

Generation of the 3D CAD model of the hull structure at the initial ship design stage and its application

Myung-II Roh ^{a,*}, Kyu-Yeul Lee ^{b,1}

^a Department of the Naval Architecture and Ocean Engineering, University of Ulsan, Mugeo2-Dong, Ulsan, Republic of Korea

^b Department of the Naval Architecture and Ocean Engineering, and Research Institute of Marine Systems Engineering, Seoul National University, Shinlim-Dong, Seoul 151-742, Republic of Korea

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Abstract

Currently, all design information of a hull structure is being first defined on 2D drawings not 3D CAD model at the initial ship design stage and then transferred to following design stages through the 2D drawings. This is caused by the past design practice, limitation on time, and lack of shipbuilding CAD systems supporting the initial design stage. As a result, the following design tasks such as the process planning and scheduling are being manually performed using the 2D drawings. For solving this problem, a data structure for shipbuilding CAD systems supporting the initial design stage is proposed and a prototype system is developed based on the data structure. The applicability of the system is demonstrated by applying it to various examples. The results show that the system can be effectively used for generating the 3D CAD model of the hull structure at the initial design stage.

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1. Introduction

1.1. Overview of shipbuilding process

A ship is a huge structure made up of a large number of hull structural parts. Here, a hull structure represents the body of the ship, and a hull structural part represents a part that is placed on the hull structure to secure the structural strength of the ship. A deadweight 300,000 tonne VLCC (Very Large Crude oil Carrier, hereafter simply referred to as the ‘300k VLCC’) has a length, breadth, and depth of about 320 m, 60 m, and 30 m, respectively. Thus, unlike an automobile, a ship cannot be constructed all at once. The ship is first divided into a number of building blocks (e.g. about 200 building blocks in the case of the 300k VLCC). Here, a building block is a unit production element of a ship. Each building block is assembled in the assembly shop near the dock. Large building blocks

called erection blocks are made by joining several building blocks together. Then, the large building blocks are moved onto the dock and welded to each other according to a suitable sequence, called the block erection to complete the final assembly of the ship. Essentially, the construction process of a ship is similar to that of a large product by use of Lego blocks.

1.2. Background and necessity of this study

At the initial stage of ship design, designer’s product (‘ship’) concept such as function, configuration, geometry, and part relationship evolves rapidly and optimizes through repetition and analysis. From the designer’s point of view, the final design output is 2D drawings that contain all design information of the ship and reflect design concepts or semantics of the designers. Fig. 1 shows one of 2D drawings of a 300k VLCC with a corresponding 3D CAD model. This drawing is used to represent and communicate the design information with other designers. As shown in Fig. 1, design results (e.g. dimension, placing position, thickness, material, etc.) of panels (or plates) and stiffeners are implicitly represented on this 2D drawing by lines, arcs, and drawing symbols.

* Corresponding author. Tel.: +82 10 6740 1907; fax: +82 52 259 2836.

E-mail addresses: myungil.roh@gmail.com (M.-I. Roh), kylee@snu.ac.kr (K.-Y. Lee).

¹ Tel.: +82 2 880 7327; fax: +82 2 888 9298.

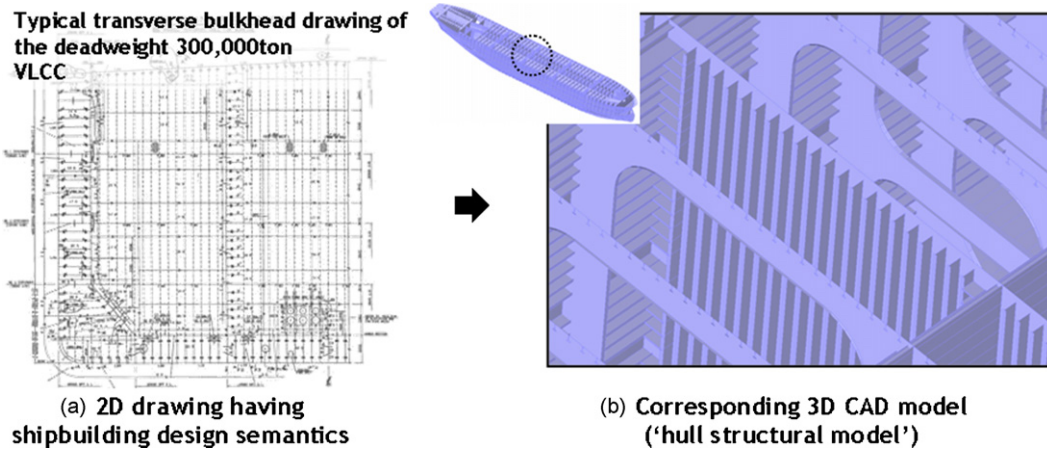


Fig. 1. Example of the 2D drawing and the corresponding 3D CAD model of the 300k VLCC.

Traditionally, 2D drafting has been manually carried out, and recently, the computer aided drafting systems have been introduced at the initial design stage. Even with computer aided drafting environment, it is still difficult to reflect and deliver all design information by the 2D drawings. That is, although this environment is available to support designers, other designers must undertake the arduous task of translating design semantics defined on the 2D drawings. Therefore, it is necessary to develop a shipbuilding CAD system based on a computerized data structure to capture and store such design semantics. Such a system would be able to satisfy and provide information required by other applications such as CAPP (Computer Aided Process Planning), CAE (Computer Aided Engineering), etc.

1.3. Related works

In the latter of 1980s, the demand for CIMS (Computer Integrated Manufacturing System) in shipbuilding increased and the importance of a 3D CAD model in the hull structural design was embossed. As a result, some projects were commenced such as 'Computerized Ship Design and Production' (CSDP, 1988–1994) in Korea and 'CIMS Pilot Model Development' (1989–1992) in Japan, and many related works were made.

In the case of researches conducted at the institutes and ship building companies, KRISO (Korea Research Institute of Ships and Ocean Engineering) conducted a subproject related to the CSDP project entitled 'Development of the Ship Structural CAD System' [1]. In this subproject, the required specification, procedures and contents of design practice about the hull structural design were analyzed for developing the shipbuilding CAD system. With these analysis results, a data structure was proposed to represent all design information. However, the system implementation was not made based on the proposed data structure. DSME (Daewoo Shipbuilding and Marine Engineering) also commenced a subproject as part of the CSDP project entitled 'Development of the Initial Process Planning and Scheduling Information Processing System' [2]. In this subproject, the procedures and contents of design practice

about the hull form definition, ship compartment arrangement, hull structural design, process planning and scheduling, etc. were analyzed for developing the shipbuilding CAD system. However, the system implementation was not completed. Only the possibility of implementing the integrated system was examined based on the VDS (Vehicle Design System), which is a general-purpose CAD system and was developed by Intergraph.

In the case of researches conducted at the universities, Nomoto et al. [3–9] commenced a subproject as part of the 'CIMS Pilot Model Development' project. They proposed a data structure based on the object-oriented concept and the prototype system called 'System Of Design and Assembling for Shipbuilding (SODAS)'. However, this data structure can only represent the limited design information of the cargo hold region of a hull structure. Furthermore, the prototype system cannot perform hull structural modeling of stiffeners which are required to secure the structural strength of a ship. Ohtsubo et al. [10,11] of Tokyo University has performed a study on the interface development between the structural analysis system of their own and Pro/Engineer system after performing the hull structural modeling with panels using the Pro/Engineer system which is one of general-purpose mechanical systems. However, it was difficult to apply their results to the hull structural modeling at the initial design stage because the hull structure was modeled with only panels without considering stiffeners. Min [12] proposed a data structure based on the object-oriented concept for developing the hull structural design and analysis system. He implemented the prototype system based on the proposed data structure. By using the system, he performed 2D CAD modeling of a simple panel structure and generated a finite element model for structural analysis from the 2D CAD model. However, this data structure could only represent the design information of a simple panel having a 2D shape, and thus this study was insufficient to represent a hull structure having a complex 3D shape. Kim [13] proposed a data structure which can store the geometric and topological information of a simple panel structure having a 3D shape, and implemented the prototype system. However, this data structure could only store the design information of a panel, and thus the prototype system

