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An MBD based systematic approach of accommodation module building with integrity

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Received: 2 September 2024 / Accepted: 5 November 2024
Published online: 11 November 2024

Abstract
The leading shipyards in the world have built up the modern shipbuilding model based on the practices and development of integrated hull construction, outfitting, and painting and integrated design, production, and management, shortened the total building period, and increased the building efficiency in recent years. The accommodation module building plays an important role during the shipbuilding development; but the integrity level of accommodation module varies in the key shipyards that there are few shipyards can build with high level integrity. This paper presents a systematic approach of accommodation module building with integrity based on model-based definition technology and real practices. Based on the general product manufacturing information of preliminary 3D model, a dedicated and professional plan in principles of facilities, lean processes, details of integrity standards is carried out, and then deepen and finalize the 3D model. Taking the model as the unique resource, to organize building execution, inspection, and evaluation. This method enables Shanghai Waigaoqiao Shipbuilding & Offshore Company to deliver approximate 30 sets of accommodation model with full integrity per year, and total building period within 100 days. This study fills the theoretic gap in IHOP and MBD application of modern shipbuilding and provides guidelines for all key shipyards to build accommodation modules with high level integrity, therefore to improve the shipbuilding effectiveness and efficiency.

Article highlights

- This paper presents a systematic approach of accommodation module building with integrity based on practices in Shanghai Waigaoqiao Shipbuilding & Offshore Company and application of model-based definition (MBD) in the processes from planning, design, production, and management. It explains well why and how the accommodation module can be built with high level integrity while many other shipyards are still struggling.
- This study fills the theoretic gap of integrated hull construction, outfitting, and painting (IHOP), and integrated design, production, and management (IDPM) in modern shipbuilding with the proposition and practice of MBD, explains well how the model promotes and improves the integrated shipbuilding method in modern shipyards. The application of MBD improves the integrated shipbuilding on both production efficiency and effectiveness, and then reaches a higher level of integrated shipbuilding.
- As a very important intermediate product of shipbuilding, the accommodation module has some special characters and causes technical and managerial difficulties in the processes of building thus challenge shipyards around the world. This paper studies it carefully and deeply, raises a series of solutions to solve these problems, and results prove them functionally and properly.

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Keywords MBD · Accommodation module · Integrity · IHOP · Deformation control

1 Introduction

Based on the theories of group technology (GT) [1] and intermediate product, the modern shipbuilding model is built by combining integrated hull construction, outfitting, and painting (IHOP) [1–5] and integrated design, production, and management (IDPM) [6]. It builds up the shipbuilding processes based on the hull construction covering the stages from assembly, block fabrication, meg-block, and dock erection, and organize the outfitting and painting work by means of pallets on these stages accordingly [1, 7]. It brings the reforming and changing of processes in shipbuilding, reforms the procedure over shipbuilding design and management, and increases production efficiency [8, 9], in particular, for some complicated and high value shipbuilding and offshore products [10].

With the support of 3D technology, leading shipyards focus on the integrity of blocks and meg-blocks, and moving the later processes in advance and earlier shipbuilding stage continually [11]; thus, shorten the period of dock erection, commissioning in quay, total shipbuilding processes, and increase the construction efficiency; simultaneously, the integrity level of blocks, meg-blocks, and even grand-block benefits the production efficiency and lead-time control [11].

Comparing the meg-blocks, grand-blocks in the main hull body including engine room, cargo holds, bow part for cargo ships, or machinery space, columns, decks for offshore engineering products, the building of an accommodation module(or called as a living quarter in some offshore engineering products, also deckhouse in some literatures) with integrity is much more different and difficult [12, 13]. When we mentioned of the main hull body building, the integrity includes the work of hull construction, outfitting, and paint as the content of IHOP defined. Although in general spectrum, outfitting includes steel outfitting, piping, electrical, HVAC, and interior [2, 14], the most shipyards still execute the interior work at the zone stage after the accommodation module erected to main hull in the drydock or slipway for some technical difficulties for a long time.

The accommodation module building with integrity plays an important role which enables the shipyard to improve the erection efficiency in the drydock and reduce the total building period of these products including cargo ships and offshore projects. In research of literatures, there still is no such study to systematically conclude the advanced technology of building the accommodation module with integrity. Thus, there still is a technical and theoretic gap in accommodation module building with integrity in the shipyards around the world.

Shanghai Waigaoqiao Shipbuilding & Offshore Company (SWSO), China, had started to build the accommodation module with integrity since 2012 and delivered approximate 30 sets per year with total building period in 100 days. SWSO has become a benchmark of integrity and standardization of the accommodation module building in the world [15].

In the practices of SWSO, the Model-based definition (MBD) technology is applied in the full processes of accommodation module building from plan, design, production, inspection, and evaluation, and therefore achieves high level integrity. MBD technology is originated in aerospace field for shortening aircraft production cycle and reducing costs [16], studied and applied in shipbuilding since 2015 [17]. Based on the theory that 3D model with product manufacturing information (PMI) to be the unique source of authority throughout shipbuilding lifecycle, experts study and develop the MBD-based ship design [16] and process design [18, 19] in shipbuilding, and obtain some local achievements. In research of literatures, there still is no such systematically application of MBD in the full processes from design, production, inspection, and management in shipbuilding.

The following sections of this paper present a technical background and methodology analysis of accommodation building with integrity, concludes the advanced MBD based systematic approach on principles plan, integrity standard, design method, building processes, inspection, and evaluation. And then key problems of accommodation building are discussed through literature reviews and practices in SWSO. The contributions and limits of this paper are summarized finally.

