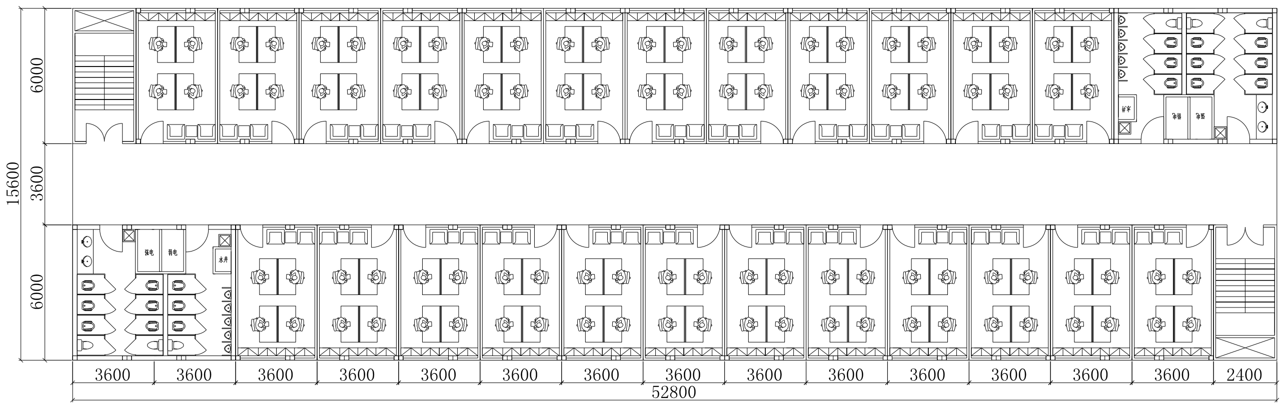


Figure 9. (b). Layout program of a project case

C. School Building

The research of school buildings in this section mainly focuses on primary and secondary schools. Compared with dormitory buildings and office buildings, the requirements and restrictions of school buildings in Chinese building codes are much more complex. These requirements and restrictions are not listed but has been already considered and met in the following layout arrangement.

A project case of a two story modular primary school will be demonstrated in this section. This school is designed using a completely modular concept. Therefore, it can be fully prefabricated in factory and assembled on-site. Furthermore, this school can also be disassembled and offsite constructed. The classroom, which is formed by four modules, is shown in Fig. 10. The layout program of the first floor is shown in Fig. 11, along with the second floor in Fig. 12. The effect pictures of the school is shown Fig. 13.

The investigation indicates that column-supported modular steel buildings can be suitable for different kinds of school buildings and has considerable architectural adaptability.