was possible to perform 3D CAD modeling of a simple hull structure having only panels. Yum [14] proposed a data structure to perform hull structural modeling at the initial design stage and developed the prototype system. By using the system, it was possible to perform modeling of a hull structural part such as a panel and stiffener. However, this data structure can only store the design information of not a whole hull structure but the limited region, i.e. cargo hold region, of the whole hull structure, and moreover the prototype system was possible to perform hull structural modeling of a VLCC. Lee et al. [15] proposed a data structure to perform hull structural modeling at the initial design stage and developed the prototype system. Using the system, it was possible modeling of a structure system unit such as a shell, deck, etc. which corresponds to the modeling unit at the initial design stage, and it was possible to generate the limited production material information of a building block such as the weight, center of gravity, and painting area. However, the proposed data structure cannot represent the relationship between hull structural parts. Thus, the joint length of a building block could not be generated. Park [16] performed a study on the automatic arrangement of stiffeners in the hopper region of the VLCC using the expert system to support the automation of the detailed design. However, this study was not of practical use since it is hard to define quantitatively all design knowledge and to maintain it when the practice of the designer for performing hull structural modeling. Hwang [17] performed a study on the mapping of the 2D hull structural information onto the 3D CAD model using various symbols defined on 2D drawings. However, this study can generate the 3D CAD model of the limited region, i.e. the cargo hold region of a hull structure.

Now let us see the case of existing shipbuilding systems. Recently, many shipbuilding companies are now attempting to perform hull structural modeling at the initial design stage. However, despite the fact that there are many shipbuilding CAD systems such as the TRIBON [18], IntelliShip [19], NUPAS-CADMATIC [20], FORAN [21], NAPA Steel [22], etc. they do not yet have a CAD system supporting the initial design stage in which design changes arise very frequently. The TRIBON system, which was developed by AVEVA several decades ago, has been widely used to generate a production model and extract drawings of a building block unit at the production design stage. This system is known for a proven CAD system. However, it is being reported by many specialists in the shipbuilding industry that the design functions of this system are insufficient to be applied at the initial and detailed design stages due to the limitations of its geometric modeling kernel which was developed long time ago [23].

The IntelliShip system, which was jointly developed among Intergraph, Samsung Heavy Industries in Korea, Hitachi Shipbuilding (currently Universal Shipbuilding) in Japan, and Odense Steel Shipyard in Denmark, is now being used to generate a detailed model of a whole hull structure and production model of a building block unit at the detailed and production design stages, respectively. The IntelliShip system can perform 3D CAD modeling of a whole hull structure at the detailed design stage. However, it is being reported by many

specialists that the size of the generated 3D CAD model is so large that it slows down the running speed due to the combination of problems that arise as a result of the conversion from a general-purpose mechanical CAD system to a shipbuilding CAD system [24]. Other systems such as the NUPAS-CADMATIC, the FORAN, etc. are being used for the production modeling of the hull structure at the production design stage in some shipbuilding companies. However, these systems also require a number of user inputs for generating the 3D CAD model of the hull structure, and thus, they are not suitable for the initial design stage. Moreover, the NAPA Steel was developed by the NAPA some years ago. It fixed a goal of generating the 3D CAD model from the initial design stage at first. However, this system also requires a number of user inputs for generating the 3D CAD model of the hull structure. It took one designer about one month to generate the 3D CAD model of the level-of-detail required at the initial design stage. Thus, it is not suitable for the initial design stage.

As can be seen from the above, many researches and systems have been focused on 3D CAD modeling of the hull structure of the ship. However, they are somewhat insufficient to generate the 3D CAD model, i.e. the hull structural model, which can contain all design information of the ship and reflect design semantics of the designers at the initial design stage. Thus, a data structure for an initial design stage is proposed and the prototype system is developed based on the proposed data structure in this study. The proposed data structure is designed to store all design information of the initial hull structure such as the geometric and topological information, design attributes of hull structural parts, and the relationship information between the hull structural parts. A hull structural model represented by the proposed data structure can reflect design semantics and be used to share the design information between designers instead of 2D drawings.

The remainder of this paper is as follows. Section 2 describes the representation method of the initial hull structure proposed in this study. Section 3 describes the proposed data structure for the initial hull structure. Section 4 describes the prototype system called ‘initial hull structural CAD system’ developed in this study based on the proposed data structure. Section 5 presents application examples. Finally, Section 6 presents a summary.

2. Modeling of the initial hull structure

2.1. Hull structural modeling unit at the initial design stage

At the initial design stage of a ship, the function-oriented definition process of a product, which is focused on functions such as the arrangement, rough definition of the shape, and determination of the dimension of hull structural parts, is necessary to calculate the structural strength and estimated production cost and to satisfy international rules and regulations. In contrast, at the production design stage, the production-oriented generation process of various 2D drawings is necessary to construct the ship as designed in short time. A

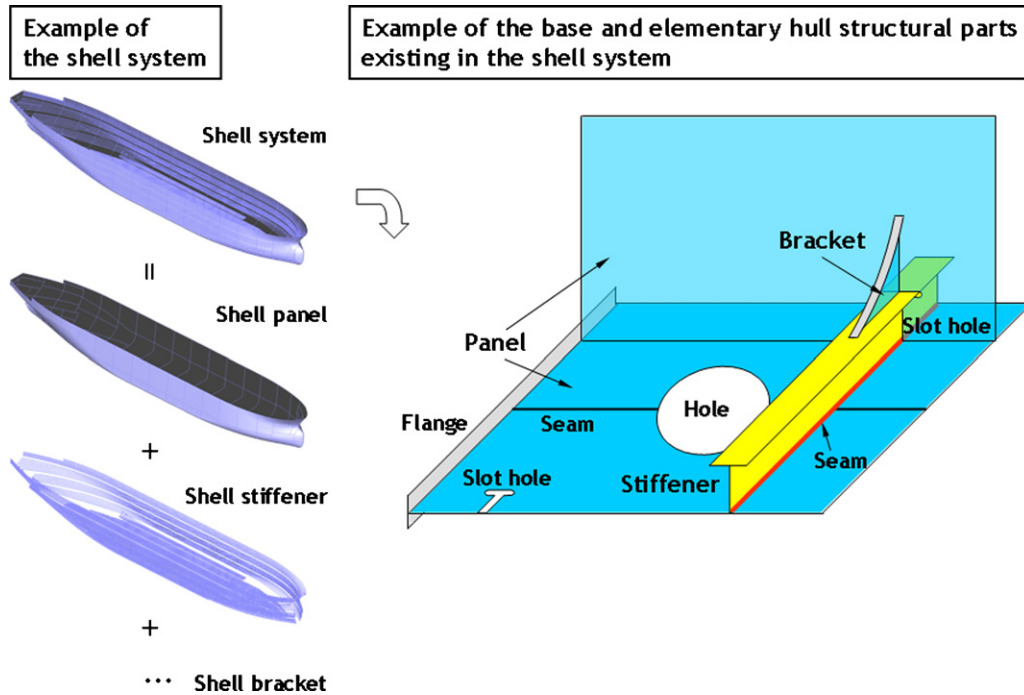


Fig. 2. Example of the base and elementary hull structural parts of the shell system in the initial hull structure of the 300k VLCC.

hull structural modeling unit at the initial design stage which satisfies this requirement is a ‘structure system’. In the initial hull structure, a shell, deck, girder, stringer, bulkhead, web frame, etc. correspond to the structure system. The structure system is composed of many base hull structural parts such as a panel, stiffener, and bracket. The base hull structural part contains many elementary hull structural parts such as a seam, hole, slot hole, and flange. An example of the shell system, base hull structural parts, and elementary hull structural parts that are found in the initial hull structure of the 300k VLCC is shown in Fig. 2.

At the initial design stage, an initial hull structural model, that is, a 3D CAD model of the initial hull structure is generated by performing the initial modeling of a whole hull structure with bigger hull structural parts, such as the structure system and the base hull structural part. Then, at the detailed design stage, a detailed hull structural model is generated by performing the detailed modeling of the whole hull structure with smaller hull structural parts, such as the elementary hull structural part. Finally, at the production design stage, a production hull structural model of a building block unit is generated by performing the production modeling of each building block according to the given block division drawing. Fig. 3 shows the hull structural modeling methods and units at the initial, detailed, and production design stages.

