Research on Modularization of Prefabricated Affordable Housing in Zhengzhou Based on the Concept of Sustainable Development

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Abstract. With the rapid development of the global economy, energy resources and environmental problems continue to deteriorate. As an industry with high energy consumption, the sustainable development of the construction industry is vital. Prefabricated housing can overcome the disadvantages of traditional construction methods such as long construction periods, low production efficiency, low engineering quality and safety, and achieve the sustainable development construction goals of fast construction, safety and durability, low carbon and environmental protection. However, it also has a series of development bottlenecks such as high production costs and low prefabrication rates. Based on the Zhengzhou prefabricated affordable housing design project, this paper studies the modularization of prefabricated affordable housing, and combines the green building technology, comprehensively evaluating the sunshine, lighting, ventilation and other indicators of the space. The modular coordination system that can be used for the design of prefabricated affordable housing is screened out, in order to effectively promote the green and sustainable development of affordable housing construction.

Keywords. Modularization, prefabricated affordable housing, modular coordination system, green building technology, comprehensive evaluation

1. Introduction

In recent years, with the acceleration of urbanization, more and more people gather in big cities. While injecting vitality and creativity into the city, they are also suffering from the housing pressure and crowding-out effect caused by high housing prices. In order to further improve the living conditions of the people and solve the housing difficulties of the urban low- and middle-income groups, the society constantly improves the relevant policies on affordable housing and vigorously strengthens the construction of affordable housing, relieving the housing pressure of low- and middle-income groups, promoting the optimal allocation of human resources, and injecting a secure source of power for industrial upgrading and technological innovation [1, 2].

With the construction of a large number of affordable housing projects, the energy consumption of buildings has also increased, which is contrary to the sustainable
development goals of the construction industry. In this context, the green transformation of traditional extensive construction methods has become the focus of the transformation of the construction industry at this stage, and the construction of green affordable housing has become the development goal of future affordable housing projects. As a new technical means, prefabricated building symbolizes a major technological change in the construction industry [3]. It is an effective way to promote the transformation of traditional construction methods to green [4], standardization, industrialization, and technology, as well as to achieve the goal of green affordable housing construction [5].

2. The Bottlenecks of Modular Development of Prefabricated Affordable Housing

The prefabricated affordable housing projects in my country started late, the market for prefabricated affordable housing is not yet complete, and the basis for standardization and industrialization is very weak, resulting in the construction cost of prefabricated affordable housing is still at a high level. The lack of standardization of the prefabricated affordable housing system, especially the insufficiency of the modular system of the affordable housing, and the fact that the graphic design does not follow the coordination of the modules, resulting in a low overall prefabrication rate, a low assembly rate, and a long construction period for the current prefabricated affordable housing, which seriously affects the comprehensive quality of prefabricated affordable housing [6]. In order to promote the development of prefabricated affordable housing projects in the direction of greening [7], standardization, industrialization, and technology, this paper studies the modularization of prefabricated affordable housing, and builds a modular coordination system [8] that meets the needs of industrial standardization, in order to provide references for the construction of prefabricated affordable housing projects [9].

2.1. Diversity of Functions

For different households, due to differences in individual characteristics, family conditions, living habits, occupational types, their own preferences and other factors, they have diverse space needs. The design of the living space needs to meet the needs of different households as much as possible to ensure the quality of life and improve the well-being of residents. In addition, with the change of the life stage of the occupants, the demands for space will also change. Therefore, the design of the living space needs to have the flexibility to meet the different needs of the occupants at different stages. Modularization is the core of the standardization of prefabricated affordable housing, which requires the modular development of prefabricated affordable housing to match the diverse needs of residents in order to enhance the competitiveness of prefabricated housing in the real estate industry.

2.2. Diversity of House Types

With the development of social economy and the improvement of industrialization level, more and more types of houses have appeared in the market to solve the problem of housing diversification of the urban population. One-bedroom households are more suitable for unemployed young people who have just entered the society or newly married couples; with the change of family structure and the arrival of children, more families of three tend to choose two-bedroom households; in view of the family of three
generations, they will choose three- or four-bedroom households with a larger area; some residents are willing to choose a larger area and more complete functions in order to pursue a more comfortable space environment and higher living quality. The diversity of house types puts forward higher requirements for prefabricated affordable housing. How to coordinate the contradiction between diversity and standardization is a problem that must be solved in the development of prefabricated affordable housing.