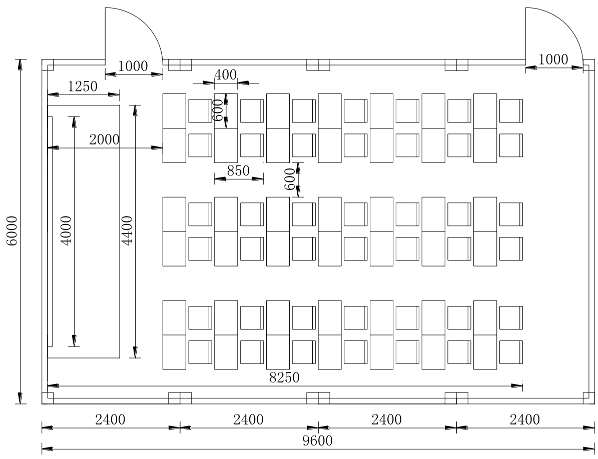


Figure 10. Classroom

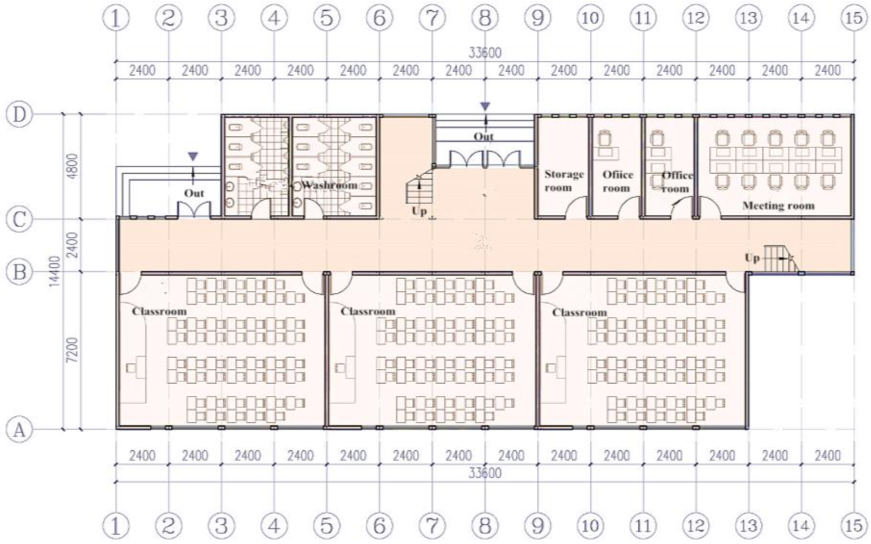


Figure 11. Layout program of the first floor

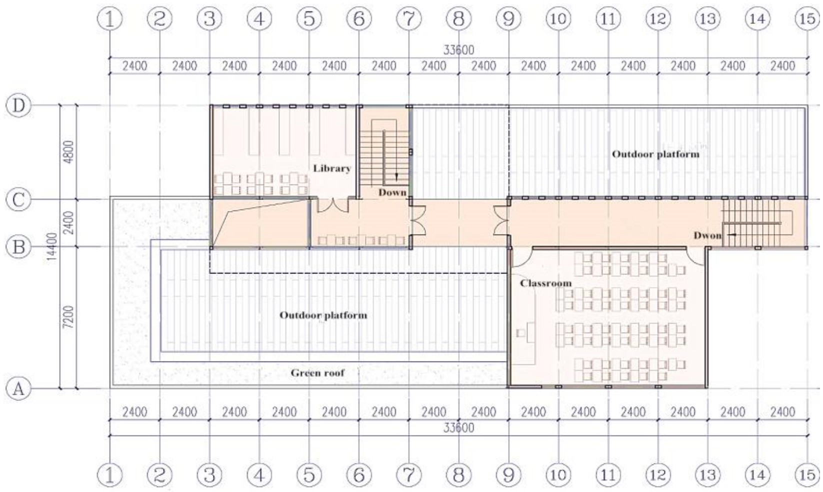


Figure 12. Layout program of the second floor

(a) Northeast side
Figure 13. Effect pictures of school

D. Residential Building

The variability and complexity of the plane space and layout in residential buildings are much more obvious than other kind of buildings. Therefore, the primary challenge for using modular steel buildings is how to make use of a box-shaped module with a fixed size to create a variety of layouts and spaces for house owners. In other word, Meets the personalize needs of house owners and ensuring high prefabricated rates at the same time.

This section will use a high-rise modular residential project case as an example. This residential building has eighteen story. As it is located in a high seismic intensity area, the main structural system adopts the shear wall core along with the mega steel truss. The modules here is only used as the auxiliary load-bearing system and the separation system. The main structural system is shown in Fig. 14. The layout program of Standard flat is shown in Fig. 15. The different house types formed by modules are shown in Fig. 16. In the design, each house type has a large balcony and most house types have a semi-open courtyard. By this kind of design, we hope residents can grow plants on balconies and courtyards as their will to enriching their family life and bringing changes to the building facade. The effect pictures of the residential building is shown Fig. 17.

The investigation indicates that column-supported modular steel buildings can be suitable for different kinds of residential buildings with variety house types and has considerable architectural adaptability.