2.2. Analysis of the modeling objects of the initial hull structure

To find the modeling objects to be modeled for the generation of the initial hull structural model, the hull structural parts existing in 2D drawings were first analyzed

such as a midship section drawing, typical transverse bulkhead drawing, typical transverse web frame drawing, etc. of various ships: a VLCC, bulk carrier, container ship, Liquefied Natural Gas (LNG) carrier, etc. Using the analysis results, the modeling objects of the initial hull structure can be divided into two classes: a longitudinal hull structural part and transverse hull structural part, according to its characteristics. A longitudinal hull structural part is required to secure the longitudinal structural strength of a ship. The product information such as the dimension, placing position, thickness, etc. of the longitudinal hull structural part is generally defined in the 2D drawings such as the midship section drawing, construction profile, etc. A transverse hull structural part is required to secure the transverse structural strength of a ship. The product information of the transverse hull structural part is generally defined in the 2D drawings such as the typical transverse bulkhead drawing, typical transverse web frame drawing, etc.

2.3. Analysis of the modeling sequence of the initial hull structure

After performing the analysis of the modeling objects of the initial hull structure, the modeling sequence was analyzed through consultation with specialists of shipbuilding companies. Fig. 4 shows the result. As shown in this figure, the hull form modeling is performed to generate a hull form model after the principal dimension of a ship is determined at the conceptual design stage. Then, the initial hull structural modeling which consists of the completion of the ship compartment model, longitudinal and transverse hull structural modeling is performed. With this result, the initial hull structural model is finally generated.

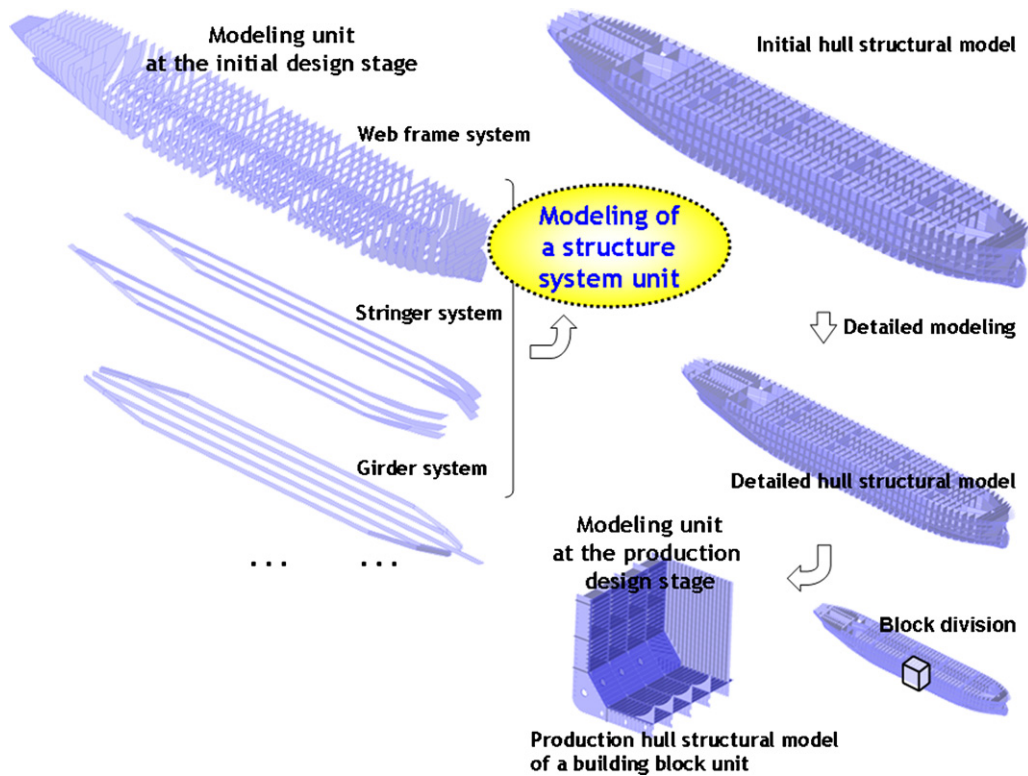


Fig. 3. Hull structural modeling methods and units at the initial, detailed, and production design stages.

2.4. Analysis of the modeling methods of the initial hull structure

The modeling methods were analyzed following the analyses of the modeling objects and sequence of the initial hull structure.

This section presents a portion of the modeling methods: the modeling method of the longitudinal panel. Readers can find more details about the methods in reference [25].

A longitudinal panel can be easily generated using other panels surrounding itself. The modeling process consists of

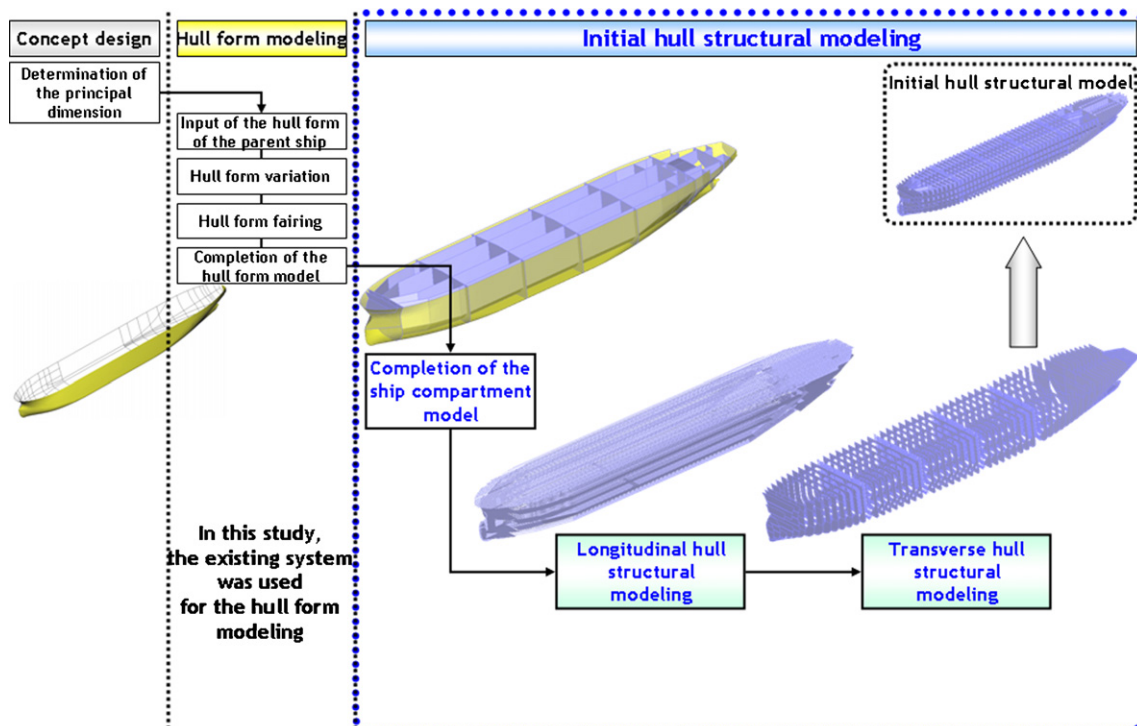


Fig. 4. Modeling sequence of the initial hull structure.

four steps. First, a designer defines the panels surrounding the longitudinal panel to be modeled. Next, the designer generates an infinite plane containing the longitudinal panel. Then, the designer generates the longitudinal panel by inserting the infinite plane to the panels surrounding the longitudinal panel and performing the intersection calculation between the infinite plane and the panels. Lastly, the designer inputs design attributes of the longitudinal panel such as the thickness, material, etc. Fig. 5 shows the modeling method of a stringer panel, which is a representative longitudinal panel and exists between the shell panel and side longitudinal bulkhead panel.