2.3. Diversity of Combination Methods

In addition to the combination of house types, the composition of a residential unit also includes public apportionment parts. Stairwells, public corridors, and inter-level public spaces in some new residential units are all components of a residential unit, and each part has the characteristics of diversity, and the combination between them also have diversity under the premise of meeting the normative standards. In order to meet the needs of spatial diversity, the structural system of residential units often does not match the modulus, which makes the size of the prefabricated components various, increases the difficulty of industrial production, and makes it difficult to reflect the advantages of prefabricated buildings.

3. Modular Design under the Comprehensive Evaluation of Green Building Technology

3.1. Assumption of the Plane Models Based on the Zhengzhou Affordable Housing Project

According to the design requirements of the Zhengzhou prefabricated affordable housing project and the “Zhengzhou Public Rental Housing Design Guidelines (trial)”, “the building area of a single-bedroom household should be less than 35 square meters, the building area of a single-bedroom household or a one-bedroom, one-hall suite for two persons and two persons with an infant shall be between 35 square meters and 50 square meters, and the building area of a two-bedroom household or a two-bedroom and one-hall suite for 3 to 4 people should not exceed 60 square meters.” It can be concluded that the building area of the single-bedroom suite type of the project should be less than 35 square meters, and the building area of the 2-4-person suite type should be between 35 square meters and 60 square meters.

ISO 6513: 1982 (E) “Building construction—Modular Coordination—Series of preferred multimodular sizes for horizontal dimensions” (Table 1) stipulates the content of building modulus as follows: First, the modulus is the selected dimension unit, as the value-added unit in the scale coordination. The value of the basic modulus is specified as 100 mm, which is represented by “M”, 1M=100 mm. Modular dimensions of the entire building and parts of the building and building components shall be multiples of the basic modulus. Second, the derived modulus shall be the expanded modulus and the divided modulus respectively, and its base should meet the following requirements: the expanded modulus base should be 2M, 3M, 6M, 9M, 12M…; the divided modulus base should be M/10, M/5, M/2.
### Table 1. Modulo sequence.

<table>
<thead>
<tr>
<th>Basic modulus (M)</th>
<th>Expanded modulus</th>
<th>Divided modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>300 900 1200 1500 3000</td>
<td>10 20 50</td>
</tr>
<tr>
<td>200</td>
<td>600 1200 1800 2400 3000 6000</td>
<td>20 40 100</td>
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<tr>
<td>300</td>
<td>900 1800 2700 3600 4500 9000</td>
<td>30 60 150</td>
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<tr>
<td>400</td>
<td>1200 2400 3600 4800 6000 12000</td>
<td>40 80 200</td>
</tr>
<tr>
<td>500</td>
<td>1500 3000 4500 6000 7500 15000</td>
<td>50 100 250</td>
</tr>
<tr>
<td>600</td>
<td>1800 3600 5400 7200 9000 18000</td>
<td>60 120 300</td>
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<td>700</td>
<td>2100 4200 6300 8400 10500 21000</td>
<td>70 140 350</td>
</tr>
<tr>
<td>800</td>
<td>2400 4800 7200 9600 12000 24000</td>
<td>80 160 400</td>
</tr>
<tr>
<td>900</td>
<td>2700 5400 8100 10800 13500 27000</td>
<td>90 180 450</td>
</tr>
<tr>
<td>1000</td>
<td>3000 6000 9000 12000 15000 30000</td>
<td>100 200 500</td>
</tr>
</tbody>
</table>

Combined with the design requirements of the Zhengzhou prefabricated affordable housing project, it selects the size of 6000 mm (60M) long and 6000 mm (60M) wide as the size modulus of a single-bedroom suite type. According to the regulations in “Design Code for Residential Buildings” (GB 50096-2011), “When calculating the building area of the suite, the area of the balcony shall be calculated according to half of the projected net area of the structural floor”. When the balcony is considered within the scope of the house type design, it can meet the requirement that the building area of the single-bedroom suite should be less than 35 square meters. In order to make the size of the apartment more standardized, it selects 6000 mm (60M) long, 12000 mm (120M) wide or 12000 mm (120M) long and 6000 mm (60M) wide as the size modulus of a 2-4-person suite type. When the balcony is considered in the scope of the house type design, it can also meet the building area requirement of the 2-4-person suite. Therefore, three simple plane models of 60M long and 60M wide, 60M long and 120M wide, and 120M long and 60M wide based on the Zhengzhou affordable housing project are constructed (Figure 1).

