Research on prefabricate-decoration integration technology based on prefabricated bathroom

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Abstract. According to the 14th Five-year Plan proposed in China, the development of green buildings is one of the most important measures to accelerate the promotion of green and low-carbon development. Prefabricated buildings have been widely promoted and applied in furnished apartments because of the high construction efficiency, energy saving and emission reduction. In order to solve the problem of the storey height wasting of the furnished apartment and the reasonable application of energy saving, this paper puts forward a new prefabricate-decoration integration technology based on the prefabricated bathroom, and realizes an integrated design of the components produced in the factory. The two-story structure on the basis of prefabricated bathroom is assembled in the form of furniture.

1. Introduction

According to the 14th Five-year Plan of China, the development of green buildings is an important measure to accelerate the promotion of green and low-carbon development. The industrial standardized production of prefabricated bathroom has developed rapidly with the blossom of prefabricated buildings, which is an important component of the prefabricated construction, widely used in hotels, schools, hospitals, residential areas. Prefabricated bathroom provides a professional, green, energy-saving and economic solution for prefabricated buildings in the aspect of bathroom [1-3]. For the decoration of traditional bathroom, a lot of cement, ceramic tile, and building glue, etc., need to be consumed. The production processes of these materials are energy intensive and highly pollutive. Sheet molding compound (SMC) used in the production of prefabricated bathroom [4, 5] is a new type of building materials. The manufacturing process has the advantages of simple operation and high automation. Therefore, prefabricated bathrooms in the production process can greatly reduce the use of traditional high energy consumption and high pollution materials with significant energy saving and emission reduction benefits [6, 7].

Prefabricated bathroom originated in Japan. In 1964, when the 18th Summer Olympic Games was held in Tokyo, Japan, Japanese invented the prefabricated bathroom that could be assembled on-site and used in the athletes' apartment [8]. In China, prefabricated bathroom develops late, appearing in China in the 1990s. Prefabricated bathroom is mainly used in hotels, guesthouses, hospitals, low-income housing and other buildings in China. It is rarely used in residential buildings and long-term rental buildings and still in the pilot application stage [9]. Hu [10] put forward her own views on how to make products popular among customers, developers, construction units and design units and how
to better select the appropriate prefabricated bathroom. Liu et al. [11] introduced the installation characteristics and quality control of prefabricated bathroom and expounded the factors affecting prefabricated bathroom in residential buildings. Wu et al. [12] compared the construction process between prefabricated bathroom and the traditional bathroom and summarized the construction process characteristics of the prefabricated bathroom. Recognizing the existing problems and deficiencies of domestic residential buildings, Guo [13] pointed out that prefabricated bathroom should follow the sustainable development and predicted the trend of future development. Gao and Yao [14, 15] not only analyzed the product integration of the fully decorated house in combination with the construction mode vigorously in China, but also discussed prefabricated design method of the kitchen and bathroom. However, most of the existing studies are limited to the design methods of prefabricated bathroom. Guo et al. [13] proposed that kitchen and bathroom should be designed as a whole structure. However, very few people had designed prefabricated bathroom and building (especially the furnished apartment) as a whole structure.

However, the unit type, construction conditions and government policies make it difficult to fully utilize the second-floor space of the apartment despite the generous usable floor height. This paper proposes a prefabricate-decoration integration technology (as shown in Figures 1-3) for a usable second floor above the prefabricated bathroom. This technology can increase the usable floor area of the apartment and reduce the waste of resources to a large extend. Meanwhile, it offers a good solution to solve the above problem. A new node design is proposed to ensure the safety and reliability of the structure. This paper simulates and analyzes the safety and reliability of the whole structure by using ABAQUS (a finite element analysis software). The safety and reliability of the structure is verified by comparing the ultimate strain with the calculated value of the maximum deflection in the code and comparing ultimate stress with ultimate strength of the supports.

