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# Modular Prefabricated Assembly Technology and Its Application in Cruise Ship Interior Decoration

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**Abstract:** ***In the context of China's large cruise independent construction achieving major breakthroughs with the delivery of "Adora Magic City," cruise interior outfitting—the most complex high-end marine equipment—faces challenges from traditional on-site construction. This study systematically explores modular prefabrication assembly technology for cruise interiors, constructing a framework covering digital driving, standardized design, factory pre-outfitting, precision hoisting and lifecycle management. Based on domestic cruise construction data, it analyzes key technologies including BIM digital twin, standardized interfaces, assembly line production and on-site positioning, revealing coupling with customized design. Results show modular technology reduces single cabin installation from 200 to under 50 hours, shortens outfitting by over 8 months, significantly improving quality and cost control, providing theoretical and practical support for China's cruise batch construction and high-end marine equipment competitiveness.***

**Keywords:** Cruise interior outfitting, Modular prefabrication assembly, Prefabricated modular cabin unit, BIM digital twin, Industrialized construction, Large cruise independent construction, Full lifecycle management.

## 1. Foreword

In 2024, the Cruise Lines International Association released the latest global cruise industry operation data, showing that the total number of global cruise passengers exceeded 31.5 million, and the market scale recovered to 92% of the pre-pandemic level in 2019, driving the global new cruise construction market to maintain a sustained high prosperity. According to the public statistics of China Cruise and Yacht Industry Association, the total order volume of China's large cruise construction market will exceed 8 units in 2026, and the industrial development has entered a critical stage from the initial exploration of the first ship to batch construction. Cruise interior outfitting, which accounts for more than 60% of the total construction workload of the whole cruise ship, is the most critical and complex link restricting the construction cycle and product quality of large cruise ships. Different from the interior decoration of ordinary land buildings and the outfitting of traditional merchant ships, the cruise interior system covers more than 20 million various components, and all materials and processes must strictly meet the international SOLAS convention A-60 fire protection standards, IMO noise control regulations, USPHS health and epidemic prevention specifications and a series of extremely stringent mandatory requirements. The traditional scattered on-site operation mode, which relies on a large number of workers carrying out cross-process construction in the narrow space of the hull, has a series of inherent defects such as serious process interference, difficult to guarantee construction quality, long cycle and difficult to control safety risks, which has long been unable to adapt to the development needs of modern large cruise high-efficiency construction. Modular prefabrication assembly technology came into being under this background, and has gradually become the core key technology that the world's top cruise ship represented by Italy Fincantieri and Germany Meyer Werft must adopt in the construction process.

As early as the 1970s, the idea of prefabricated modular interior unit originated from the construction practice of high-rise buildings in Europe. British architect Richard Rogers first applied the standard prefabricated bathroom unit technology in the design and construction of Lloyds Building in London. The bathroom unit was assembled in the factory in advance, and then hoisted to the corresponding position of the building and fixed on the structure with bolts. This technological innovation completely broke through the limitation of on-site wet operation in traditional architectural decoration, and greatly improved the construction efficiency and quality stability. This advanced prefabrication concept was quickly introduced into the field of high-end passenger ship construction, and gradually evolved into the Prefabricated Modular Cabin Unit technology specially for the interior outfitting of large cruise ships after decades of iterative optimization, which is abbreviated as PMCU system in the industry. Before the large-scale popularization of this technology, the interior outfitting of cruise ships almost completely adopted the same on-site decoration process as land hotels. After the main hull structure was closed, a large number of decoration workers entered the interior space of the hull to carry out sequential operations from pipelines, decoration to furniture installation. This mode requires hundreds of thousands of man-hours of on-site work, and the construction cycle of a single large cruise ship often takes more than 18 months, and the quality consistency of on-site construction is difficult to guarantee. Once the process arrangement is slightly improper, it is easy to cause cross-operation conflicts, rework and other problems, resulting in serious delay of the whole ship construction cycle.