2 Methodology

2.1 Research background of accommodation module building

Accommodation module is a large deckhouse erected on the main deck of a cargo ship or an offshore project, and designed to accommodate manoeuvring, working and living of the crews based on structural strength optimization [20, 21]. The size of a certain accommodation is decided by the ship type, crew number, and location on the main deck, which defines the height of the bridge according to the least blind area of the ship requested by the International Convention for the Safety of Life at Sea (SOLAS) [22].

For an accommodation module of a cargo ship or an offshore project, there is 15–36 m high at 5–10 layers of decks, and 600–2500 tons weigh based on typical products, as shown in the Table 1. This study doesn't consider the accommodation module for these smaller ships with deadweight of less than 50,000 tons as it is certain smaller in size and weight than the table mentioned below.

Apart from the large size and weight requested the proper facilities, the major differences of accommodation modules from the main hull grand-blocks are their complicated outfitting including steel, piping, HVAC, electrical, electronic, cable fittings, and accommodation decoration; in particular, the materials such as glass, flooring, panels et al. of interior is apt to damage caused by deformation during the lifting and moving operation.

In comparison to the structure of the main hull, the steel plates in accommodation module are much thinner and the structural strength is much weaker than the main hull body [23, 24], large amount of 6mm to 8mm plates are used in the accommodation module. The deformation control of thin plate welding still challenges in the shipbuilding industry [25], consequently, the deformation impacts a negative influence on the interior work.

The most work of shipbuilding processes from block fabrication, meg-block, to grand-block are assembly and welding in main hull body, so the manpower and facilities in a shipyard are arranged suitable for the assembly and welding work [11]. By contrasting, the building processes of accommodation is much different due to the interior work and the facility and manpower demand comes different. Building the accommodation module in a separated designed production line becomes an economic and efficient solution [12].

The 3D model with PMI can handle above mentioned difficulties effectively and efficiently. Therefore, an MBD based systematic approach of engineering and building accommodation module with integrity can be applied to improve building efficiency and achieve cost saving. The methodology and technology contribute to the shipbuilding theory and can be applied to enhance the coordination of ship design, engineering, and building.

2.2 MBD based methodology of accommodation module building with integrity

Based on the MBD technology, the 3D model of shipbuilding includes large amount of information, thus, design information, production information, and management information as shown in Fig. 1 [16].

Table 1 Typical parameter of accommodation module

Ship type	Number of Decks	Outline Dimension(m) Length × Width × Height	Weight(t)
114,000t Oil Tanker	5	16.5 × 44 × 14.7	600
158,000t Oil Tanker	5	18.6 × 48 × 15.7	650
300,000t VLCC	7	19.1 × 37.5 × 32.9	900
82,000t Bulk Carrier	6	13.4 × 32.3 × 17.8	515
180,000t Bulk Carrier	7	16.8 × 45 × 21.8	475
210,000t Bulk Carrier	7	15.2 × 48.5 × 22.2	755
180,00TEU Container Ship	9	10.5 × 54.1 × 32.7	950
20,000TEU Container Ship	10	10.4 × 52.1 × 34	1315
300,000t FPSO	10	28 × 86 × 36	2455

The height of accommodation mentioned above refer to the structure from bottom to the compass deck excludes the height of radar mast and other outfitting