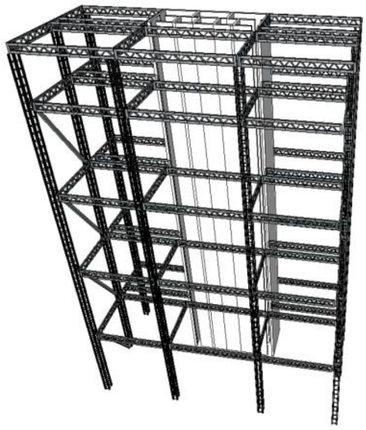


Figure 14. Main structural system

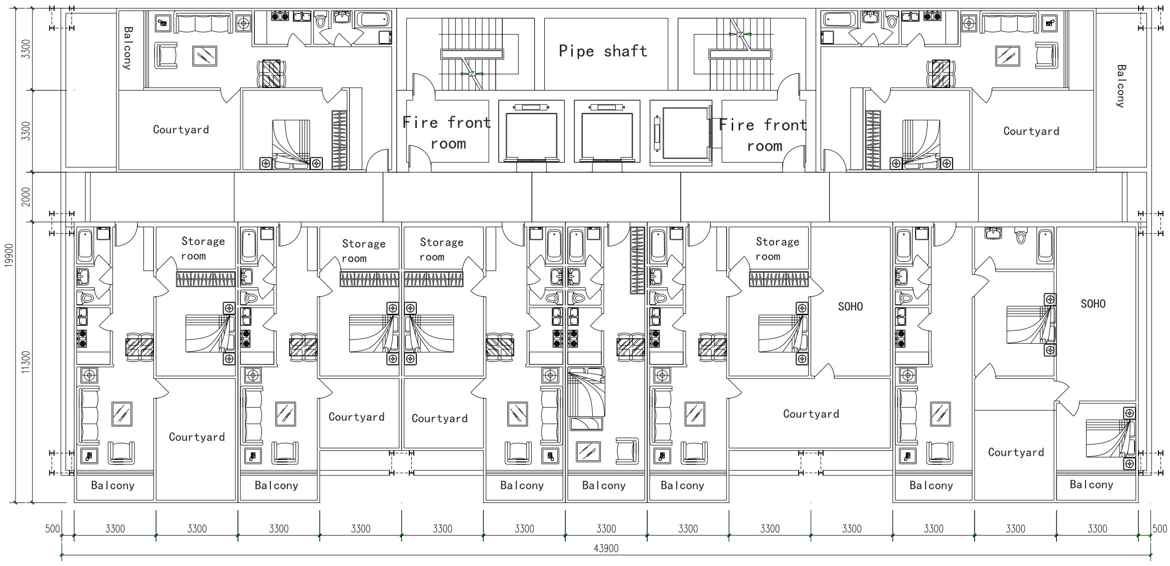
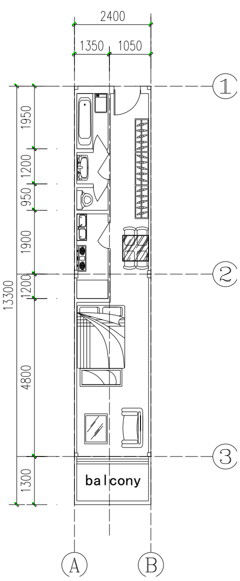
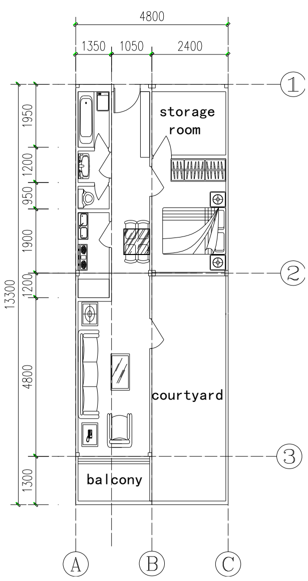


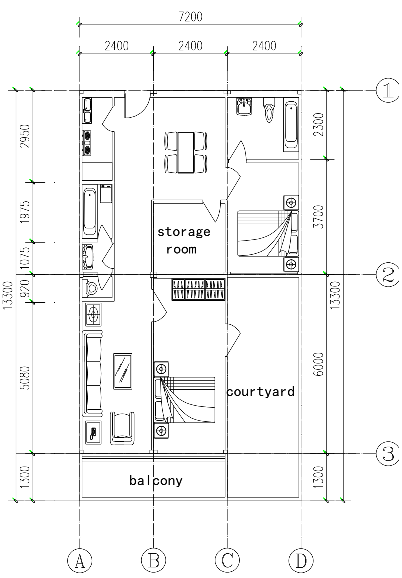
Figure 15. Layout program of standard flat