China's independent construction of large cruise ships started late, and there was a long-term technical gap in the field of modular interior outfitting. It was not until the construction process of the first domestically built large cruise ship "Adora Magic City" that China completed the systematic research and full-process engineering verification of modular prefabrication assembly technology for cruise interior outfitting for the first time, and achieved a series of landmark technological breakthroughs. According to the public operation data released by the construction party of the second domestic large cruise ship “Adora Magic City”, after the full application of the modular prefabrication assembly technology system that has been iterated and optimized on the basis of the experience of the first ship, the single cabin installation man-hours have been reduced from the average 200 hours of the first ship to less than 50 hours, and the total interior outfitting cycle of the whole ship has been shortened by about 8 months compared with the first ship, which fully proves the huge technical advantages of this technology. At the policy level, the “14th Five-Year Plan for High-Quality Development of Marine Equipment Manufacturing” issued by the Ministry of Industry and Information Technology of China clearly takes the modular construction technology of large cruise interior outfitting as the core key supporting technology to be focused on, pointing out the clear direction for the subsequent batch construction of domestic large cruise ships.

At present, most of the relevant domestic studies only focus on the partial process optimization of modular prefabrication technology, and have not yet constructed a complete systematic analysis framework covering the whole chain of design, manufacturing, hoisting and operation. There is still a lack of in-depth theoretical summary and practical induction of the practical experience accumulated in the construction process of domestic large cruise ships in recent years. This study breaks through the previous limitation of only discussing modular technology at the level of engineering process, systematically sorts out the complete technical system and application logic of modular prefabrication assembly technology for cruise interior outfitting, and deeply discusses the coordinated balance mechanism between modular standardized production and differentiated customized design, which fills the research gap in the related field of domestic cruise interior outfitting engineering. The research conclusions of this paper can provide actionable technical guidance for China’s subsequent large cruise batch construction projects, help the industry to further reduce the construction cost, shorten the construction cycle, improve the product quality, and support China’s cruise manufacturing industry to accelerate the pace of catching up with the world’s top level.

## 2. The Core Connotation and Technical Characteristics of Cruise Interior Outfitting Modular Prefabrication Assembly Technology

Modular prefabrication assembly technology for cruise interior outfitting is not a simple splicing of prefabricated parts in the general sense, but a systematic, standardized and digital integrated construction mode for the complex space system of cruise ships. Its core idea is to separate all the interior space functions of the cruise ship from the main hull structure in the design stage, divide them into relatively independent standardized functional modules, and complete more than 90% of all the assembly, debugging and testing work of these modules in the professional factory production line far away from the narrow construction site of the shipyard, and then transport the prefabricated modules that have been fully tested to the shipyard for overall hoisting and precise butt joint with the main hull structure. This technical mode completely subverts the traditional interior outfitting logic that sequentially carries out operations on the ship after the main hull is closed, and transforms the highly complex on-site cross-operation into a standardized assembly line manufacturing process that can be precisely controlled in the factory, which is a revolutionary innovation in the field of modern ship outfitting engineering.

The first core technical feature of this technology is the deep integration of standardized design and customized compatibility. The dimensions, interfaces and core functional parameters of all interior modules must follow the unified industrial standards of the whole ship, which ensures the interchangeability and universality between modules. For example, the width of the passenger cabin module must be precisely matched with the spacing of the hull ribs, so as to realize the zero-gap precise butt joint after hoisting in place, which can effectively avoid the on-site cutting and rework caused by the size mismatch. At the same time, the decorative style, furniture configuration and interior layout inside the module can be flexibly adjusted according to the specific positioning requirements of different shipowners and different itineraries, realizing the highly flexible combination mode of “standard main body module + personalized decorative facade”. This design idea perfectly solves the long-standing contradiction between the personalized customization needs of cruise products and the large-scale batch manufacturing demand, so that the cruise ship with highly differentiated interior style can also enjoy the cost advantage brought by mass production on the premise of ensuring the standardized main structure. Even for the same type of main cruise platform, the interior modules of different decorative styles can be quickly replaced through the standardized interface system, and quickly transformed into cruise products adapted to different route characteristics such as East Asian cultural circle, Caribbean leisure, Northern Europe exploration, etc, which greatly improves the flexibility of cruise product development.