**Figure 1.** Schematic diagram of prefabricate-decoration integration model.

**Figure 2.** 3D model drawing of prefabricate-decoration.

**Figure 3.** Physical drawing of prefabricate-decoration.
2. The conception of prefabricate-decoration integration

Prefabricated building includes a design, production, construction, decoration and management. It has relatively significant integrated features and the characteristics of the new-type industrialization. It needs to adopt the construction of the integrated model and realize the integration and efficient utilization of information in the process of project implementation to achieve the goal of improving value [16]. The prefabricate-decoration integration technology proposed in this paper refers to the whole process of design, production, construction and management connected by Building Information Modeling (BIM) technology. In order to solve the problem of the height wasting of the furnished apartment, the whole bathroom is used as the main support to add a second story space, and the furniture such as stairs and cabinets is designed as the auxiliary supports. Company can design, select materials, produce and install differently according to specific furnished apartment type. At the same time, they also provide the stairs, wall cabinet, wash basin, toilet and other necessary furniture to realize the integration and efficient utilization of the information in the process of project implementation so as to achieve the purpose of saving resources and green environmental protection.

3. The main technical points

3.1. Ensemble structural design

This paper takes a furnished apartment (plane size is 7400mm×3400mm and 3765mm in height) as an example to design an integrated structure of prefabricated bathroom and the interlayer based on the existing prefabricated bathroom. Firstly, CAD (plane design software) is used to design plane and elevation. The main way to increase space usage based on ensuring accord with ergonomics is through the reasonable design of a series of facilities such as toilet, tea room, stair and wall ark. In this example, the area of the prefabricated bathroom is 1900 mm × 1500 mm, and the height is 1900 mm. A staircase is set opposite the bathroom door to the second floor, and a storage locker is located under the staircase, which can increase the actual usable area. The corridor is 1100 mm in the middle. A tea room is set next to the prefabricated bathroom, with a U-shaped bar counter. The rest area is used as a living room. The interlayer is 1570 mm in height. Furniture such as bed and chest of drawers can be placed on the interlayer (details are shown in Figures 4-6). Moreover, SOLIDWORKS (3D modeling software) is used to conduct solid three-dimensional model, which was evaluated from the perspective of aesthetics and economic practicability. After that, the final scheme was determined.

Figure 4. Schematic diagram of ground floor plane design.
3.2. Node connection design

The interlayer is built on the prefabricated bathroom. It is vital to consider the connection of prefabricated bathroom and the interlayer. It requires not only safety and aesthetics, but also the convenience. The connection design of the node should ensure that the structure can bear enough load and bending moment. The joint design should avoid on-site welding, wet operation, on-site cutting, on-site opening groove and meet the requirements of large-scale production, easy transportation and on-site assembly. Based on the above requirements, this paper proposes a new type of node connection. The interlayer is connected with the prefabricated bathroom through the U-shaped keel. The U-shaped keel and the middle keel are welded in advance in the factory (as shown in Figure 7). This connection
can be assembled on site, avoiding directly cutting hole, welding and wet operations. It can reduce the dust, noise and carbon emissions so as to achieve the purpose of environmental protection and green energy saving.

![Schematic diagram of structural connection between the prefabricated bathroom and the interlayer.](image)

**Figure 7.** Schematic diagram of structural connection between the prefabricated bathroom and the interlayer.

### 3.3. Structural safety analysis

In this paper, ABAQUS is used to establish the prefabricate-decoration integration product model. The model includes a prefabricated bathroom and an interlayer. Prefabricated bathroom bottom is evenly supported by 16 galvanized iron I-supports and uses keel to connect them as a whole structure, supporting the whole structure. Because the real model requires many parts and the modeling process is cumbersome and complex, this paper simplifies the product model. Wallboard, keel and base are only kept as the main supports. The interlayer floor and prefabricated bathroom floor are loaded and simulated. Some parts are imported through SOLIDWORKS and some parts that have little influence on the calculation results such as round holes and rounded corners are ignored. After the loading process, the changes of stress and strain are analyzed to find out the weak or vulnerable parts of the product. All the components in the model are deformable entities and are divided into 692,740 units. The established finite element model is shown in Figure 8.

