

Research on Modular Design, Production, and Construction Integration of Municipal Prefabricated Bathroom Stations

Qiang Huang*

Shenzhen 518000, China

**Author to whom correspondence should be addressed.*

Copyright: © 2025 Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), permitting distribution and reproduction in any medium, provided the original work is cited.

Abstract: This article focuses on the municipal prefabricated bathroom station. It elaborates on its modular design concept, including key design points such as spatial layout, functional modules, and determination of key parameters; introduces the optimization of intelligent production processes, precision control, and integration of construction technology, and also mentions the verification of full lifecycle applications and quality control; as well as emphasizes the importance of BIM + IoT platform and looks forward to the future.

Keywords: Municipal prefabricated; Bathroom station; Modular design

Online publication: October 10, 2025

1. Introduction

With the acceleration of urbanization, the demand for municipal infrastructure construction continues to increase. The *Guiding Opinions on Promoting the Coordinated Development of Intelligent Construction and Building Industrialization*, issued by China in 2020, emphasized the importance of building industrialization and the application of intelligent technology in it. As a part of urban infrastructure, the design and construction of municipal prefabricated bathroom stations have received widespread attention. This study focuses on the municipal prefabricated bathroom stations, starting from the modular design concept, exploring key design parameter determination, intelligent production process optimization, precision control, construction technology integration, and full lifecycle application verification, aiming to improve its design efficiency, production quality, construction accuracy, and operation and maintenance management level to meet the needs of urban development and provide better public service facilities for urban residents.

2. Construction of a modular design system

2.1. Modular design concept

The modular design concept is the core guiding principle for the design of municipal prefabricated bathroom

stations. It emphasizes the decomposition of the overall space into multiple modules with specific functions, which are both independent of each other and can be organically combined to meet different scenarios and user needs. By standardizing the spatial layout design, the overall structure of the bathroom station and the size and location of each functional area are consistent and standardized, improving design efficiency and replicability. The universal design of functional modules emphasizes the universality and interchangeability of modules, ensuring that modules with similar functions in different projects can be used interchangeably and reducing production costs. At the same time, the integration of ergonomic design points makes each module more in line with the physiological and psychological needs of the human body, improving user comfort and satisfaction ^[1]. Combining BIM technology to establish a parametric model library, further optimizing module design and assembly processes, and achieving visualization and precision in design.

2.2. Determination of key design parameters

The determination of key design parameters is crucial in the modular design of municipal prefabricated bathroom stations. For structural systems, it is necessary to consider load combination conditions for optimized design. Different usage scenarios and geographical locations can lead to varying load situations. By accurately analyzing various possible load combinations, such as live loads, wind loads, snow loads, etc., the bearing capacity and stability requirements of the structure can be reasonably determined. Research on integrated design methods is crucial in the areas of water supply, drainage, and electrical systems. It is necessary to clarify the connection methods and technical parameters between each component to ensure the efficient operation of the system. For example, the diameter and slope of water supply and drainage pipelines, as well as the voltage, current, and other parameters of electrical circuits, need to be accurately determined based on the actual needs of the station and the design of the module. At the same time, the clarification of standardized interface technical parameters for components is also an important part of achieving modular design, which ensures accurate connection and collaborative work between different modules ^[2].

3. Intelligent production process optimization

3.1. Construction of an intelligent manufacturing system

The development of a material management system based on the BOM list is the key to the construction of an intelligent manufacturing system in the optimization of the intelligent production process. In the selection of automated cutting equipment, it is necessary to comprehensively consider factors such as cutting accuracy, efficiency, and material adaptability to ensure that the high-quality requirements for the production of prefabricated bathroom stations are met. The modular mold matching scheme should be designed based on the standard modules of the product to improve the universality and reusability of the mold and reduce production costs ^[3]. The configuration of welding robot workstations should be based on the characteristics of production processes and welding tasks, and the number, model, and working parameters of robots should be reasonably determined to ensure the stability and consistency of welding quality, and to improve overall production efficiency and product quality.

3.2. Research on precision control technology

Establishing a critical dimension tolerance allocation model is an important foundation for precision control. By analyzing the dimensions of each module in the prefabricated bathroom relay station, considering the accumulation of errors in manufacturing and assembly processes, a reasonable allocation of tolerances is necessary to ensure the matching accuracy of each component during assembly ^[4]. The proposal of temperature deformation

compensation technology is aimed at the influence of different environmental temperatures on materials and component dimensions. Study the temperature change law and adopt appropriate compensation methods, such as reserving expansion space or using temperature-adaptive materials, to reduce dimensional deviations caused by temperature changes. The development of a pre-assembly testing process allows for the pre-assembly of modules before formal assembly, promptly identifying and correcting issues such as dimensional discrepancies. At the same time, establish packaging protection standards for modular components to prevent component deformation caused by collisions, squeezing, etc., during transportation and storage, which may affect assembly accuracy.