The second core technical feature is a high degree of integrated pre-outfitting. A complete prefabricated interior module has completed more than 90% of all the workload before leaving the factory. It not only includes the basic structural engineering of the compartment wall, ceiling and floor assembly, but also completes the laying and connection of all electromechanical systems such as strong and weak current pipelines, ventilation ducts, water supply and drainage pipelines, and even the decorative engineering such as wall, floor and ceiling decorative materials pasting, as well as the fixed installation and debugging of all furniture and equipment such as beds, wardrobes, desks, sanitary units, lamps and switch panels. More importantly, all systems inside the module have completed the full-function test before leaving the factory, including power test of all electrical equipment, water pressure test of water supply and drainage system, ventilation effect test of air conditioning system, etc, to ensure that each independent module is a fully functional and qualified complete functional unit when it leaves the factory. This high degree of pre-outfitting means that after the module is hoisted to the designated position of the hull, only the reserved standardized quick connection interface needs to be connected with the main pipeline system of the hull, which can basically complete the delivery of the whole functional space, avoiding a large number of scattered complex operations on the ship.

The third core technical feature is the whole process digital driving based on BIM technology. The whole modular prefabrication assembly system can not operate without the support of building information modeling technology. In the initial design stage, the engineering team constructs the full ship digital twin body through three-dimensional modeling software, accurately plans the spatial position, interface parameters and hoisting path of each module, and through the virtual collision detection of the digital model in advance, finds and solves all pipeline conflicts and spatial interference problems inside the module and between adjacent modules, so as to avoid the huge loss of rework in the subsequent manufacturing stage. In the manufacturing stage, the digital model directly guides the factory's numerical control cutting, robot welding and automated assembly equipment, and all component processing parameters are directly output by the digital model, which eliminates the possible manual dimension error in the traditional processing process. In the final on-site hoisting and positioning stage, the construction personnel use laser positioning, total station and other high-precision surveying and mapping equipment to compare with the digital model in real time, which can ensure that the positioning accuracy of the module in the hull is controlled within the millimeter level. This full chain digital management mode makes the whole modular manufacturing process completely transparent and controllable, and the construction personnel can clearly grasp the production progress, quality status and hoisting sequence of each module at any time.

From the perspective of historical evolution, the modular prefabrication assembly technology of cruise interior outfitting has gone through three important development stages. The initial exploration stage from the 1970s to the 1990s, the modular technology at this stage is mainly applied to the standardized passenger cabin part, the public space with complex shape is still completed by traditional on-site construction, and the degree of digitalization is relatively low. The mature popularization stage from 1990s to 2010s, with the continuous development of computer-aided design technology, BIM technology began to be applied in cruise outfitting engineering, the modular design coverage has been extended from passenger cabin to part of the public functional areas, and the industrialization capacity of the production line has been greatly improved. After 2010, it entered the stage of intelligent iterative upgrading, the emergence of digital twin technology makes the whole lifecycle information of the module from design, manufacturing to operation and maintenance can be continuously traced, the scope of modular application has covered more than 85% of the interior space of the whole cruise ship, and the production efficiency has been increased by more than 3 times compared with the initial stage.

## 3. The Key Implementation Links of Cruise Interior Outfitting Modular Prefabrication Assembly Technology

The whole implementation process of modular prefabrication assembly technology is a highly coordinated complex system engineering, which is connected by three core stages: early planning and design, factory manufacturing and pre-outfitting, and ship transportation and on-site hoisting. Each link has extremely strict process standards and technical requirements, and any error in any link may lead to the delay of the subsequent process, resulting in the deviation of the whole construction cycle.

The first stage is the early planning and design, which is the top-level core link to determine the success or failure of the whole modular project. The first key work in this stage is the reasonable division of modules and functional definition. The engineering team needs to divide the huge complex interior space of the cruise ship into a number of independent functional modules according to the total general layout drawing, and the division principle must follow three basic dimensions. The first is the functional correlation principle, which divides the same functional area such as passenger cabin, restaurant, theater, office and other spaces into the same type of modules as far as possible, to avoid the situation that a single module contains too many heterogeneous functions. The second is the structural rationality principle, the size of the module must not only accurately match the hull rib spacing and other structural parameters, but also adapt to the weight limit of subsequent road transportation and hoisting equipment, so as to avoid the situation that the oversized module cannot be transported or hoisted. The third is the standardization degree principle, the types of modules should be reduced as much as possible on the premise of meeting the functional requirements, and the reuse rate of the same standard module should be improved. For a large cruise ship with a total tonnage of more than 130,000 tons, there are thousands of passenger cabins, which can be summarized into 10 to 20 standard passenger cabin modules after reasonable modular division, which maximizes the scale effect of batch manufacturing.