![The model of prefabricate-decoration integration structure in ABAQUS.](image)

**Figure 8.** The model of prefabricate-decoration integration structure in ABAQUS.

In order to improve the meshes’ quality and avoid calculation error, irregular parts are divided manually. Most of the meshes are symmetrical and uniform hexahedron. For the main stress...
components, the mesh density of the keel are set at 5 mm. The mesh density of the wall panel is set at 20 mm. The mesh density of the roof and floor is set at 50mm. Considering that the distortion of the product is small and there is more contact between the components, the choice of non-conforming finite element model for discrete can overcome the problem of shearing self-locking well and have a high computational accuracy. The base geometry is complex, and the meshes are set into cubes of 5.3 mm size. The diagram of final mesh is shown in Figure 9.

![Diagram of mesh division of the model in ABAQUS.](image)

Figure 9. Diagram of mesh division of the model in ABAQUS.

According to the actual situation that the product is placed in the house type, the base and the bottom surface of the support rod are completely consolidated. Only the degree of freedom in the Z direction is limited only. The load can be approximated as static because there are only human activities on the interlayer. The method of calculation simulation is chosen as static analysis. The interlayer needs to hold some weight, including a bed of 1800 mm×2000 mm, 2 groups of nightstands, general necessary bedding, one group of panel wardrobe of 1500mm×2000mm×600 mm and more than 10 adults. A uniform load of 4000Pa was applied to the bed placement, and a load of 3000Pa was applied to the rest of the space and the floor. The value of the load is conservative and can be used to test the bearing capacity of the product.

After the finite element simulation calculation (strain diagram shown in Figure 10, strain diagram shown in Figure 11), the maximum strain is 4.01 mm and the maximum stress of 643.1 MPa appears in the middle support at the bottom. The ultimate strength of galvanized iron support is 640 MPa. Considering that the load is conservative and the modeling of the bottom support is simplified, the actual stress value will be less than the simulation value. Though the maximum stress and the ultimate strength are similar, the correct conclusion that the structure is safe and reliable can be drawn. As for the strain, most of the other parts are about 2 mm, which meet the design requirements. According to the Code for Design of Concrete Structures (GB 50010-2010), when the span of flexural member does not exceed 7m, the calculation formula of the deflection limit is as follows.

\[
\omega = \frac{l_0}{200}
\]

where \(\omega\) denotes the deflection limit of bending member; \(l_0\) denotes the span of the flexural member.

In this paper, the minimum span of the interlayer of the model is 800 mm and the ultimate deflection can be obtained as 4mm from Equation (1). In the finite element analysis model shown in Figure 8, the deflection of the plate is 4.01mm, which is close to the standard value. The maximum strain position is located at the connection between the stairs and the interlayer and the actual load will be less than 3000Pa. In the actual production process, the lower part of the stair will not be supported by baffles, so the actual deflection will be far less than the simulation value. Consequently, the security and reliability of this structure have been well verified.
4. Discussion
With the development of construction industrialization, people have higher and higher requirements for buildings, which not only requires buildings to have more functions, but also pay more attention to green energy conservation. To start with, the prefabricated-decoration integration technology proposed in this paper eliminates on-site welding, on-site coating, on-site cutting and on-site grooving. Carbon emissions, noise, dust, the trash of formwork and other pollution are reduced in the construction process [17, 18] when comparing prefabricate-decoration integration structure and cast-in-place concrete buildings [19]. Moreover, the prefabricated bathroom is independent of the main structure. And the installation space of water, electricity and equipment is required between the building wall, floor and ceiling, which reduces the actual use space [20]. Prefabricate-decoration integration structure increases the usable area of the whole furnished apartment and solves the problem of height waste. Then, prefabricated buildings have the advantage of labor saving, but the prefabricate-
decoration integration technology saves labor to a greater extent. The complete assembly only takes about 4 hours for two skilled workers to complete [21-22]. Finally, the parts of the prefabricate-decoration integration structure are all produced by the same company and installed by technicians from the same company, which not only provides technical support, but also maximizes the use of resources. Therefore, this technology is in conformity with the concept of green development and should be widely developed.

5. Conclusions
The prefabricate-decoration integration technology has vigorously developed the building, innovated the energy use in building and helped to achieve the goal of "carbon neutral" and "carbon peak" in the building field. Based on the previous analysis, the following conclusions can be drawn:

(1) Prefabricate-decoration integration technology can solve the problem of height waste of furnished apartment well and increase the usable area.