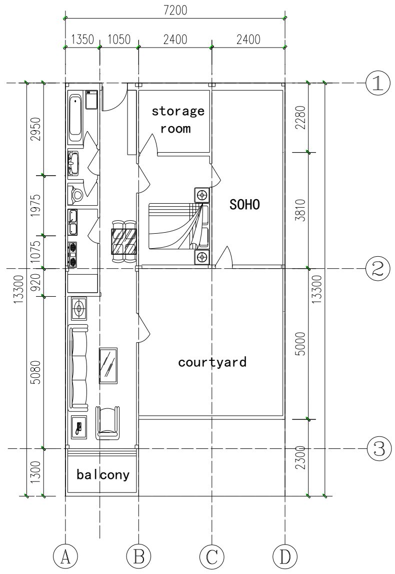
(a) 30m^2 house type made by 2 modules



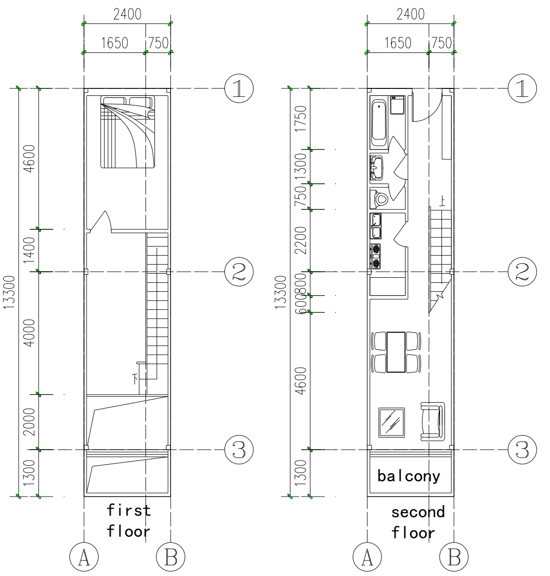
(b) 54m^2 house type made by 3 modules



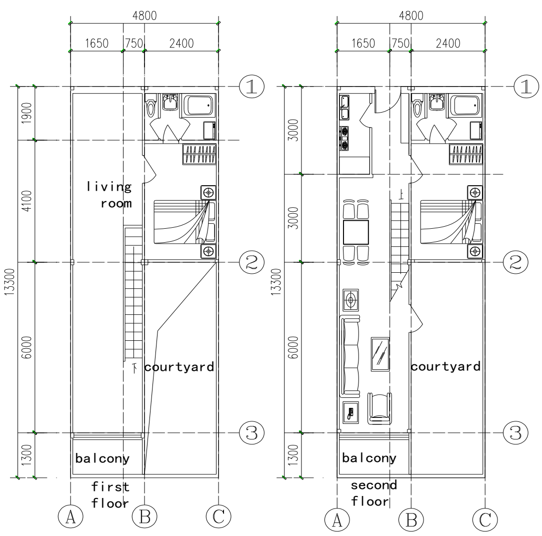
(c) 84m^2 house type made by 5 modules



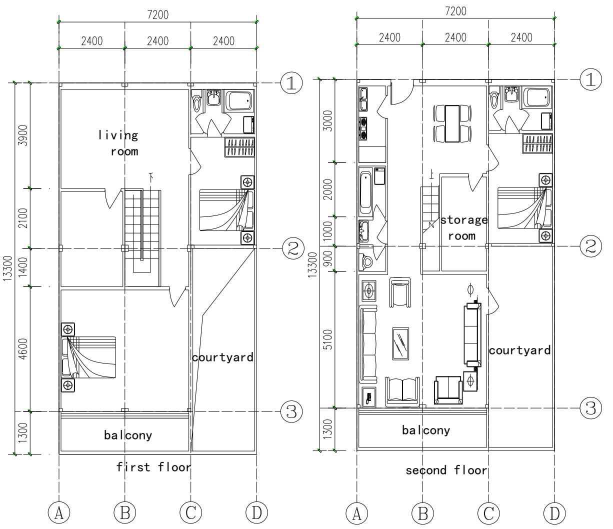
(d) 71m^2 house type made by 4 modules



(e) 56m^2 duplex house type made by 4 modules



(f) 105m^2 duplex house type made by 6 modules



(g) 147m^2 duplex house type made by 6 modules

Figure 16. Different house types formed by modules

Figure 17. Effect pictures of residential building

IV. Conclusion

A new kind of column-supported modular steel buildings along with its module-to-module connections was proposed. All the modules are prefabricated in factory and assembled on-site using bolt connections, therefore, on-site welding and cast-in-place concrete work are avoided.

According to the architectural modulus and transportation limits, the sizes of individual module are determined as 6.0 meters for length, 2.4 meters for width and 3.0 meters for height.

The architectural adaptability of column-supported modular steel buildings is investigated. It indicates that the proposed modular steel buildings can adapt to dormitory buildings, office buildings, school buildings and residential buildings well.

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