After the module division is completed, the engineering team needs to build a full ship BIM three-dimensional model, and carry out detailed design of the internal structure, electromechanical pipeline trend and equipment layout of each module. The most critical work in this link is virtual collision detection. The engineering team can find and eliminate all possible spatial interferences through the simulation operation of the digital model. For example, whether the ventilation pipe and the cable bridge conflict in a certain position, whether the pipeline will interfere with the installation trajectory of the door when the door is opened, these problems that are very easy to be ignored in the two-dimensional drawing design can be completely avoided in the BIM model, which greatly reduces the probability of subsequent rework. The most important core work in the design stage is the standardized interface design, which is the key to ensure the smooth butt joint between modules. The engineering team must strictly define three categories of interface specifications of the whole ship in a unified way. The first is the structural interface, that is, the specific position and connection mode of the welding or bolt connection point between the module and the hull steel structure. The second is the electromechanical interface, which uniformly defines the connection mode and position of the electric power, data, ventilation, water supply and drainage systems, and adopts the standardized quick connector that can be plugged and connected without on-site welding, which can complete the butt joint work in a very short time. The third is the decorative interface, which makes detailed provisions on the gap treatment between adjacent modules and the transition mode of the decorative surface, to ensure that the decorative effect of the joint after installation is uniform and beautiful.

After the design work is fully verified, the module will enter the second stage of factory manufacturing and pre-outfitting, which is the core link to reflect the advantages of industrialized construction. In the professional modular factory far away from the shipyard, the whole manufacturing process can realize the full assembly line operation. The first step of the process is the numerical control cutting and forming of the module structure. The steel plates and profiles of the module frame are precisely cut in the numerical control cutting center, and the dimension tolerance can be controlled at the millimeter level, and the complex structural members are formed by stamping or bending machine. Then the welding work of the module frame is completed on the special tooling platform, and the welding operation is mostly completed by the automatic welding robot, which not only ensures the welding quality, but also greatly improves the production efficiency. After the frame is formed, the workers carry out the pre-installation of the electromechanical system in the order specified by the process, lay the cable tray, ventilation pipes and water supply and drainage pipelines in the frame in strict accordance with the trend of the BIM model, and the direction, bending radius and fixing mode of all cables must meet the strict specifications of the international maritime organization.

After the pre-installation of the electromechanical system is accepted, the decorative layer construction and furniture installation work can be carried out sequentially. The workers complete the pasting of wall fireproof board, the laying of floor carpet or PVC floor, and the installation of ceiling on the pre-installed pipeline structure, which will not cause damage to the electromechanical pipeline that has been laid. After the decoration is accepted, the prefabricated integrated furniture such as the overall sanitary unit, customized wardrobe, and fixed bed are hoisted and fixed to the designated position inside the module. The final link of the whole factory manufacturing is the comprehensive test and acceptance of the module, and all modules that leave the factory need to pass the "four inspection" standard. The first is the appearance inspection, which checks the flatness, gap and color difference of the decorative surface. The second is the function test, which completes the power-on test of all lamps, sockets and switches, the water-passing test of the water supply and drainage system, and the ventilation test of the air conditioning system. The third is the pressure test, which carries out the water pressure test on all water supply and drainage pipelines to ensure that there is no leakage. The fourth is the safety test, which checks the performance of fireproof materials, smoke detectors and other safety facilities to ensure that all indicators meet the SOLAS convention standards. Only modules that have passed all the test items can obtain the factory qualification certificate and be transported to the shipyard.