2.5. Representation method of the initial hull structure

As explained above, the modeling objects, sequence, and methods of the initial hull structure were analyzed. After completing these analyses, the representation method of the initial hull structure was proposed considering the relationship between the hull structural parts. The representation method proposed herein will be explained in detail in the following subsections.

2.5.1. Horizontal relationship between the hull structural parts

A seam which can be regarded as a welding line is used to represent how two hull structural parts are connected to each other. There are two types of the seam: fillet seam and butt seam. The fillet seam represents the welding line between two different base hull structural parts, e.g. the welding line between the panel and stiffener. One the other hand, the butt seam represents the welding line between two plates in one base hull structural part, e.g. the welding line between two plates in the panel. Here, the welding line between the hull

structural parts can be regarded as the horizontal relationship between them. This relationship information is required to generate the production material information such as the joint length, and can be used to generate a finite element model for structural analysis later. Thus, in this study, butt and fillet seams are introduced and contained explicitly in the data structure to represent the horizontal relationship between the hull structural parts. Fig. 6 shows an example of the representation of the horizontal relationship between a panel and stiffeners by using fillet seams in the TRIBON system and existing studies [13–15], IntelliShip system, and this study.

In the existing systems and studies, a list of the stiffeners placed on the panel is stored as a design attribute of the panel or in an independent data base in the form of a table called a relation table. The joint line is calculated from the intersection calculation between the panel and stiffener whenever deemed necessary. In this study, a seam was introduced explicitly in the data structure. The seam contains information on the hull structural parts which are welded to each other by the seam and its geometric information as design attributes. For example, ‘Fillet seam 1’ has ‘Panel’ and ‘Stiffener 1’ and joint line (‘Curve 1’) as design attributes. Here, the joint line is generated by performing the intersection calculation between them when ‘Stiffener 1’ is placed on ‘Panel’. Thus, the hull structural parts which are welded to each other by the butt or fillet seam can be obtained from the corresponding seam. Furthermore, the joint line can be immediately obtained from the geometric information of the corresponding seam without having to perform any additional intersection calculation. Like this, the horizontal relationship between the hull structural parts is represented as the butt or fillet seam in this study.

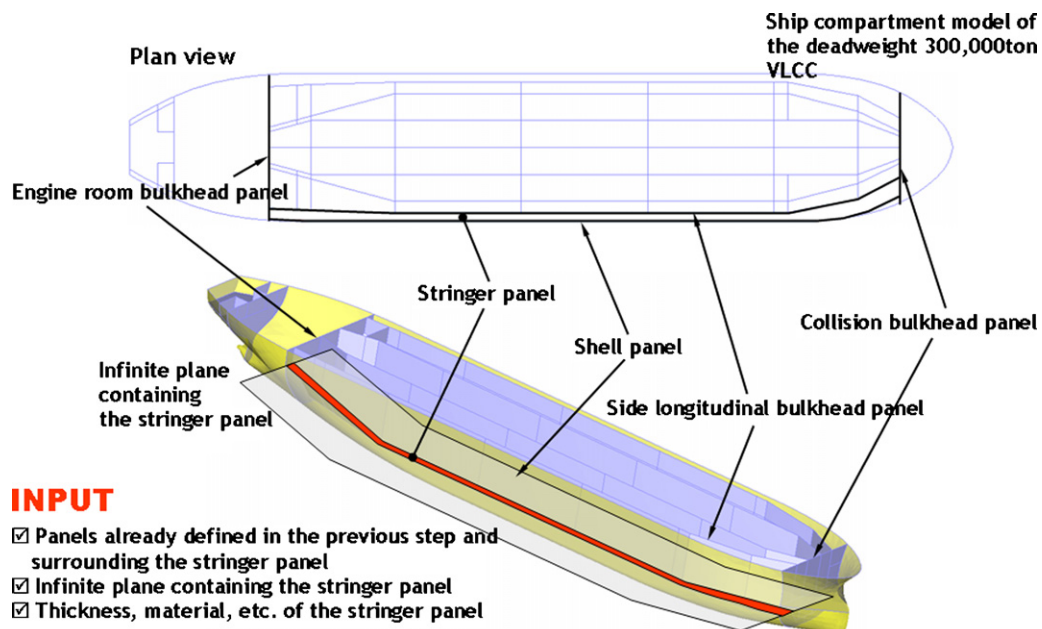


Fig. 5. Modeling method of the stringer panel by using other panels surrounding itself.

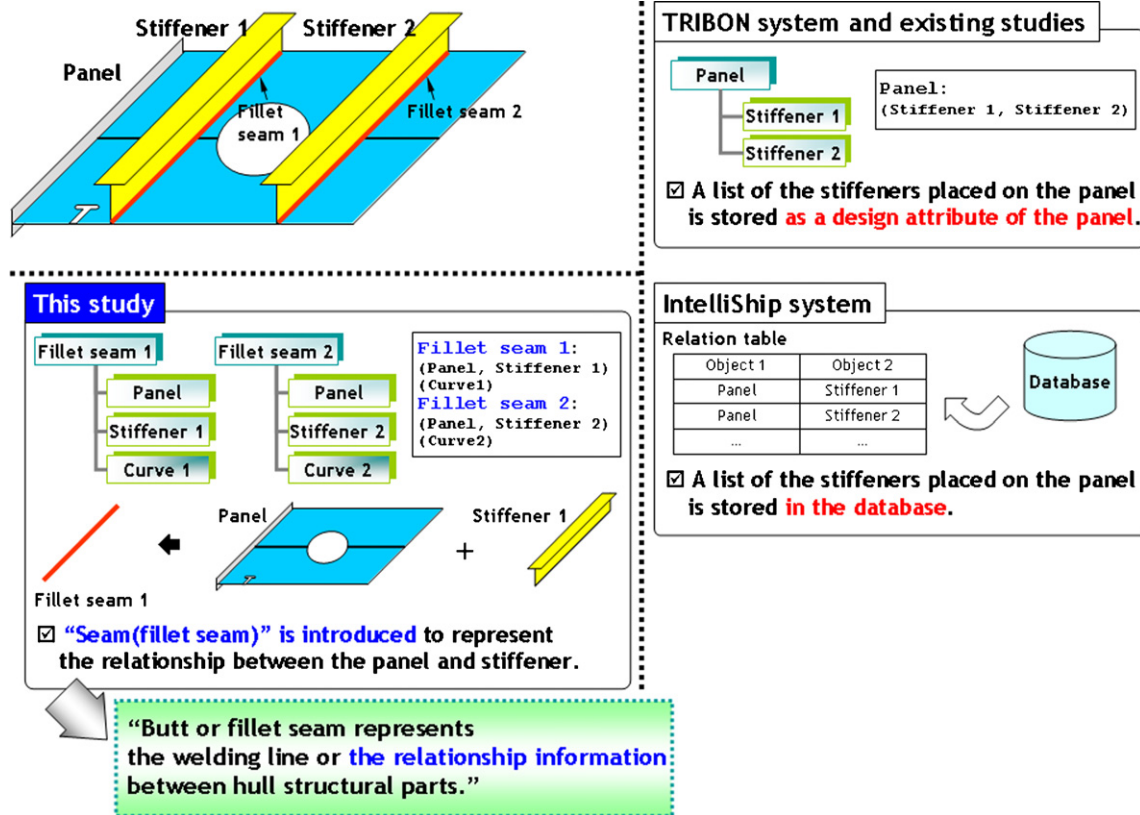


Fig. 6. Representation of the horizontal relationship between the hull structural parts in the TRIBON system and existing studies, IntelliShip system, and this study.

