Research on Modular Coordination of Indemnificatory Finished Product Housing in Severe Cold Region of China — —A Case Study of an Experimental Residential Project in Harbin

Yu Shao 1, 2, Yizhou Mo 1, 2

1 School of Architecture, Harbin Institute of Technology, Harbin 150001, China
2 Key Laboratory of Cold Region Urban and Rural Human Settlement Environment Science, Ministry of Industry and Information Technology, Harbin 150001, China
shaoyuu@163.com, Yizhoumo0@outlook.com

Abstract. This paper study the case of an experimental house built in Harbin and analyses the modular coordination of indemnificatory housing in severe cold area. Using case analysis and literature research methods, the modular coordination system of the experimental house is analysed, and this conclusion is elaborated from three aspects: component position, space optimization size and modular grid. The research shows three key problems in modular coordination of indemnificatory finished product housing in severe cold region: how to select the positioning mode of building components; how to select the optimal size according to the infill parts; and how to establish modular grid according to the spatial organization.

1 Introduction
The indemnificatory finished product housing in severe cold area refers to the indemnificatory housing delivered in the form of finished house. The concept of finished housing delivery refers to the provision of new industrial housing with direct use function. The delivery standard of the finished residence is that the internal covering and finishing are completed, the equipment and pipeline ports are complete, and the door parts, window parts, kitchen and bathroom parts are also installed in place.

The concept of indemnificatory finished product housing in severe cold area is based on the industrialization of housing, and the construction system of "SI house" [1] which separates support and infill parts in Japan is used for reference, including the Infill, equipment and pipeline system, building main structure system and exterior enclosure system [2]. The professional cooperation among architectural design, structural design and electromechanical design is the premise to ensure the coordination of each subsystem. This kind of coordination needs to establish a rule to solve the problem of size coordination, that is, to establish a modular coordination system belonging to the finished product housing.

The modular coordination system for the laboratory includes three aspects: component positioning mode, optimal size of space and module grid setting.

1.1 Modular Grid
Building modular grid is the systematic expression of modular coordination results. The setting needs to meet the needs of component installation and spatial organization. Modular grid consists of a series of datum lines, and the relationship between building components and datum lines is also known as its
positioning mode. And the distance between successive datum lines should be selected from the preferred size series conforming to modulus [3].

1.2. Two Ways of Component Positioning

The two positioning modes of components are shown in figure 1 and figure 2. Among them:

- The way of axis positioning is more commonly used, which is conducive to structural safety calculation and determine the size of prefabricated structural members.
- The way of interface positioning is conducive to ensure that the clear space of the building conforms to the module, and is conducive to the installation of the Infill parts, especially the integrated infill parts.

![Figure 1. Axis positioning.](image1)

![Figure 2. Interface positioning.](image2)

1.3. Space optimal Size and Preferred Size

Under certain type of positioning ways, we can tell preferred size from space optimal size. The selection of space optimal size is related to architecture design. The goal of optimal size design of indemnificatory house is to obtain intensive space [4]. It is necessary to conduct quantitative research on the size of each space to find a balance between space economy and human use.

This paper aims to investigate and summarize the current situation of indemnificatory housing in Harbin. Using qualitative and quantitative research methods, the paper puts forward the modular coordination strategy and key points of the experimental house.

2 Basic Information of the Studied Building

2.1. Climate Condition of the Building Environment

According to the Code for Design of Civil Buildings (GB 50352-2005), Severe Cold Region is one of five different climate zones in China, and Harbin is a typical city in severe cold area (table 1). Harbin lies between 125 ° 42 ′ - 130 ° 10 ′ E and 44 ° 04 ′ - 46 ° 40 ′ n. The climate condition of Harbin is presented in table 1.

| Climate Region | Temperature     |
|----------------|-----------------|
|                | Hottest | Coldest  |
| Severe Cold    | ≤ 25°C  | ≤− 10°C  |

Data Source: Code for Design of Civil Buildings (GB 50352-2005).
2.2. Details of the Studied Building

The experimental house built in Harbin has three floors, with a total floor area of 224 m². The total height of the building is 10.6m, and the standard height of each floor is 3.4m. Figure 3 shows the floor plan of the house. The first floor of the house is the exhibition hall. The second floor is mainly composed of the indoor space and corridor of the residence. It can be arranged as an apartment with two rooms, and the third floor is the roof auxiliary facilities.