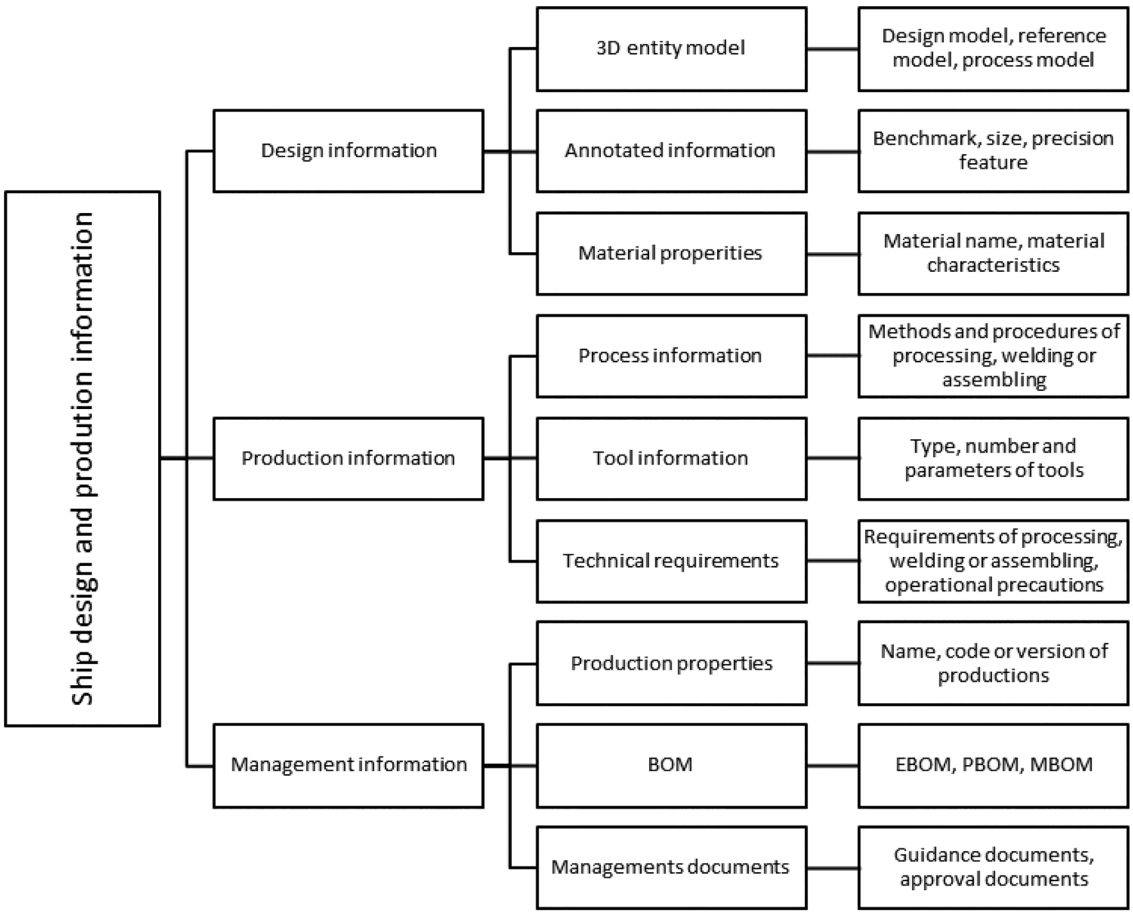

Fig. 1 Ship design and production information

The model of accommodation module is also established in separate industrial software platform and contains detail information as shown as Fig. 2. It becomes unique resource [26] and provides the basic input of plan and design, and updated for building, inspection, and evaluation after the building processes finalized. Therefore, it becomes the tool and foundation of the MBD based systematic approach of accommodation building with integrity.

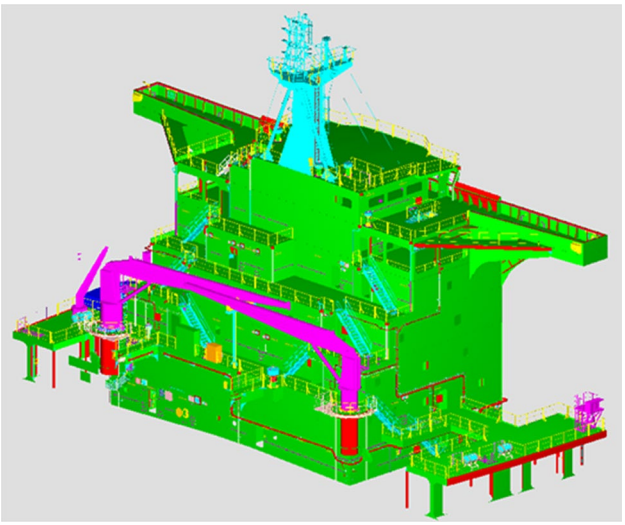

Fig. 2 Model sample of accommodation module

The unique resource model of MBD technology is not built up completely one time, but circulated and coordinated with other planning of production and management in shipbuilding. It is initiated and developed from basic design, detail design, and finalized in production design [27]. Based on the basic design and the detail design approved by the class and the client [27], a preliminary model is provided for the planning, supply chain, and other preparation, and then finalized for production execution, inspection, and management in production design.

3 MBD based plan and execution of accommodation module building

3.1 MBD based plan of accommodation module building with integrity

Principle plan for designing and building is a very important process of accommodation module building with integrity based on the MBD technology; it connects and coordinates the processes of design, building, and management as IDPM request [6]; and also instructs the detail design, production design, and building processes. It is carried out based on the evaluation of the production scope with facilities capacity, production plan, and the lean level of the production management at the stage of a preliminary model being provided with general product information of structure, outfitting, interior etc. [11]. The content of principle plan of accommodation module building with integrity includes the building methodology, building capacity, production organization, safety technology, detail processes, the integrity standard, execution details coordinate the respects shown as Fig. 3.

The first consideration of facilities is the lifting and moving capacity for the accommodation module building where the module built. The maximum safety load weight of the lifting crane and transportation vehicle limits the grand-block size of the accommodation module. In case the total weight exceeds the crane capacity, the accommodation module shall be divided to contain the most decks from the top in order to maximize the work inside the accommodation module. With the preliminary model of the accommodation module, it is convenient to know the weights of grand-block divided on different sizes. Therefore, the best integrity level of the upper accommodation module can be achieved and the most part of outfitting, accommodation decoration job can be done before the module erected in the dock. Simultaneously, the assembly possibility and operation convenience of key equipment and related foundation, pipes, wiring, and other connection is to be checked through the preliminary model when the dividing section is chosen.

Based on the best coordination of the facilities and work scope, as shown as Fig. 3, the integrity standard and processes are defined. Therefore, these principles enable the fabrication processes to flow at an optimal details including production load per working category, minimum production period etc. Thus, production plan and management are decided according to the project milestone.

The design work is the start of the planning of accommodation building with the preliminary model for consideration, and then the production design deepens and reflects the results of principle plan.