2.5.2. Vertical relationship between the hull structural parts

The feature-based modeling method [26,27] involves generation of the 3D CAD model of a product by using a feature as well as geometric entities which correspond to the low level entity such as a vertex, edge, face, etc. Here, the feature represents the high level entity which has an engineering meaning in the corresponding field such as mechanical engineering, shipbuilding, etc. Brunetti and Golob [28] proposed the concept of the feature-based product data model. The basic concept of this model is to systematically store the design information of a product such as the product information consisting of various features, through four steps: an assembly level, part level, feature level, and generic level, as shown in Fig. 7. The product information of the assembly level (e.g. an engine assembly, steering assembly, etc. for a car; a shell, deck, etc. for a ship) is represented as the composition information of assemblies and the assembly sequence information of them represented as a tree type. The product information of the assembly level contains also the information of parts existing in each assembly. The product information of the part level (e.g. a shaft, gear, etc. for a car; a panel, stiffener, etc. for a ship) contains all product information of parts existing in the assemblies, as well as the information of features existing in each part. The product information of the feature level (e.g. a chamfering, hole, pocket, etc. for a car; butt and fillet seams, hole, slot hole, etc. for a ship) contains all product information of features existing in the parts, as well as the information of

geometric information, design attributes, function, etc. existing in each feature. The product information of the generic level (a surface, curve, etc. for a car and ship) contains all product information of geometric information, design attributes, function, etc.

If a designer defines the relationship of the product information by using the feature-based product data model, it is possible to trace the hierchic or vertical relationship between objects according to the product modeling process and to keep up with design changes. Furthermore, it is easy to search for and manage the product information because the designer can compose systematically the assembly sequence, generation of the production material information, extraction of the Bill Of Material (BOM), etc. as well as the product itself. This function is one of the important functions of the Product Data Management (PDM) system, which began to be widely in recent years. Thus, in this study, the feature-based product data model which is known to have many merits was applied to represent the vertical relationship between the hull structural parts. Fig. 7 shows the representation of the vertical relationship between the hull structural parts by using the feature-based product data model.

2.5.3. Product information of the hull structural part

As mentioned in Section 1.2, at the initial design stage, a designer defines most of the product ('ship') information on 2D drawings. Fig. 8(a) shows the product representation method of the midship region of the 300k VLCC which was

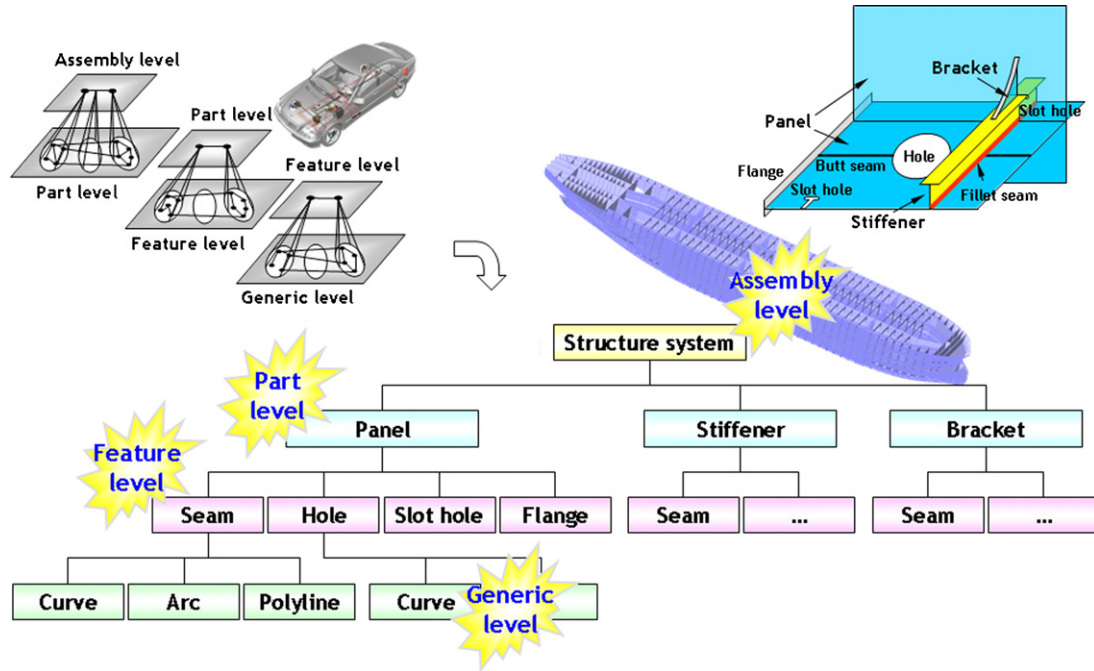


Fig. 7. Representation method of the vertical relation between the hull structural parts by using the feature-based product data model.

represented on 2D drawing by the designer. Fig. 8(b) shows the corresponding 3D CAD model reflecting design semantics, that is, shipbuilding design meaning of the designer as well as containing all design information. Fig. 8(c and d) shows the portions of the 2D drawing and 3D CAD model shown in

Fig. 8(a and b), respectively. In Fig. 8(c), the dashed line and arrow represents the stiffener that is placed in a specific position on the back side of the panel. This is how a designer represents the design results of the product with the minimal product information on the 2D drawing. Here, the minimal product

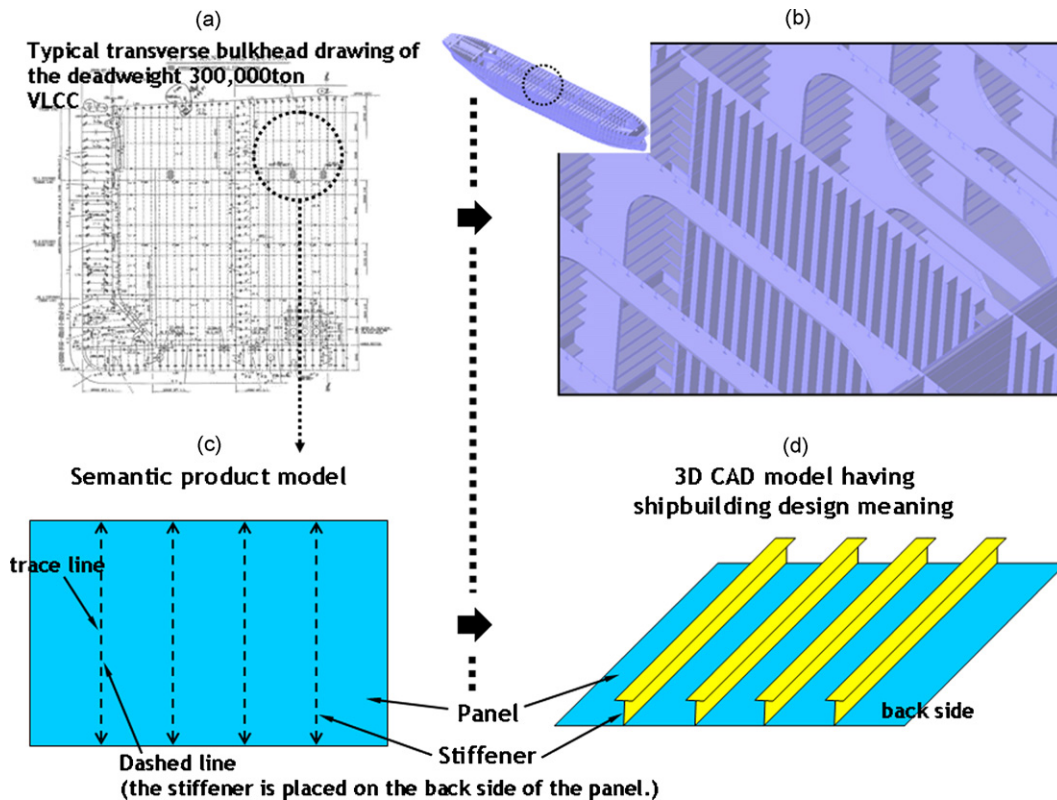


Fig. 8. Representation of the product information of the hull structural part by using the semantic product model.

information is the geometric information of the placing curve of the stiffener ('trace line'), design attributes (e.g. section type, material, etc.), and relationship information between the panel and stiffener, that is, the information representing that the stiffener is placed on the back side of the panel. However, it would be better if the designer can represent the 3D CAD model containing the design information and reflecting his design semantics on the 2D drawing. To this end, the semantic product model, which had been early proposed by us, was introduced in this study. Here, the semantic product model means the 3D CAD model having shipbuilding design meaning which is represented by the minimal product information. The minimal product information of the hull structural part, also called the semantic product model information, looks like simplified digital information on the outside. However, on the inside, it contains all the product information necessary to generate the 3D CAD model having shipbuilding design meaning. Thus, such 3D CAD model can be generated from the minimal product information at any time. In this study, the product information of the hull structural part, that is, the product information which the hull structural part should have was successfully represented using the semantic product model.