The building main structure subsystem of the experimental house is composed of shear wall and coupling beam. The load-bearing member is a group of Cast-in-place Short-leg Shear Walls with a thickness of 200 mm. The shear walls are connected by cast-in-place or prefabricated coupling beams. The main structure does not need to use prefabricated components.

The interior components of the laboratory are mainly included in the Infill parts subsystem, equipment subsystem and pipeline subsystem. Infill is the key to realize the "delivery in the form of finished products" of finished housing. The interior decoration of the experimental house includes integrated bathroom, integrated kitchen, overhead ground system, lightweight partition system and other equipment, etc. In order to meet the regional demand, the raised flooring systems and the under-floor heating system are arranged in combination.

The exterior enclosure subsystem of the experimental house needs to meet the regional needs. The subsystem consists of light embedded enclosure subsystem and mounted external enclosure subsystem, and adopts filled wall, insulation board, facade curtain walls and other modules.

3 Method
In this paper, SPSS Statistics 25.0 is used to analyse the data that obtained from the case investigation. The original data source is presented in table 2.
Table 2. Basic information of public rental housing project.

| Project name                     | Type                                    | Floor area (㎡) | Sample size |
|----------------------------------|-----------------------------------------|-----------------|-------------|
| HuaRunKaiXuanMen                 | High-rise Apartment                      | 49~60           | 7           |
| LvHaiHuaYuan                     | High-rise Apartment                      | 36~41           | 5           |
| ZhongShanLongJun                 | High-rise Residential Building           | 53~58           | 3           |
| DongDuGongYuan                   | High-rise Residential Building           | 40~49           | 4           |
| GeLanYunTian                     | High-rise Residential Building           | 38~59           | 12          |
| MingGuangShuiAn                  | High-rise Apartment                      | 48~50           | 7           |
| HengDaMingDu                     | High-rise Residential Building           | 48~49           | 3           |
| HuaYuanShuiMuQingHua             | High-rise Apartment                      | 43~53           | 5           |
| JinRuiLinCheng                   | High-rise Residential Building           | 48~50           | 8           |
| LvHaiHuaTing                     | High-rise Apartment                      | 47~49           | 20          |
| ZhongTianFuCheng                 | High-rise Residential Building           | 47~49           | 4           |
| YuanChuangYueFu                  | High-rise Residential Building           | 52~63           | 12          |

Through case analysis, this paper summarizes the modular data of the space size of indemnificatory housing in severe cold area, and puts forward the positioning ways of the components through comprehensive evaluation, obtains the space optimal size series of the housing space and draws the modular grid plan.

Due to the timeliness of the construction demand, this paper investigates 30 newly-built indemnificatory housing projects in Harbin, and obtains 90 sets of samples by random sampling survey. The information of component and space size of indemnificatory housing are sorted into database. Through quantitative description and qualitative analysis, this paper summarizes the spatial characteristics and functional requirements of indemnificatory housing, and provides the basis for the spatial design and component selection of experimental room.

According to relevant standards, the floor area of single indemnificatory housing is controlled within 50 square meters. In the severe cold area, the floor area is large under the same use area, so the floor area of the investigated case is between 40 to 60 square meters. The housing types investigated include ordinary housing, apartments and affordable housing. The project nature, quantity and other information of the case are also shown in table 2.

4 Results and Analysis

4.1. Optimal Size Series

The data of spatial layout and spatial size of indemnificatory housing in severe cold area are obtained and BIM database is formed. The design of space optimal size series needs to meet three conditions: first, it can realize the intensive layout of space; second, it can cover the commonly used size range; third, it can adopt appropriate multi-module [5].

The analysis of spatial dimension database can summarize the common spatial layout and the range of spatial dimension. IN the process of selecting and expanding modulus, the factors considered are coordination, applicability and economy. The multi-module is coordinated with the whole module system. The size formed by multi-module can satisfy various spatial layout modes. The modulus value is beneficial to the economy of component construction [6].