4. Integrated assembly construction technology

4.1. Innovation in construction organization and management

4.1.1. Three-dimensional site layout technology

In the municipal prefabricated bathroom station project, three-dimensional site layout technology is crucial. The application of BIM + GIS technology enables precise modeling and analysis of construction sites. Through construction simulation, potential issues that may arise during the construction process can be understood in advance, such as unreasonable use of site space and obstruction of module transportation. At the same time, based on the simulation results, module transportation path planning is formulated to ensure efficient and safe transportation process, and avoid interference with the surrounding environment ^[5]. In addition, it is necessary to establish standards for site handover and acceptance, clarify the requirements for indicators such as site flatness and bearing capacity, and provide a good foundation for the installation of modular bathroom stations to ensure construction quality and progress.

4.1.2. Rapid assembly process development

In the integration of prefabricated construction technology, it is necessary to innovate construction organization management and develop rapid assembly processes. It is crucial to innovate the modular unit lifting timing control method for municipal prefabricated bathroom stations. By accurately planning the lifting sequence, construction efficiency can be improved, and construction time and costs can be reduced ^[6]. Meanwhile, the development of new node connection devices is a crucial step. This device should exhibit characteristics such as high strength, reliability, and ease of installation to ensure the stability and safety of the bathroom station structure. In addition, a construction quality control system should be established to strictly control the quality of node connections, including connection processes, material quality testing, etc., in order to ensure the quality and performance of the entire prefabricated bathroom station.

4.2. On-site integrated installation system

4.2.1. Comprehensive pipeline installation technology

Establishing a construction process for separating mechanical and electrical pipelines from structural bodies is the key to comprehensive pipeline installation technology. This process can prevent mutual interference between pipelines and structures in traditional construction and improve construction efficiency and quality ^[7]. The development of prefabricated support and hanger systems has further optimized pipeline installation. It is characterized by standardization and modularization, which can quickly and accurately install pipelines, and is easy to maintain and adjust in the later stage. Meanwhile, concealed engineering detection technology is also crucial. Through advanced detection technology, problems in concealed engineering can be detected in a timely manner, such as whether the connections of pipelines are tight, whether the installation of supports and hangers is firm, etc., ensuring the reliability and safety of the entire pipeline installation project.

4.2.2. Reserved intelligent operation and maintenance interface

In the on-site integrated installation system of prefabricated construction technology integration, the reservation of intelligent operation and maintenance interfaces is crucial. The reasonable arrangement of embedded parts for intelligent monitoring systems should be considered, which needs to be combined with the actual usage needs and functional zoning of bathroom stations to determine the optimal location of sensors and other monitoring equipment, in order to accurately obtain relevant data ^[8]. At the same time, standardized design specifications for equipment maintenance ports should be established, and the size, position, and opening method of the maintenance ports should be standardized to facilitate later equipment maintenance and repair. This can not only improve operation and maintenance efficiency but also reduce costs, ensuring that prefabricated bathroom stations maintain good performance and functionality during long-term use.

5. Full lifecycle application verification

5.1. Application analysis of demonstration projects

5.1.1. Typical project construction cases

In the study of municipal prefabricated bathroom stations, three types of municipal scenario demonstration projects were selected for analysis. By comparing the adaptability parameters of the site in different scenarios, it was found that there are differences in spatial utilization and integration with the surrounding environment. Meanwhile, research has been conducted on the optimization effect of the construction cycle, and the results show that the integration of prefabricated design and construction significantly shortens the construction cycle. For example, in a bustling commercial street scene with limited space and strict requirements for construction time, the prefabricated bathroom station was quickly assembled through reasonable module design, reducing the impact on surrounding commercial activities ^[9]. In the park setting, it better adapts to the natural environment, complements the landscape, and the construction process is efficient, further verifying the advantages of this integrated model in different municipal scenarios.

5.1.2. Full process benefit evaluation

Establish a comprehensive evaluation index system that includes carbon emissions, cost savings rate, and failure repair rate, and conduct a full process benefit evaluation of municipal prefabricated bathroom stations. The carbon emission index can measure its impact on the environment, reflected in the greenhouse gas emissions during material production, transportation, construction, and use ^[10]. The cost-saving rate reflects the economic advantages of modular integrated design, production, and construction compared to traditional methods, including savings in material costs, labor costs, and time costs. The failure repair rate is related to product quality and later maintenance costs, and a lower failure repair rate means higher reliability and durability. By comprehensively evaluating these indicators, we can gain a comprehensive understanding of the performance benefits of municipal prefabricated bathroom stations throughout their entire lifecycle, providing a basis for their further promotion and optimization.

5.2. Construction of key parameter database

5.2.1. Standardized component data module

The full lifecycle application verification requires the construction of a key parameter database and a standardized component data module. The formation of the standardized parameter table for size modulus serialization is the foundation, which should cover the key size parameters of various components of municipal prefabricated bathroom stations, ensuring compatibility and universality between different components. At the same time,

establish component attribute coding rules to assign unique identity identifiers to each component, facilitating precise management by the information management platform. This information management platform integrates various attribute information of components, including design parameters, production processes, construction requirements, etc., to achieve data traceability and collaborative management of the entire process from design to construction, improve the efficiency and quality of the entire project, and provide strong support for the modular design, production, and construction integration of municipal prefabricated bathroom stations.