The representation method of the initial hull structure proposed in this study can be summarized as follows. First, the horizontal relationship between the hull structural parts is represented using the butt and fillet seams. Second, the vertical relationship is represented using the feature-based product data model. Finally, the product information of the hull structural part is represented using the semantic product model.

3. Proposal of the data structure for the initial hull structure

A 3D CAD model generated from the general-purpose CAD system with geometric and topological entities such as points, curves, surfaces, vertices, edges, faces, etc. does not have specific meaning in itself. An initial hull structural model of the 300k VLCC shown in Fig. 8(b) is merely the 3D CAD model before specific meaning is given to the model. To give specific meaning in a certain engineering field to the 3D CAD model, the specific meaning suitable for the field is to be given to the geometric and topological entities existing in the model. For example, these entities need to have specific meaning which indicates that they correspond to certain structure systems or hull structural parts so that the 3D CAD model becomes the initial hull structural model having shipbuilding design meaning. This is possible by developing a data structure for the initial hull structure which makes it possible to store the product information of the initial hull structure, that is, the hull structural information in the 3D CAD model.

As described in Section 2, we performed analyses of the modeling objects, modeling sequence, and modeling methods of the initial hull structure, and then proposed the representation method of the initial hull structure. Based on these results, we proposed a data structure for the initial hull structure. It will be presented below.

3.1. Data structure for the initial hull structure

The proposed data structure can store the hull structural information. Here, the hull structural information to be stored in the data structure is the geometric and topological information, design attributes of hull structural parts, and relationship information between the hull structural parts. Fig. 9 shows the proposed data structure represented in the form of a class diagram of UML. In this figure, the class 'EzStuctSystem' corresponds to a structure system. The classes 'EzPanel', 'EzStiffener', and 'EzBracket' correspond to a base hull structural part such as a panel, stiffener, and bracket. The classes 'EzSeam0', 'EzSeam1', 'EzHole', 'EzSlot', 'EzFlange', 'EzScallop', and 'EzMarking' correspond to an elementary hull structural part, such as a seam, hole, slot hole, flange, scallop, and marking line. Finally, the classes 'EzPolyEdge', 'EzPolyEdge0', 'EzPolyEdge1', 'EzGeoCurve', 'EzGeoArc', 'EzGeoPolyLine' are used to represent the geometric information of a hull structural part.

3.2. Representation of the initial hull structure by using the proposed data structure

Fig. 10 gives an example of the representation of a simple hull structure by using the proposed data structure. The simple structure consists of one structure system which is made of two panels, one stiffener, and one bracket. As shown in this figure, the hull structural information for roughly representing the structure system consists of four elements: 'Panel List', 'Stiffener List', 'Bracket List', and 'Property'. The 'Panel List', 'Stiffener List', and 'Bracket List' represent lists of the panels, stiffeners, and brackets existing in the structure system, respectively. The 'Property' represents design attributes of the structure system such as the name. Here, these elements correspond to the minimal product information for representing the corresponding structure system, that is, the semantic product model information.

Fig. 11 gives an example of the representation of the panel ('Panel 1') in the structure system shown in Fig. 10. As shown in this figure, the hull structural information for representing the panel consists of four elements: 'BB (Base Boundary)', 'Layer', 'Property', and 'Model'. The 'BB' represents an outer boundary of the panel without regarding the shape of elementary hull structural parts such as butt and fillet seams, hole, slot hole, and flange. The 'Layer' represents a list of the elementary hull structural parts placed on the panel. The 'Property' represents design attributes of the panel such as the thickness, material, etc. Lastly, the 'Model' represents the final shape, that is, the 3D CAD model or initial hull structural model of the panel with regarding the shape of the elementary hull structural parts. Here, the 'BB', 'Layer', and 'Property' correspond to the semantic product model information. The 'Model' corresponds to the information for generating the initial hull structural model of the panel which can be generated using the semantic product model information. That is, the hull structural information of the 'BB', 'Layer', and 'Property' is stored and then kept in the data structure. On the other hand,

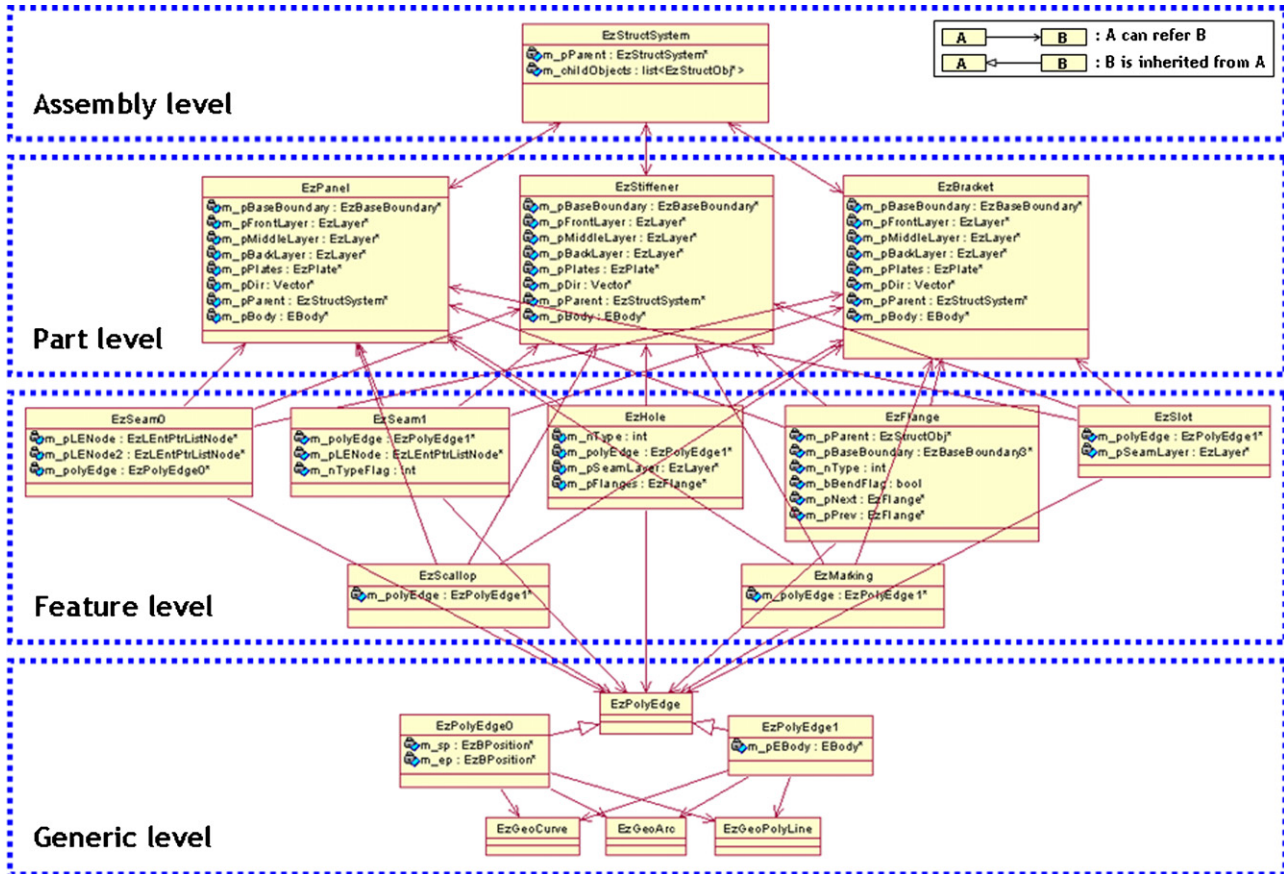


Fig. 9. Proposed data structure for the initial hull structure in the form of the class diagram of UML.