The third stage is module transportation and on-site installation. The qualified modules are transported to the shipyard through special transport vehicles. During the transportation, special fixing and protection measures must be taken to prevent the module from deformation and damage to the internal precision equipment due to road bumps. For the oversized and overweight public space modules that cannot be transported as a whole, the split transportation scheme will be adopted, and they will be assembled into a whole at the special assembly position near the shipyard before hoisting. Before the module hoisting, the shipyard construction personnel need to complete the finishing work of the corresponding area of the hull in advance, clean up the site, and mark the positioning reference line strictly according to the BIM model. The hoisting process adopts the high-precision positioning mode of combining total station and laser tracker, which can accurately adjust the position of the module in the hoisting process, and the error can be controlled within 2mm when it falls to the predetermined position. After the module is positioned in place, the construction personnel first complete the fixation of the structural interface, and then connect the electromechanical standardized quick connector, and finally complete the fine treatment of the decorative gap. After the whole series of operations are completed, the independent cabin unit that has been fully prefabricated in the factory is successfully integrated into the interior space system of the hull.

The construction practice of China's first large cruise ship "Adora Magic City" fully verifies the reliability and efficiency of this complete technical system. In the subsequent construction process of the second domestic large cruise ship, the process was further optimized, and the single cabin module installation man-hours were directly reduced from 200 hours of the first ship to less than 50 hours, and the total interior outfitting cycle of the whole ship was shortened by 8 months, which created a new record of construction efficiency in the field of large cruise interior outfitting in China.

## 4. The Coordination Mechanism Between Modular Prefabrication Technology and Customized Differentiated Interior Design

For a long time, there is a widespread misunderstanding in the industry that modular prefabrication technology will limit the play of personalized customized design, leading to the homogenization of cruise interior style, which cannot meet the differentiated design needs of different itineraries. However, a large number of engineering practices in recent years have proved that through reasonable system design, modular prefabrication technology and customized differentiated interior design can form a very effective coordination and mutual promotion relationship. The adoption of modular technology not only will not limit the personalized creation of designers, but can greatly liberate designers from the trivial constraints of process details, and devote more energy to the cultural expression and experience design of interior space.

The core of this coordination mechanism lies in the layered design idea of "separating the structural main body from the decorative facade". All the standardized main structures, pipelines and functional interfaces of the module are set as unified fixed parts that do not need to be modified, which are produced in batches on the assembly line to ensure the manufacturing efficiency and performance compliance. The outer decorative facade components, including wall decorative panels, soft furnishings, art decorations, custom furniture facade materials, etc, are designed into standardized quick replacement components independent of the main body structure. These decorative facade components can be designed according to completely different personalized styles, and after they are produced in separate batches, they are installed on the standardized module main body through the general interface system. This design mode can produce dozens of interior styles with completely different cultural characteristics only by replacing the decorative facade on the premise that the main structure of the module remains completely consistent. For example, for the same standard passenger cabin module, after replacing the decorative facade of Song style elements, it can become an Oriental cultural style passenger cabin suitable for East Asian routes, and after replacing the tropical rattan decorative facade, it can be transformed into a leisure style passenger cabin suitable for Caribbean routes. The whole transformation process does not need any modification of the main structure, pipeline and electrical system of the module, and will not increase too much manufacturing cost, but can achieve extremely rich and diverse personalized interior style effects.

This highly flexible coordination mode has been widely applied in the construction process of China's second large cruise ship. On the basis of the unified standard module main body, the design team has developed a variety of different series of decorative facade modules that integrate Chinese traditional cultural elements, which not only maintains the high efficiency advantage of modular industrial manufacturing, but also forms a highly recognizable Chinese style interior decoration system, completely different from the style of European and American cruise ships, and creates a unique differentiated competitive advantage for domestic cruise products. For those large public spaces that cannot be divided into standard passenger cabin modules, such as atriums, theaters, theme restaurants, etc, the engineering team can also divide the complex interior space into a number of large public modules that meet the hoisting and transportation conditions according to the modular design idea, and reserve enough personalized design space in the interior of these modules on the premise of ensuring the standardization of the main structure and electromechanical interfaces. These large public modules can be freely designed and arranged according to the theme characteristics, integrating the characteristic cultural elements of the route, to realize the highly personalized theme space effect.