5.2.2. Construction deviation warning model

In the full lifecycle application verification, the construction of key parameter databases and construction deviation warning models is crucial. For the key parameter database, it is necessary to collect key data covering all stages of design, production, and construction, including material characteristics, component dimensions, installation requirements, etc. At the same time, it is necessary to ensure the accuracy and completeness of the data in order to provide a reliable basis for subsequent analysis.

Develop a machine learning-based 3D scanning deviation recognition algorithm for construction deviation warning models. Utilize 3D scanning technology to obtain actual data from the construction site, analyze the data through algorithms, and identify deviations from design standards. On this basis, an error accumulation propagation prediction model is constructed, considering the transmission and accumulation effects of errors during the construction process, to predict possible large deviations in advance, and take timely measures to adjust, ensuring the construction quality and accuracy of prefabricated bathroom stations.

5.3. Innovation of standardized management mechanism

5.3.1. PDCA quality control cycle

In the municipal prefabricated bathroom station project, the PDCA quality control cycle runs through the entire process. In the Plan phase, a detailed quality plan is developed based on project requirements, clarifying quality objectives and key control points for each stage of design, production, and construction. During the Do phase, design, production, and construction activities are carried out according to the established plan to ensure that each link meets quality requirements. During the Check phase, establish a three-stage quality traceability mechanism for design–production–construction, rigorously inspect key processes, and refer to the established visual acceptance standards for key processes to promptly identify quality issues. In the Act stage, effective measures are taken to address the identified issues, lessons learned are summarized, successful experiences are incorporated into standards and systems, deficiencies are improved, and reference is provided for subsequent projects to achieve continuous improvement in quality.

5.3.2. Development of a collaborative management platform

Building a multi-party collaborative work platform combining BIM and Internet of Things is the key to achieving full lifecycle management of municipal prefabricated bathroom stations. This platform integrates data from various stages of design, production, and construction, and provides accurate 3D models through BIM technology to visually display component information and assembly processes. The IoT technology enables real-time monitoring of component production, transportation, and on-site construction status. At the same time, the integrated quality traceability QR code system assigns a unique identification to each component. By scanning the QR code, users can obtain all information about components from raw material procurement to installation completion, including quality inspection reports, production batches, installation personnel, etc., ensuring quality traceability, improving standardized management level, and promoting efficient collaboration among all parties involved.

6. Conclusion

This study comprehensively explored the municipal prefabricated bathroom relay station. In terms of modular design, innovation has been achieved, optimizing space utilization and functional layout. Breakthroughs have been made in intelligent production technology, which has improved production efficiency and quality. The prefabricated construction process has been optimized, shortening the construction period and reducing the amount of on-site work. At the same time, the development direction of the operation and maintenance management system based on digital twin technology is proposed, which will provide more efficient and accurate support for later maintenance and management. Looking ahead to the future, modular buildings have broad prospects for promotion and application in the construction of new urbanization. They can meet the needs of rapid construction, energy conservation, and environmental protection, improve the level and quality of urban infrastructure construction, and provide more convenient and comfortable public service facilities.

Disclosure statement

The author declares no conflict of interest.

References

- [1] Smith RE, 2010, *Prefab Architecture: A Guide to Modular Design and Construction*, John Wiley & Sons.
- [2] Shroff DN, Joshi AT, 2022, *Pre-Fabricated Architecture for Urban Adaptability: Factory Built Constructions—Sustainable & Flexible Urban Solutions*, dissertation, Politecnico di Torino.
- [3] Tembhurkar S, Ralegaonkar R, Azevedo A, et al., 2022, Low Cost Geopolymer Modular Toilet Unit for ODF India—A Case Study. *Case Studies in Construction Materials*, 16: e00937.
- [4] Lawson M, Ogden R, Goodier CI, 2014, *Design in Modular Construction*, CRC Press, Boca Raton, FL.
- [5] Vaz-Serra P, Wasim M, Egglestone S, 2021, Design for Manufacture and Assembly: A Case Study for a Prefabricated Bathroom Wet Wall Panel. *Journal of Building Engineering*, 44: 102849.
- [6] Zhou JX, Shen GQ, Yoon SH, et al., 2021, Customization of On-Site Assembly Services by Integrating the Internet of Things and BIM Technologies in Modular Integrated Construction. *Automation in Construction*, 126: 103663.
- [7] Boafu FE, Kim JH, Kim JT, 2016, Performance of Modular Prefabricated Architecture: Case Study-Based Review and Future Pathways. *Sustainability*, 8(6): 558.
- [8] Issabayev G, Slyambayeva A, Kelemeshev A, et al., 2022, Development of the Project of Modular Prefabricated Buildings. *EUREKA: Physics and Engineering*, (4): 36–45.
- [9] Lacey AW, Chen W, Hao H, et al., 2018, Structural Response of Modular Buildings—An Overview. *Journal of Building Engineering*, 16: 45–56.
- [10] Jiang Y, Zhao D, Wang D, et al., 2019, Sustainable Performance of Buildings Through Modular Prefabrication in the Construction Phase: A Comparative Study. *Sustainability*, 11(20): 5658.

Publisher's note

Bio-Byword Scientific Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.