![Figure 1. Three simple plan models.](image)

### 3.2. Sunshine Analysis and Conclusion

14 types of occlusions for single-person suite type of 60M long and 60M wide (code A), 48 types of occlusions for 2-4-person suite type of 60M long and 120M wide (code B), and 51 types of occlusions for 2-4-person suite type of 120M long and 60M wide are
Green building sunshine analysis technology is used to analyze the sunshine situation of the simple plane models. According to the “Zhengzhou Public Rental Housing Design Guidelines (trial),” “complete sets of small-scale houses should ensure that each set has a living space to obtain effective sunshine time with full windows on a cold day shall not be less than 2 hours,” and “more than half of the rooms in the single-type dormitory set should have good orientation, and meet the requirements of the effective sunshine time with full windows not less than 2 hours on a cold day.” It screens out simple plane models that can be used in the design of prefabricated affordable housing. In the type A, the types that cannot be used for architectural design are A10, A12 and A13, and the types that are not recommended are A2, A8, A9 and A14. In the type B, the types that cannot be used for architectural design are B41, and the types that are not recommended are B16, B17, B19, B22, B26, B27, B29, B30, B31, B34, B37, B38, B40 and B42. In the type C, the types that cannot be used for architectural design are C40 and C47, and the types that are not recommended are C14, C19, C33, C34, C39 and C46.

### 3.3. Research on Modularization of Basic Function Space

“Design Code for Residential Buildings” (GB 50096-2011) and “Zhengzhou City Public Rental Housing Design Guidelines (trial)” clearly stipulate the basic functional space of the unit type. The basic functional space of the apartment can be classified into four common basic functional space categories, including bedroom, living room, kitchen and bathroom. In order to realize the industrialization and standardization, it is necessary to carry out the modular design of the basic functional space with the basic module M=100 mm, and summarize a set of modular basic functional space dimensions suitable for Zhengzhou prefabricated affordable housing project.

- **Bedroom**

  The bedroom is a space for family members to rest. Two-bedroom households and multi-bedroom households usually have a master bedroom and a second bedroom, and the area of the master bedroom is generally larger than that of the second bedroom. For the family structure with children or the elderly, the design of the bedroom also needs to take into account the physical characteristics and behavioral characteristics of children and the elderly, and meet the requirements of barrier-free design (Figure 3).
• Living room

The living room is the most intensive space for family activities, and it occupies an extremely important position in all basic functional spaces. For suites without a special dining room, the living room also doubles as a dining room; for suites with high work requirements and no special work space, the living room can also serve as a work space. The living room is a part of the suite with a high degree of functional compounding and great spatial flexibility. Most of the daily activities of family members are carried out in the living room, and the living room is the most frequently used space by users (Figure 4).

![Figure 3. Module for the bedroom.](image)

![Figure 4. Module for the living room.](image)

• Kitchen

The kitchen is a space for storing cooking food and the necessary food for life, providing meals for the whole family. Its interior can be subdivided into three areas: storage, washing and cooking. In addition to the basic functions of food preparation, the larger kitchen can also function as a restaurant. In addition, the kitchen is also an important place for family members to communicate and interact, and it also plays an important role in the layout design (Figure 5).

• Toilet

The toilet is an essential functional space for each house type. The interior should be equipped with at least three sanitary equipment, toilet, bath and face wash, or reserved positions and conditions for them. The usable area of the toilet with three pieces of sanitary equipment centralized should not be less than 2.5 square meters (Figure 6).
3.4. **Build a Modular House Type Library**

Arranging and combining the basic functional space modules within the range of three simple plane models, the modularization that can be used in Zhengzhou prefabricated affordable housing projects can be obtained by sorting and eliminating duplicate house
types. The modular house type library includes 5 types of 60M long and 60M wide (code a) single-person suites, 10 types of 60M long and 120M wide (code b) 2-4-person suites, and 12 types of 120M long and 60M wide (code c) 2-4-person suites (Figure 7).

3.5. Combination of House Types and Shared Parts

The public shared parts mainly include the traffic spaces, public corridors, and inter-level public spaces in some new residential units. The traffic core is the most important public sharing part that is necessary for the house and affects the structural design of the prefabricated affordable housing. According to the different building height (represented by h), it can be subdivided into 5 categories, namely: h≤21 m, 21 m<h≤27 m, 27 m<h≤33 m, 33 m<h≤54 m, h>54 m. According to the requirements of relevant regulations, the setting of traffic cores at different building heights is also different (Figure 8).

According to the design requirements of Zhengzhou affordable housing project, the numbers of high-rise residential buildings in this project are 11 floors and 18 floors respectively. The building height of the 11 layers residential building is about 33 m, with a closed stairwell and a fire-fighting elevator, and the traffic core adopts a module of 60M long and 60M wide modulus. The height of the 18 layers residential building is close to 54 m. It adopts smoke-proof stairwells and is equipped with two elevators, one
is a fire elevator and the other is an elevator that can accommodate stretchers. The traffic core adopts 75M long and 60M wide modulus (Figure 9).