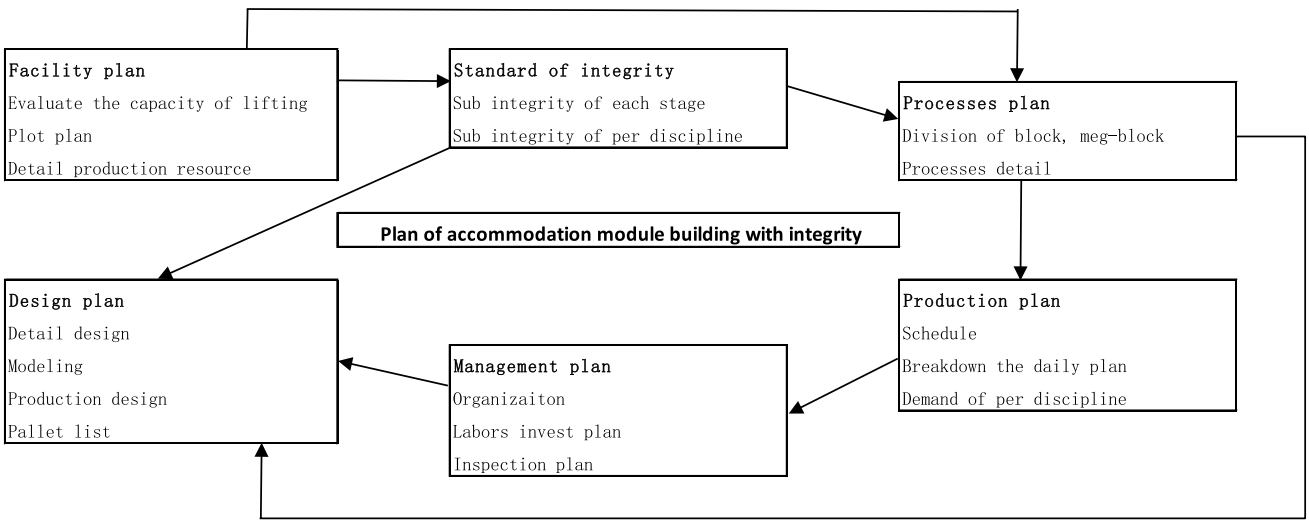

Fig. 3 Plan of accommodation module building with integrity

All structures, equipment, fittings, material shall be modeled in the production design model, identified the installation stages of assembly, block, meg-block, and the module and other detail manufacture information.

3.2 MBD based standard of accommodation module building with integrity

The integrity is to be carefully identified in the technical details based on the model and the building principles plan above mentioned. The logical principle of accommodation module building with integrity is the maximizing completion in terms of structure, outfitting, decoration, painting, and electrical details. Actually, the technical details that impede the erection process of the accommodation module grand-block in the dock shall be carefully optimized and/ or kept remnant.

The first remnant consideration is that these fittings and work may be damaged during the welding and/or lifting work when the module is erected to the main hull. Therefore, the lowest layer of the module shall be addressed on the following details from all floors above,

a. All hull structure and outfitting installed by welding, including steel outfitting, pipes, cable tray, and HVAC etc., on the top and side bulkhead underneath the lowest deck, must be done and the fittings connected to the floor of the next lower deck shall be kept remnant as there is only a top deck and side bulkheads in the lowest layer of space.
b. Insulation and final coating can be finished on top and side bulkheads in the lowest layer of space and kept the lowest part about 1.5m above the bottom-line remnant.
c. Interior decoration including panel, ceiling, furniture, and other accessories inside the lowest space, is not installed and kept remnant until erected in the dock.

The second remnant consideration is that equipment and devices that can't be installed, in particular, equipment, fittings, and flooring on the deck where the accommodation erected to. The cables in the accommodation module are laid from top to bottom, therefore the rest cables leading to engine room, cargo area, bow area will be rolled up and fixed in the space of the accommodation module bottom.

The integrity standard of the accommodation module can be carried out based on the analysis above mentioned shown as the Fig. 4,

In case of the situation that the lifting capacity exceeds the total weight of the accommodation module, then the module is divided, the upper meg-block of the module keeps the standard as Fig. 4. The integrity standard of the lower meg-block(s) is set with the consideration on the principles analyzed above to keep the structural integrity and quit the interior integrity as the examples shown in Fig. 5. Detail standards are also defined based on the model.