Through the analysis of the above three conditions, the optimal size series of indemnificatory housing space in severe cold area is obtained as shown in figure 4 [7].
4.2. Component Positioning

The experimental house can be divided into four subsystems. The main structure system mainly consists of load-bearing structural components, the Infill, equipment and pipeline system mainly consists of Infill parts, and the exterior enclosure system mainly consists of exterior parts.

The positioning mode of main structure components is shown in figure 5. It has the following advantages:

It can choose more kinds of thermal insulation materials and adopt passive technology to deal with regional problems, excluding the interference of different materials, forms and thicknesses of the external enclosure system on the other systems; The positioning mode contributes a complete internal clear space that conforms to the module. It is conducive to the organization of parts in the interior space.

After comprehensive consideration, the way of interface positioning is adopted for the Infill parts. There are two subtypes:

Interface positioning method are adopted to integrated bathroom and integrated kitchen unit (figure 6); Residential living room, bedroom, corridor space adopted interface positioning method and set the zone of grid (figure 7).
Figure 6. Integrated bathroom layout with interface positioning.

Figure 7. Interface positioning of bedroom and corridor unit.

Similar to the poisoning of main structure subsystem, the exterior enclosure subsystem uses the way of interface positioning to avoid the interference to other building components. The following two subtypes are shown in figure 8:

Light embedded enclosure system, ALC (Autoclaved Lightweight Aerated Concrete Panel) is used to fill the enclosure structure; The light external enclosure system is located in the outer layer of the main structure, and the auxiliary datum line is used to locate the components. The mounted external enclosure system adopts vacuum insulation board and other related materials to meet the insulation performance requirements in the severe cold area, and the mounted external curtain wall is used as the façade (figure 9).

Figure 8. The positioning mode of the light embedded enclosure system and the light external enclosure system.

Figure 9. ALC block products, polystyrene thermal insulation layer and mounted external concrete curtain wall.

4.3. Modular Grid

The component positioning ways provides the qualitative conclusion, and the optimal size series provides the quantitative conclusion of the modular coordination. On this basis, a modular grid suitable for the experimental house can be proposed. Among them, the module coordination problem of the second floor is the most typical, and the module grid plan is shown in figure 10.
Figure 10. modular grid plan of the second floor of experimental house.

5 Conclusion
The finished product housing provides a new construction mode for indemnificatory housing in severe cold area. The main problems in the application of modular coordination system are as follows:

First, in the process of building modular grid, reasonable and optimal size should be selected. The selection of optimal size should consider the economic and human needs, and the space corresponding to the modular grid should be intensive.

Second, the component positioning mode shall meet the regional requirements. In this case, the passive means to increase the thermal performance of the enclosure structure is selected, and the active heating mode is provided by the overhead ground system and the under-floor heating system. It has a significant impact on the positioning mode of components.

Third, in the process of building module grid, the zone of grid shall be set reasonably to ensure the coordinated installation of the Infill parts, especially the Integrated infill parts, so as to achieve the purpose of the delivering of finished product housing.

Acknowledgment
This work was supported by the National Natural Science Foundation of China (51878199).

References
[1] Seiichi F, Xinxin G The history of developments toward Open Building in Japan 2011 J. New Architecture.6 14-7(in Chinese).
[2] Cuperus Y 2001 An introduction to Open Building 9th Annual Conf. of the Int. Group for Lean Construction (Singapore: Ballard G & Chua D).
[3] Xin Z, Wei X 2013 The application research of Europe and the United States construction module in residential industrialization system J. Architecture & Culture 2 82-5 (in Chinese).
[4] Hasim A, Nicola G, Sam M and Antonio F 2015 Redesigning terraced Social Housing in the UK for flexibility using building energy simulation with consideration of passive design J. Sustainability 7(5) 5488-5507.
[5] Xiaohong Z, Lin L, Jishou Z 2012 Development and application of modern building modulus theory J. Architectural J.4 30(in Chinese).
[6] Yoshiya U General System of Construction Industrialization 1983 Build. Construct. Syst. (Shanghai Scientific & Technical Publishers) (in Chinese).
[7] Hua L 2015 Secondary modular system and its use in housing construction J. Architectural J. 1 237-41 (in Chinese).