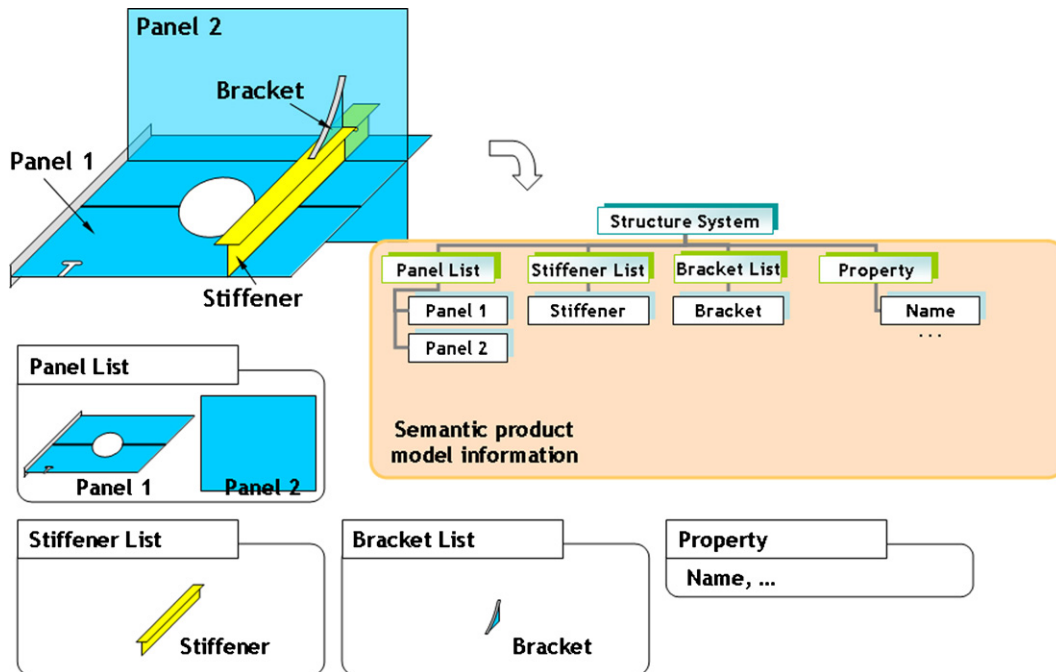


Fig. 10. Example of the representation of the structure system by using the proposed data structure.

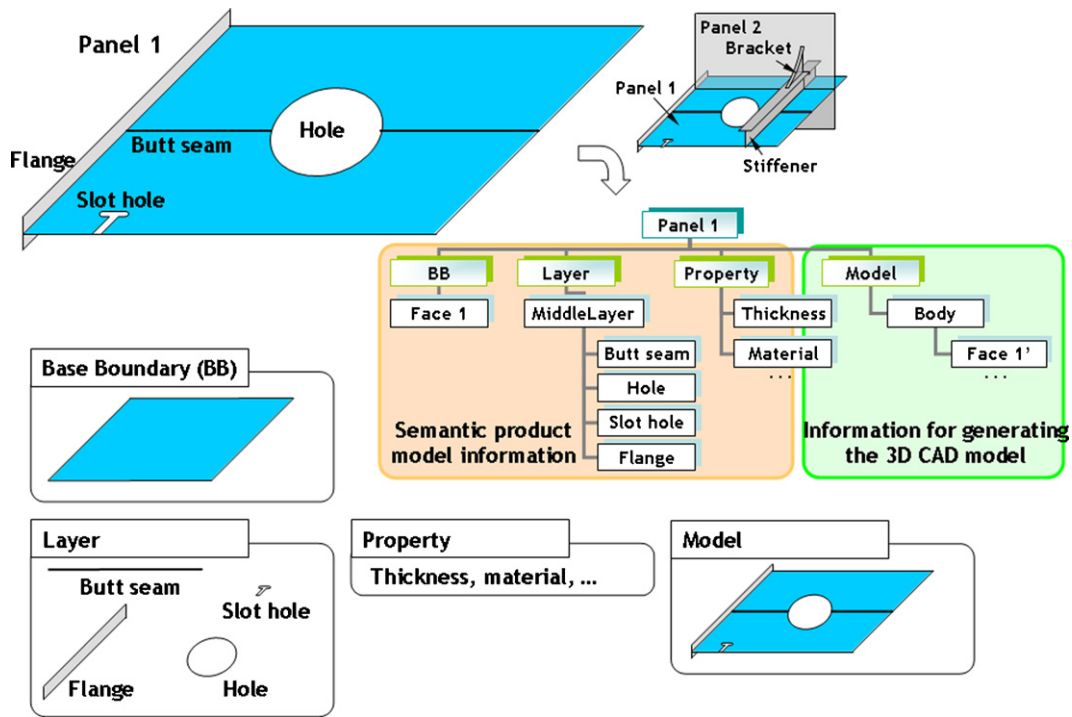


Fig. 11. Example of the representation of the panel by using the proposed data structure.

the hull structural information of the ‘Model’ is temporarily generated and then used when the initial hull structural model of the panel needs to be known.

Fig. 12 gives an example of the representation of the stiffener (‘Stiffener’) placed on the panel in the structure system. As shown in this figure, the hull structural information for representing the stiffener is similar to that of the panel. The

only difference is the ‘BB’ which represents an outer boundary of the stiffener. To be brief, in the case of the panel, the ‘BB’ consists of a set of faces, whereas in the case of the stiffener, the ‘BB’ consists of a set of edges representing the trace line of the stiffener. Of course, in the latter case, the ‘BB’ can be also comprised of a set of faces as in the case of the panel. However, the ‘BB’ of the stiffener consists of a set of edges in this study.

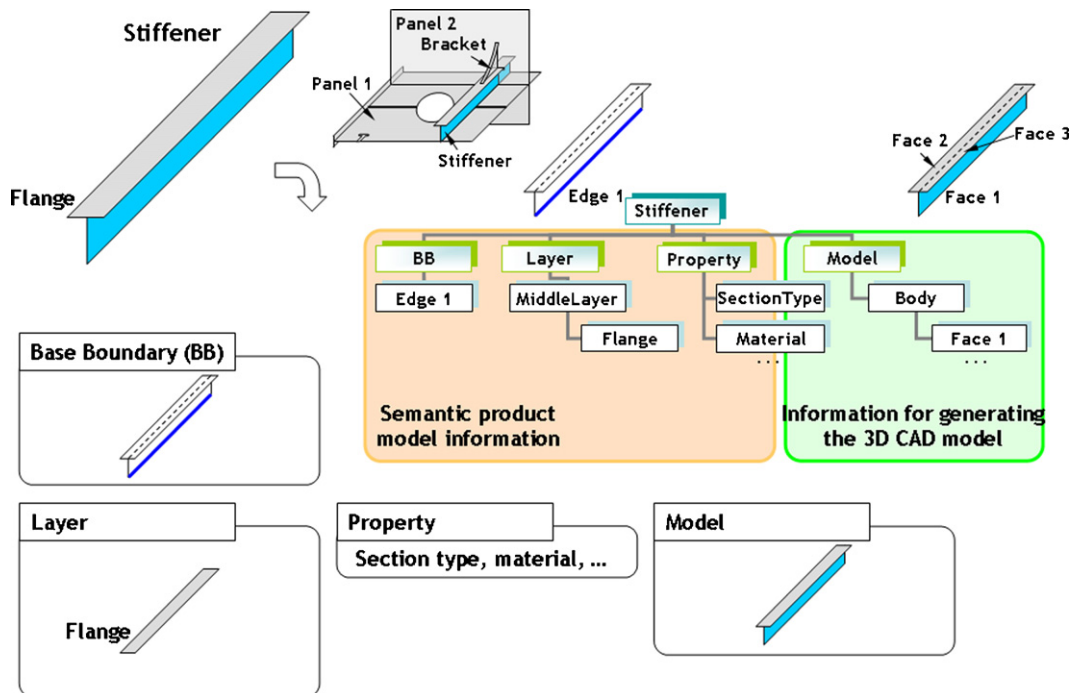


Fig. 12. Example of the representation of the stiffener by using the proposed data structure.