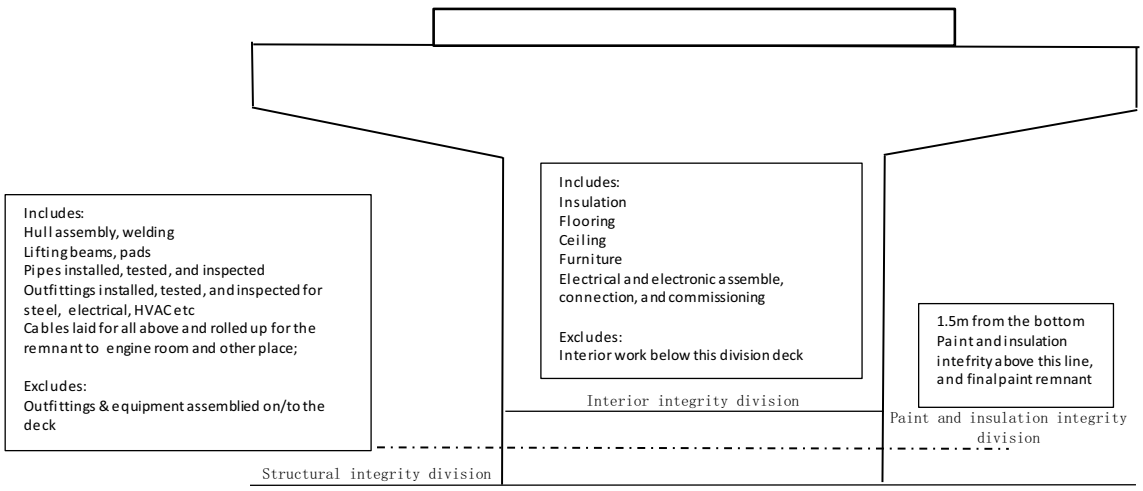

Fig. 4 Integrity Standard of accommodation module

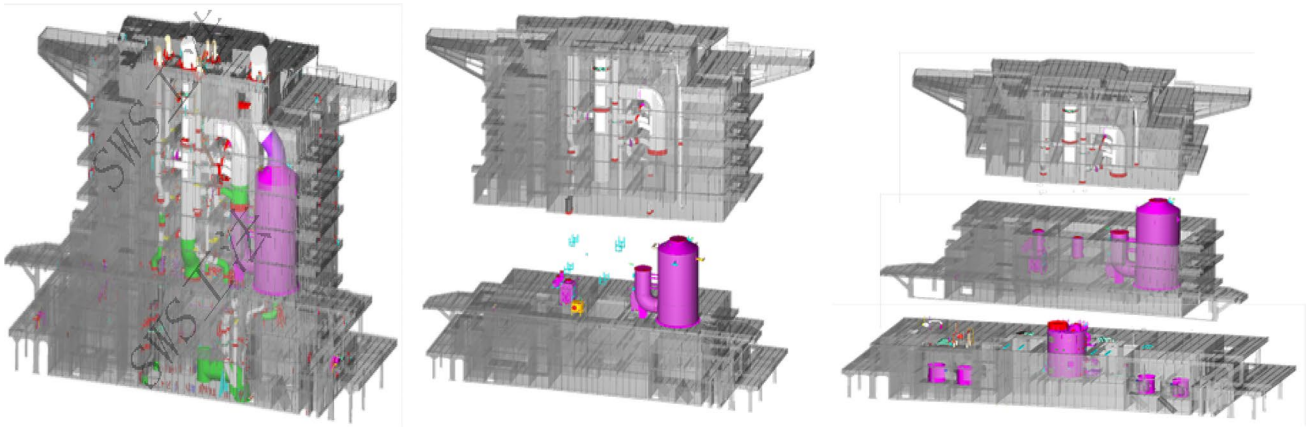

Fig. 5 Sample of meg-block division

3.3 MBD based design of accommodation module building with integrity

As MBD technology defined [16], the process of design in shipbuilding is oriented and developed with the unique model resource from basic design, detail design to production design. The production design is carried out based on and representing the planed principles and approved detail design. The output model and related drawings of production design is the resource to instruct and coordinate all the processes of production and management.

In normal ship production design, the design team is organized based on the design disciplines as hull, outfitting, piping, HVAC, electrical, and processes, and the designers of per discipline build modeling separately and then coordinate the modeling together to ensure there are no interferences or mistakes. Except for some outfitting modules, the supports and foundations in other ship parts are normally separately, but the supports and foundations in the accommodation area can be combined as shown in Fig. 6 and optimized since the workload is normal low [28]. It requests the designers are familiar with related disciplines and can work on general outfitting models including piping, HVAC, and electrical as well. Based on the practices and finite element calculation proven, a set of combined

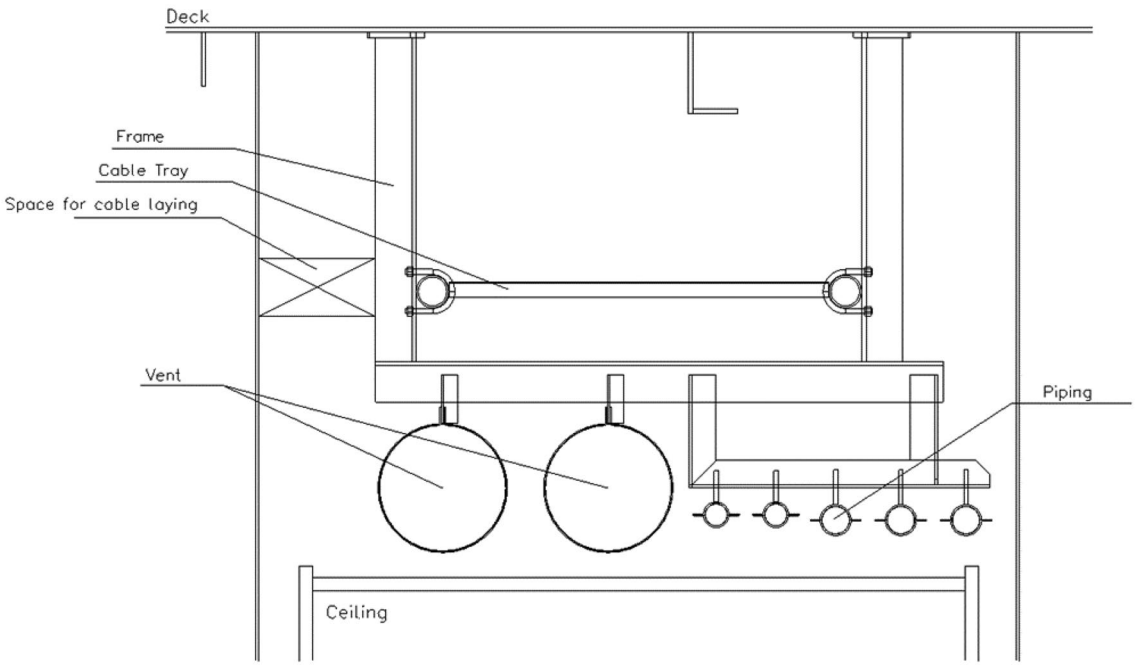

Fig. 6 Sample of combined support

support guidelines and standards is established. Therefore, the costs of materials and space are saved accordingly the samples shown as Fig. 6.

The typical details are carefully specified in the Ship Design Standard (SDP) and followed by the designers during the production design period. During the building and coordination of the model, all related information including hull structure assembly, fabrication, installation, parts list in per pallet, and work processes of outfitting for piping, outfitting, interior, paint, and electrical are defined in a systematic approach. Every detail in principle plan, work sequences, and technical processes is reflected and specified in these related drawings.

Interior design is also a very important part in the design of accommodation module which form the comfortable and healthy environment of the living space for crews. The cultural preference, favorite colors, types of ceiling, panel, and curtain, etc., and cabin arrangement shall be discussed and mutual agreed upon with the shipowner [12]. Based on the preliminary agreement, the interior designers carry out the detail decoration in the model and submit in 3D for owner's approval, for example the officer's mess room as shown as Fig. 7.

After the full modeling of the accommodation module built, coordinated, and checked with interference, the production design information is extracted from the model and delivered for supply chain management, production, and inspection [29].

3.4 MBD based building of accommodation module building with integrity

Based on the planning and principles of IHOP, the processes of accommodation module building are arranged on the stages of assembly, block, meg-block, outfitting shown as Fig. 8 [10, 11]. The detail work and processes of hull construction, outfitting, interior, and painting in block, meg-block, and module are implemented according to the production design model.

As the output of production design model specified, the production is organized in respects of supply of material, fittings, components, and intermediate product, job division of workers, and daily job according to defined schedule [27].