(2) Through the finite element simulation, the maximum strain of the structure is close to the maximum deflection in the code under the action of conservative load, which is safe and reliable.

(3) Prefabricate-decoration integration technology eliminates on-site welding, on-site coasting, on-site cutting and on-site grooving and realizes the goal of low carbon environmental protection and energy saving.

(4) It only takes about 4 hours for two skilled workers to complete the whole structure and the parts are produced by the same company, which greatly saves the labor cost and economic cost.

References
[1] Zhai G B 2018 Analysis of the application prospect of the prefabricated bathroom in the prefabricated building in China J. Tianjin Construction Technology 28 32-35
[2] Wei S W and Miao Q 2019 Practice and Thinking of prefabricated type interior decoration -- key points of prefabricated bathroom design and application J. City Housing 26 117-121
[3] Liu B, Zhang T Y, Zhang T, Tian X, Wang C X and Zhao X Y 2020 The development and application of prefabricated bathroom in the industrialized design of residential buildings J. Sichuan Building Materials 46 25-26
[4] Zhang Z J, Wang W, Yang Y, Liu Y, Fei Q F, Ye F L, Zhang Y Q and Wang Q 2015 Development progress of SMC untwisted roving for prefabricated bathroom J. Glass Fiber 1 12-14
[5] Qiao C Z and Pan Q 2021 Research on production energy consumption and carbon emission of SMC components of prefabricated bathroom J. Energy Conservation 40 5-8
[6] Liu M X, Cao Y J and Wang J N 2012 Analysis of energy saving and emission reduction benefits of prefabricated bathroom J. China Engineering Consulting 11 70-73
[7] Abey S T and Anand K B 2019 Embodied Energy Comparison of Prefabricated and Conventional Building Construction J. The Institution of Engineers (India): Series A 100 777-790
[8] Lv Y 2020 Application of prefabricated bathroom in rental housing J. Housing Technology 40 70-72+77.
[9] Ding L S 2019 Study on the design of prefabricated bathroom in the renovation of centralized long-term rental apartments Beijing: Beijing Jiaotong University
[10] Hu H Q 2014 Industrialization of new interior decoration and development of housing industrialization J. Architectural Journal 7 59-61
[11] Liu H S and Guan X J 2014 The development prospects, advantages and disadvantages of the prefabricated bathroom and the existing problems of residential building applications J. Journal of Qingdao University of Technology 35 93-96
[12] Wu S G and Ding J C 2014 Analysis on the domestic application prospects of the prefabricated bathroom in the prefabricated concrete residence J. Construction 36 201-203
[13] Guo L J 2010 Research on the Design Method of Industrialized Products of prefabricated
bathroom[D]. Tianjin University
[14] Gao Y 2006 Housing industrialization—research on integration technology and strategy of housing parts system[D]. Tongji University
[15] Yao K 2013 Research on the application of integrated kitchens and bathrooms in the industrialization of residential interiors[D]. Yanshan University
[16] Li Y H, Ma Y M, Geng Y L and Song R 2020 Analysis on the application of prefabricated bathroom in prefabricated building J. Residence 4 53-54
[17] Zhang X X 2019 Research on the ageing renovation of existing residential bathroom space under the system of building industrialization[D]. Beijing University of Civil Engineering and Architecture
[18] Chen L 2019 Analysis on the use of key modules in prefabricated interior J. Green Building 11 63-65
[19] Yu S S, et al. 2021 Review of thermal and environmental performance of prefabricated buildings: Implications to emission reductions in China J. Renewable and Sustainable Energy Reviews 137
[20] Liu S Y, Pan Y R and Deng X 2018 Development status and existing problems of prefabricated bathroom under the background of housing industrialization J. Sichuan Building Science Research 44 122-127
[21] Zhang X X 2018 Application and research of prefabricated bathroom in interior industrialization J. Architectural Engineering Technology and Design 29 3756
[22] Cheng D Y 2021 Technical analysis of design and construction integration of prefabricated buildings J. Architectural Engineering Technology and Design 7 764