In addition to the setting of traffic cores and public corridors, this project also sets up some public shared spaces between floors. The functions of shared spaces include bookstores, coffee houses, gymnasiums, nursery rooms, audio-visual rooms and sun rooms (Figure 10). These spaces can promote residents’ communication, meet residents’ needs for public space, and further enhance residents’ happiness. In order to make the project more standardized, the modulus of the public shared space matches the modulus of the apartment, which are 30M long and 60M wide and 60M long and 60M wide. It is easy to combine with the suites and traffic cores to form an integrated, standardized, modular, less-specified, and more-combined residential unit system.

Figure 9. The traffic cores of Zhengzhou affordable housing project.

Figure 10. Shared spaces and their functions.

Based on the environment, site, climate, orientation, sunshine and setting requirements of this project, the suite types and the shared parts are combined to form T3 (222), which is three 2-4-person suite types, and T4 (2211), which is two 2-4-person suite types and two single-person suite types, T6 (222211), which is four 2-4-person suite types and two single-person suite types (Figure 11).
3.6. Further Evaluation of Green Building Technology

From the general layout of Zhengzhou prefabricated affordable housing project, it can be seen that there are 6 high-rise residential buildings in this project, 2 each of T3 (222), T4 (2211) and T6, of which T3 and T4 are both 11-storey buildings. T6 is an 18-story building (Figure 12).

Green building technology evaluation software is used for further evaluation of green building indicators such as lighting and ventilation of the 6 residential buildings obtained by arrangement and combination [10]. It can study whether the lighting and ventilation indicators of the buildings meet the green building design standards, and guide the further optimization design of the buildings under the requirements of the green building standards. This project has been further evaluated by green building technology, and all indicators can meet the requirements of green building evaluation standards (Figure 13).
4. Conclusions and Design Suggestions for Prefabricated Affordable Housing

4.1. Conclusion

The following conclusions can be drawn from the research on the modularization of Zhengzhou prefabricated affordable housing project. First, for the Zhengzhou prefabricated affordable housing project, 6000 mm (60M) as the basic suite model has strong adaptability and can meet the requirements of project design and related specifications. Second, for basic functional spaces such as bedrooms, bathrooms, living rooms and kitchens, choosing the basic modulus $M=100$ mm stipulated in the “Building Modular Coordination Standard” (GB/T 50002-2013) can satisfy the basic function of the design of the affordable housing. Third, the public part in the unit building is also one of the important factors affecting the modularization of residential design and its structural form. Therefore, when designing the modulus of public parts such as traffic cores and shared spaces between floors, it should be consistent with the model number of the suite as much as possible, or form a multiple or series relationship with the modulus of the suite types, so as to facilitate the combination of various parts. At the same time, it can solve the problems of difficult industrial production, low prefabrication rate and low assembly rate caused by various sizes and types.

4.2. Design Suggestions for Prefabricated Affordable Housing

Combined with the specific situation of Zhengzhou prefabricated affordable housing project, the following suggestions are put forward. First of all, in the context of the continuous deterioration of global energy and resources, the standardized design of prefabricated affordable housing should be combined with the concept of green buildings to maximize the purpose of saving resources, protecting the environment, reducing pollution, and promoting the design of prefabricated affordable housing enter a new stage of “standardization and green”. Secondly, modularization is the core of standardization. The main reasons for the low overall prefabrication rate, low assembly rate and poor market liquidity of prefabricated affordable housing projects in China are the lack of modularization concept and universal modular coordination system, therefore, adopting a unified modular coordination system in the design and formulating a general modular coordination standard is the only way to promote the standardization and industrialization of prefabricated affordable housing projects. Finally, the three theories of modularization, green building and prefabricated technology go hand in hand. The transformation around these three aspects has become the key point of the transformation of the construction industry. Green building technology provides technical support for environmental protection and sustainable development. Modularization is the core concept of the development of prefabricated affordable housing in the direction of intensification, standardization and industrialization. Prefabricated technology is an effective way to promote the transformation of traditional construction methods to intensive, green, environmental protection, technology and industrialization. The three jointly promote the standardization and sustainable development of prefabricated affordable housing construction.

To sum up, through the research on the modularization of Zhengzhou prefabricated affordable housing projects under the background of sustainable development, this paper proposes a complete modular system suitable for Zhengzhou prefabricated affordable
housing projects, and builds alternative modular house type library, in order to provide a reference for the development of prefabricated affordable housing.

References