In SWSO, the building plots are designed with normally 2–3 pre-erection plots as Y1 and Y2, two outfitting plots (A, C) interlaced with two erection plots (B, D), and three interior plots (E, F, G) that form the flow production line of the accommodation module building as shown as Fig. 9. This arrangement enables the building module to move ahead through the main processes and achieve optimal utilization of the facilities.

The plots of Y1, Y2, and A to G form a flexible production line of accommodation module. In this production line, the building modules flow from plot to plot on the speed of standard takt [7]; therefore, the related elements are optimized as the defined takt; thus, it achieves the best production efficiency on the circulating for the perfection of lean production [27].

3.5 MBD based inspection and evaluation of accommodation module building with integrity

Based on the standard of accommodation module building with integrity and principles plan above mentioned, all structures and systems shall be inspected and tested for quality, tightness, and function accordingly so that there is no additional work will be done after erection in the dock except the remnant items.

Integrity shall be checked and evaluated with performance measurement by the detail checklist and related model requested in the standard compiled by SWSO [30].

Fig. 7 Layout in Office's mess room

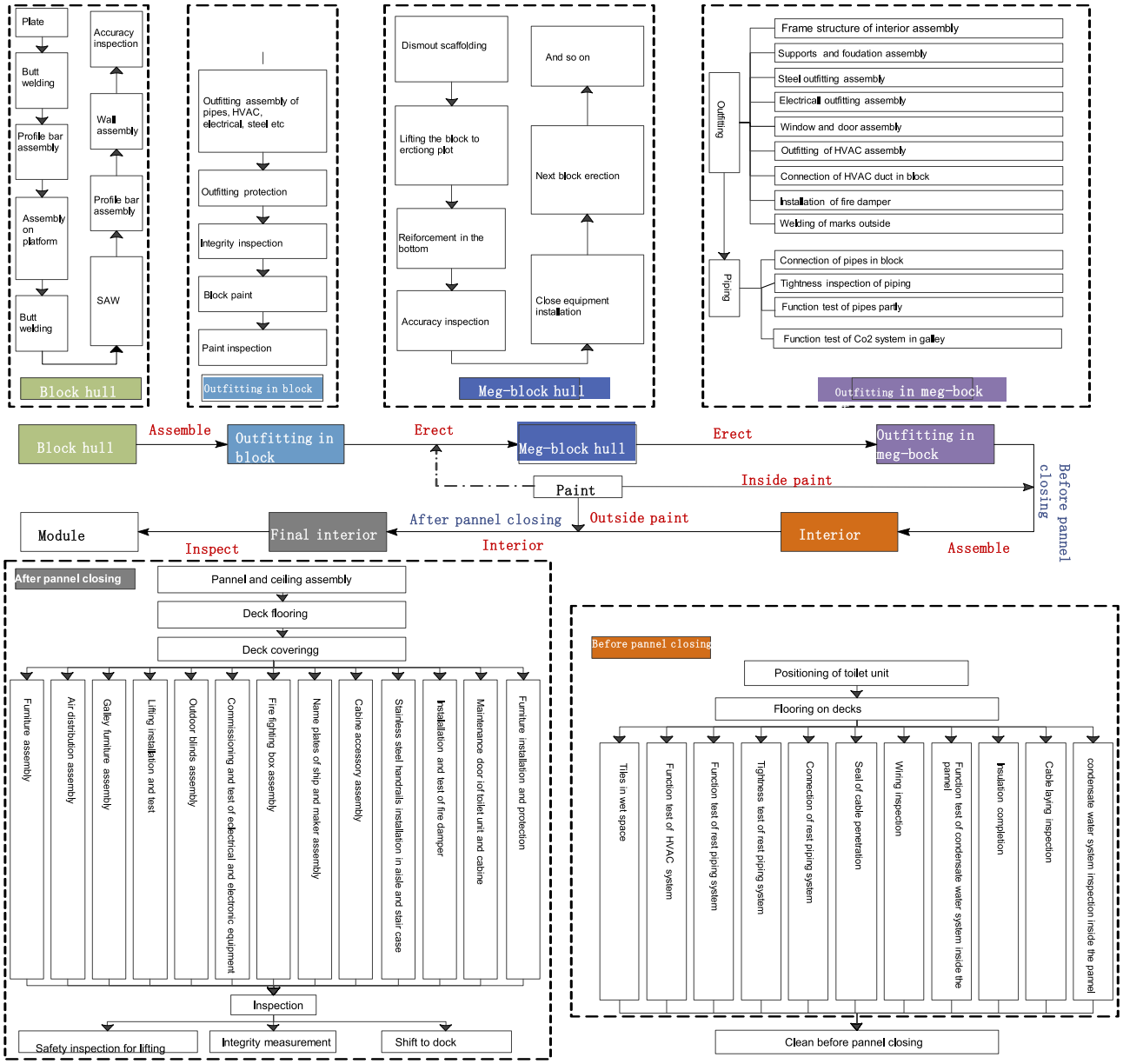

Fig. 8 Building flow chart of accommodation module

4 Discuss: key problems of accommodation module building

4.1 Prevention and rectification of welding deformation of thin plates

From a structural strength point of view, the accommodation module is much weaker than the main hull body though it is approved and confirmed by the model of finite element and almost does not bear the general longitudinal load [20]. Plate thickness of bulkheads and deck are 7–10mm, and some of inner bulkhead are only 6mm thick steel plate as usual. Welding deformation of thin plates always is a difficult in shipbuilding [25], only strict processes and rational precautions can reduce the welding deformation.