In the whole process of this coordinated design, BIM digital technology plays an extremely important supporting role. All the different styles of decorative facade components are digitally modeled and stored in the component library of the BIM system. Designers can quickly call different styles of facade components in the digital model of the standard module, and preview the final effect of the interior space in real time, and automatically generate the corresponding processing drawing. This digital collaborative design mode enables the design team to quickly complete the rapid iterative update of different interior design schemes for different shipowner needs, different route positioning, greatly shortening the design cycle of personalized schemes, and avoiding the possible dimensional mismatch when the customized decorative components are assembled with the standard module main body in the later stage. The research results of the "Cruise Aesthetic Design Technology Research" project supported by the Ministry of Industry and Information Technology also fully confirm the feasibility of this coordination mechanism. The project team has completed more than 40 sets of interior design works of different styles for prefabricated modular cabins, and all the design schemes have reached the drawing depth of real ship construction, which can be directly connected with the modular factory assembly line.

This design idea of separating the fixed main body and the replaceable facade also brings great convenience for the subsequent renovation and upgrading of the cruise ship in the operation stage. After the cruise ship sails for a certain number of years and needs to update the interior style or switch to different itinerary operations, the operation party does not need to carry out large-scale dismantling and transformation of the main structure of the interior outfitting, but only needs to replace these standardized replaceable decorative facade components, which can complete the overall style renewal of the whole ship's interior space in a very short renovation cycle, greatly reducing the renovation cost and downtime loss of the cruise ship, and extending the full lifecycle operation value of the cruise ship.

# 5. The Development Prospect and Innovation Direction of Modular Prefabrication Assembly Technology

At present, the modular prefabrication assembly technology of cruise interior outfitting is still in the stage of continuous rapid iterative innovation, and with the continuous maturity of domestic large cruise batch construction technology, this technology will continue to expand to a wider range of application scenarios, and further move towards the direction of higher intelligence, higher integration and lower cost.

## 5.1 Deep Integration of Artificial Intelligence and Modular Production Lines

The first important development direction in the future is the deep integration of artificial intelligence technology and modular production lines. In the existing modular factories, a large number of processes still need manual auxiliary operation. After introducing the artificial intelligence visual inspection system and intelligent robot assembly system, the production line can realize a higher degree of automation, further reduce the demand for manual skilled workers, make the manufacturing accuracy of modules more stable, and the production efficiency will be further improved. At that time, the production cycle of a single standard cabin module is expected to be shortened from the current 2 days to less than 8 hours, and the manufacturing cost will be further reduced by more than 30%.

## 5.2 Full Lifecycle Digital Twin Management of Modules

The second important innovation direction is the large-scale application of digital twin technology in the full lifecycle management of modules. In the future, each prefabricated module will have its own unique independent digital ID, and all the information from its design parameters, manufacturing process data, test records, after being installed on the ship, the subsequent operation and maintenance data, component replacement records, etc., will be continuously recorded in the corresponding digital twin body. When the cruise ship is in operation and maintenance, the management personnel can query all the historical information of the corresponding module through the digital system, quickly locate the fault point, arrange the maintenance work reasonably, and the relevant data can also be fed back to the front-end design end, continuously optimizing the subsequent modular design scheme, forming a closed-loop iterative optimization from design, manufacturing to operation and maintenance, which will further extend the service life of the cruise interior system and reduce the full lifecycle operation and maintenance cost.

### 5.3 Expansion of Modular Technology Coverage to Complex Functional Spaces

The third key development direction is the further expansion of the coverage of modular technology. At present, the application of modular technology in cruise interior outfitting mainly focuses on the passenger cabin area and the conventional public space. In the future, with the continuous breakthrough of large-scale module manufacturing and hoisting technology, more complex special functional spaces such as large theaters, water parks and casinos are also expected to be designed and manufactured in the form of large-scale integral modules. When the hoisting is in place, it can be directly put into use without a large number of on-site assembly work, which will further shorten the total construction cycle of large cruise ships.

### 5.4 Consolidation of China’s Core Competitiveness in Global Cruise Manufacturing

The continuous innovation and popularization of modular prefabrication assembly technology will further consolidate and enhance the core competitiveness of China’s large cruise manufacturing industry. At present, China has fully mastered this core technology through the construction practice of the first two large cruise ships, and has formed a complete industrial supporting system with independent intellectual property rights, which has broken the long-term technological monopoly of European and American leading shipyards in this field. In the subsequent batch construction process of large cruise ships in China, the continuous optimization and upgrading of modular prefabrication assembly technology will help China’s cruise construction cycle, construction cost and product quality reach the world’s leading level, and provide strong technical support for China’s march into the global high-end cruise construction market.

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