The first precaution for welding deformation is to reduce the heat input during steel cutting and welding, so laser cutting and welding are much better than plasma cutting and electrical arc welding in the processes of

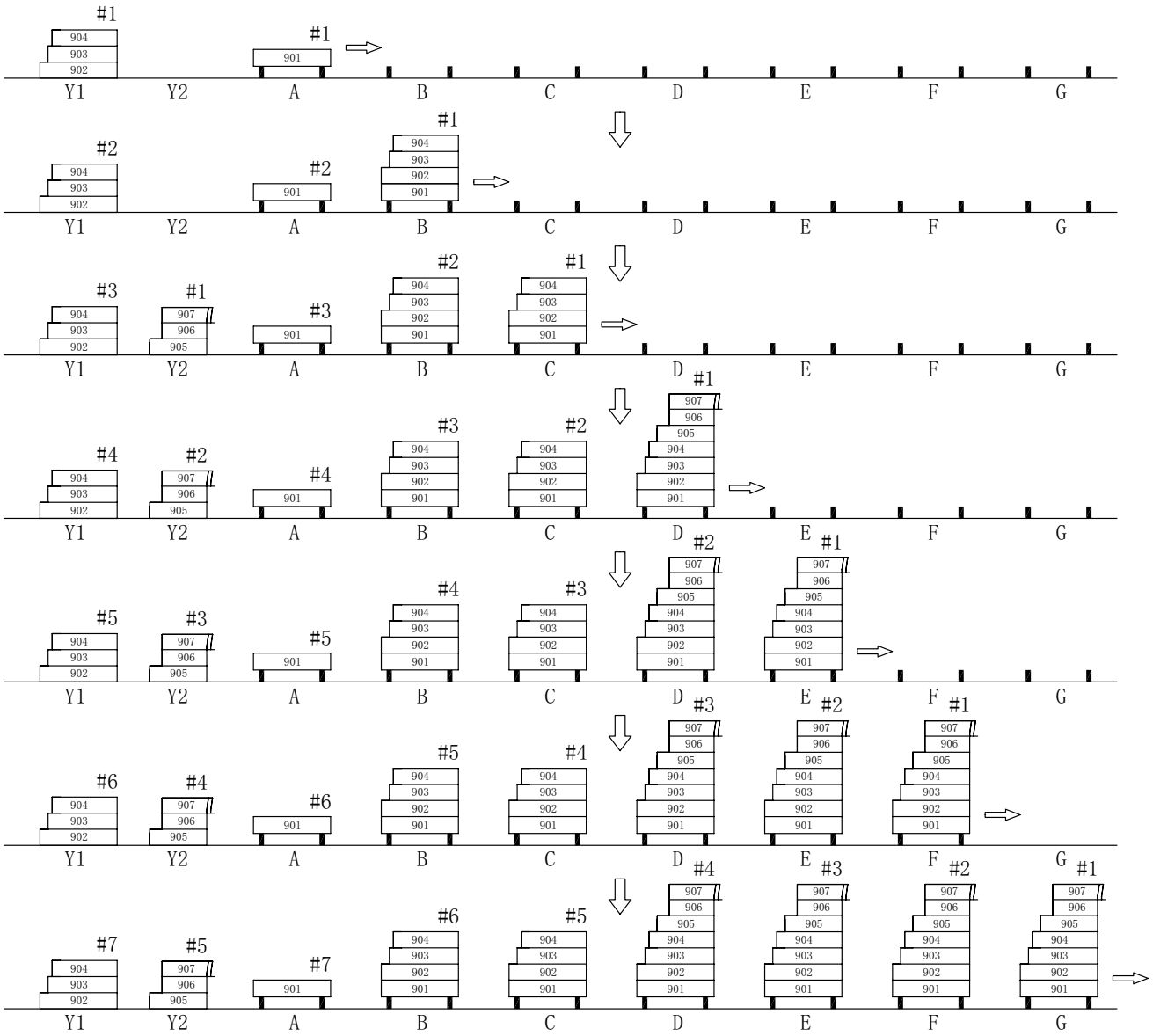

Fig. 9 Building flow of accommodation module

accommodation module building [31, 32]. For electrical arc welding, a certain pre-shrink margin as a precaution is necessary measurement for these thin plates in the accommodation module [33].

Temporary reinforcement in way of big opening, open box, and free end of the structure is necessary to prevent the structure deformation during the block, meg-block stage of the accommodation module building [34]. Back fire in way of angle bar or other profile bar welded to the bulkhead or deck plates can rectify the welding deformation after welding.

4.2 Prevention of lifting and transportation deformation

The deformation of the accommodation module caused by lifting or other transportation after the integrity building is so harmful to the interior decoration in particular flooring, wall panel, ceiling, and window glasses that although 20-30mm deformation in the structure would cause large damage and big loss. Therefore, the deformation requirement of the completed accommodation module is much stricter than other ordinary meg-blocks and grand-blocks.

A full modeling of finite element by MSC Patran is equipped with all related structure, outfitting, lifting pads, and temporary reinforcement, and calculated with deformation that make sure the total deformation within elastic limits

under all relevant conditions during lifting and transportations [35–37], example as shown as Fig. 10. With the MBD technology, the finite element model is abstracted from the basic design model and shared with the unique model resource.

As mentioned above, the strength of the accommodation module bottom is very weak due to the large void space. Therefore, a fabricated steel platform is designed and arranged as a foundation with additional structural reinforcement for the accommodation module during the erection, outfitting installation, interior decoration, and transportation to the dock by vehicle or barge.

4.3 Improvement of interior design

With the development of interior design and living quality demand from the crew members, the interior requirements of accommodation for cargo ships have improved quickly in recent years. The comfortable, beautiful, and convenient living space shall be made for the accommodation module through advanced interior design.

The interior design of the accommodation module shall be initiated and reflected the value, cultural characteristics, and personalities of crew [12]. A questionnaire included the detail information about style preferences, favorite colors, hobbies and entertainment, and material preferences is prepared before starting the interior design for the client's input. Based on this, the interior designers outline the cabin arrangement and interior solution. The 3D model of interior will be submitted for client's final approval after coordinating and balance for interferences with other design disciplines. Thus, MBD methodology makes the client satisfied more conveniently.

Some new technology, for example, the digital spray can improve the color diversity and the size of pictures. It enables the very large pictures to be possible sprayed on the walls of cabins and corridors, examples as shown in Fig. 11.

5 Conclusion

The accommodation module building with integrity is the most difficult and challenging part, but it plays a significant role in the progress of shortening the building period and improving the building efficiency in shipbuilding. The MBD technology provides a good method to plan and instruct the accommodation module building with integrity. As result, SWSO achieves good efficiency and effectiveness, and delivers approximate 30 sets of accommodation model with full integrity per year, and total building period within 100 days.

This paper presents a systematic approach to establish a standardized methodology and procedure with the MBD technology. It is the first to raise the application of MBD in accommodation module building even in shipbuilding. This

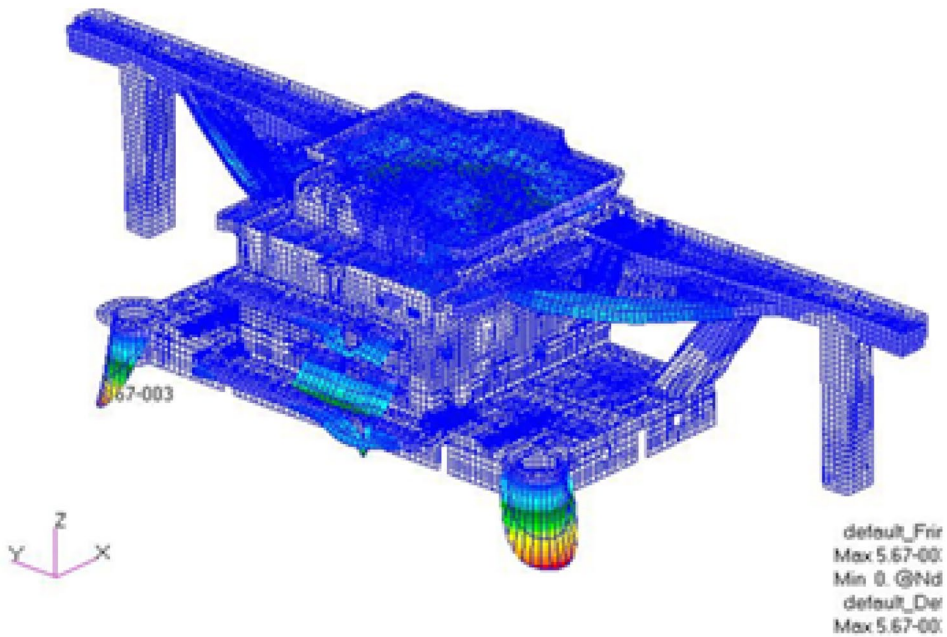

Fig. 10 sample of finite element calculation for accommodation module

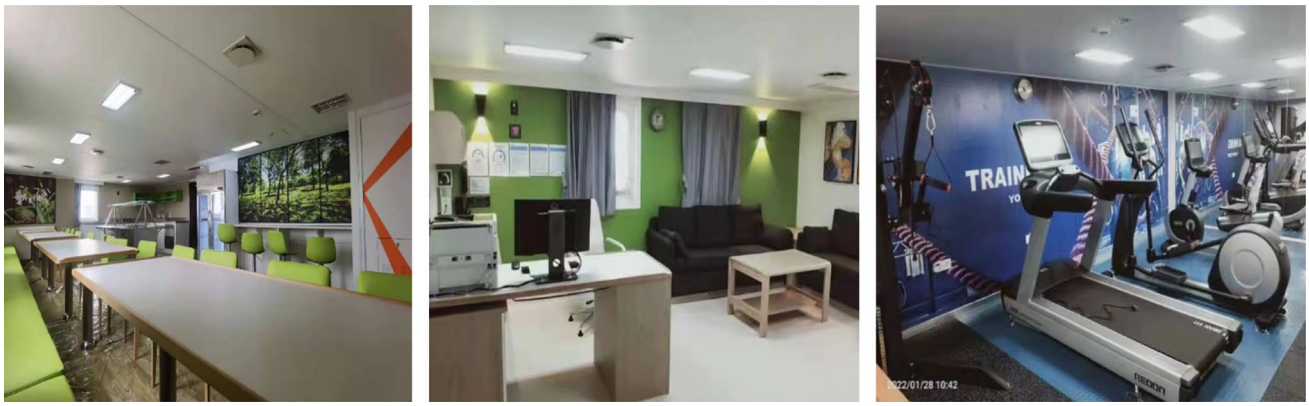

Fig. 11 samples of final interior

study fills the theoretic gap in IHOP and IDPM of modern shipbuilding, provides guidelines for key shipyards to build accommodation modules with high level integrity and consequently to improve the shipbuilding capacity.

Due to the knowledge shortage of authors and limitation of the article length, this study does not present the further details of the algorithm and software of modeling, the exchange and connection among special calculation models of hydrodynamics, strength, noise, and vibration etc.

Based on MBD methodology, further study of automatic machinery such as steel cutting, assembling, welding, and painting driven by the design model will be developed to promote the digital transition in shipbuilding, therefore, to improve the shipbuilding effectiveness and efficiency further in future.

Author contributions Jincheng Wang leads the project, organize the resource, and form the main concept. Huilong Ren reviews the paper, makes major revision. Niansheng Chu drafts the paper, collects the data.

Data availability The authors declare that the data supporting the findings of this review are available within the paper.

Declarations

Competing interests The authors declare no competing interests.

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