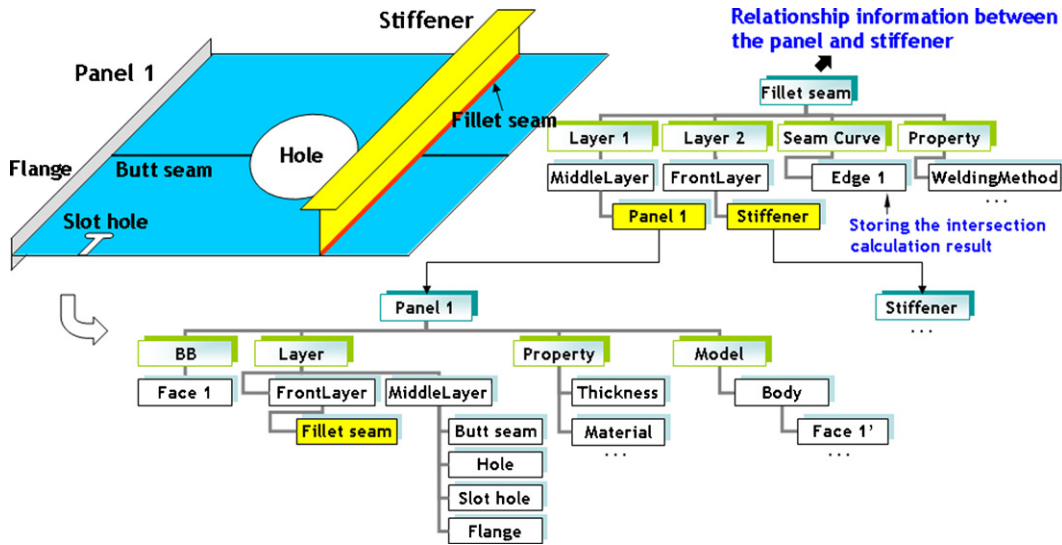


Fig. 13. Example of the representation of the fillet seam by using the proposed data structure.

This coincides with the concept of the semantic product model that the hull structural part should be represented with the minimal product information. Moreover, this helps to efficiently represent a great number of stiffeners existing in the initial hull structure.

When the stiffener (“Stiffener”) is placed on the panel (“Panel 1”), a welding line, that is, a fillet seam representing the relationship between them should be generated. Fig. 13 gives an example of the representation of the fillet seam (“Fillet seam”).

As shown in this figure, the hull structural information for representing the fillet seam consists of four elements: ‘Layer 1’, ‘Layer 2’, ‘Seam Curve’, and ‘Property’. The ‘Layer 1’ represents the first base hull structural part that is connected by the fillet seam (e.g. ‘Panel 1’ in this figure). The ‘Layer 2’ represents the second one (e.g. ‘Stiffener’ in this figure). The ‘Seam Curve’ represents the geometric information of the fillet seam after placing the ‘Stiffener’ on the ‘Panel 1’. Lastly, the ‘Property’ represents design attributes of the fillet seam such as

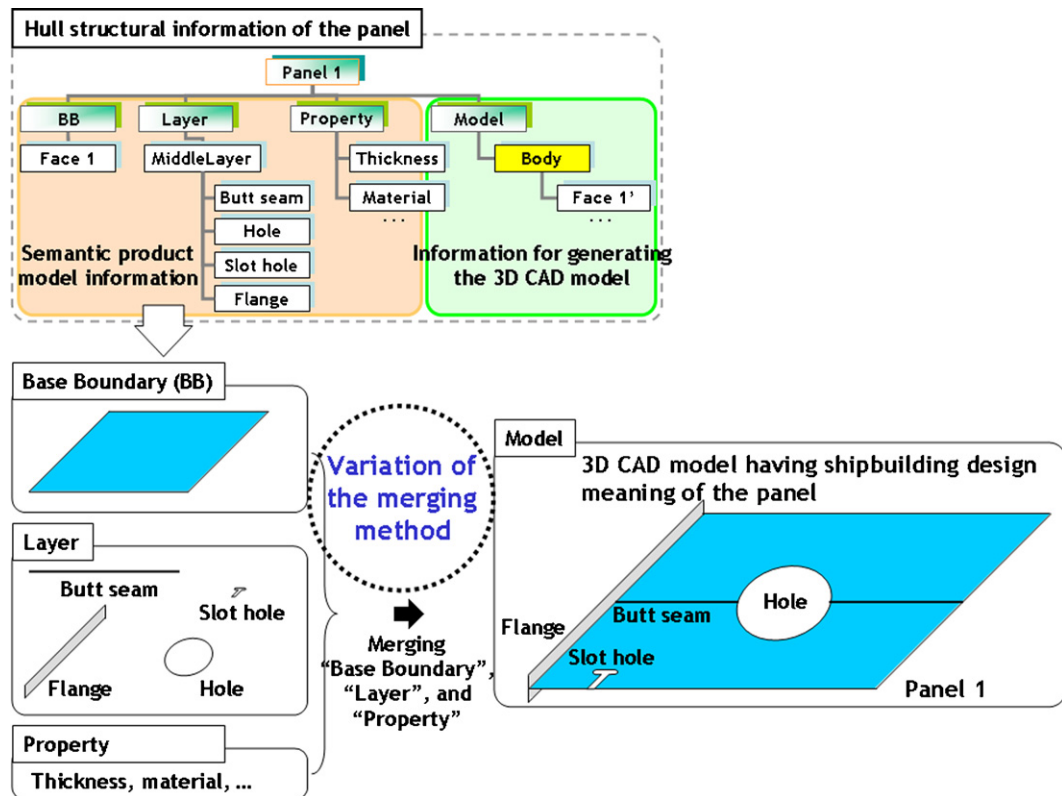


Fig. 14. Example of the generation of the initial hull structural model of the panel from the hull structural information in the data structure.

the welding method, welding thickness, etc. That is, the fillet seam contains information on the hull structural parts which are welded to each other by the seam, its geometric information, and design attributes. Thus, a fillet seam is an important hull structural part to represent the relationship between hull structural parts in this study.

3.3. Generation of the initial hull structural models of various level-of-details

As described above, the hull structural information of the base hull structural part is separately stored into two portions in the proposed data structure. The first portion (e.g. ‘Model’) is essential and the second portion (e.g. ‘BB’, ‘Layer’, and ‘Property’) can be temporarily generated from the first portion at any time, as shown in Fig. 14. Thus, the initial hull structural models of various level-of-details can be generated in the manner the designer wishes when the information of the ‘Model’ is generated from the information of the ‘BB’, ‘Layer’, and ‘Property’.

For this, the representation method of various level-of-details of each elementary hull structural part such as a butt seam, hole, slot hole, and flange was predetermined in this study, as shown in Fig. 15. For example, in the case of the butt seam, in the low level-of-detail, the butt seam is not regarded on the base hull structural part. In the medium level-of-detail, only the trace line of the butt seam is imaginarily represented on the base hull structural part and the butt seam is not actually placed on the base hull structural part. The butt seam is actually placed on the base hull structural part in the high

level-of-detail. Therefore, the initial hull structural model of a low level-of-detail of the base hull structural part can be generated using that of a low level-of-detail of each elementary hull structural part. Similarly, the initial hull structural models of a medium and high level-of-details of the base hull structural part can be generated using those of a medium and high level-of-details of each elementary hull structural part, respectively.

Fig. 15(a–c) shows examples of the generation of the initial hull structural models of the low, medium, and high level-of-details of the panel, respectively.

Fig. 16 gives an example of the generation of the initial hull structural models of various level-of-details of the 300k VLCC. In this figure, the initial hull structural model of the low level-of-detail (‘the simplified model’) is shown with that of the high level-of-detail (‘the more detailed model’).

In this manner, the initial hull structural models of various level-of-details can be generated as desired by the designer, using the hull structural information of the initial hull structure which is stored in the data structure. That is, the simplified model can be generated by considering only outer boundaries of the base hull structural parts. This can be very useful when performing rapid hull structural modeling or generating a finite element model for the global structural analysis. Furthermore, the more detailed model can be generated by considering outer boundaries of the base hull structural parts with regarding the shape of the elementary hull structural parts. This can be very useful when performing detailed hull structural modeling or generating a finite element model for the local structural analysis.

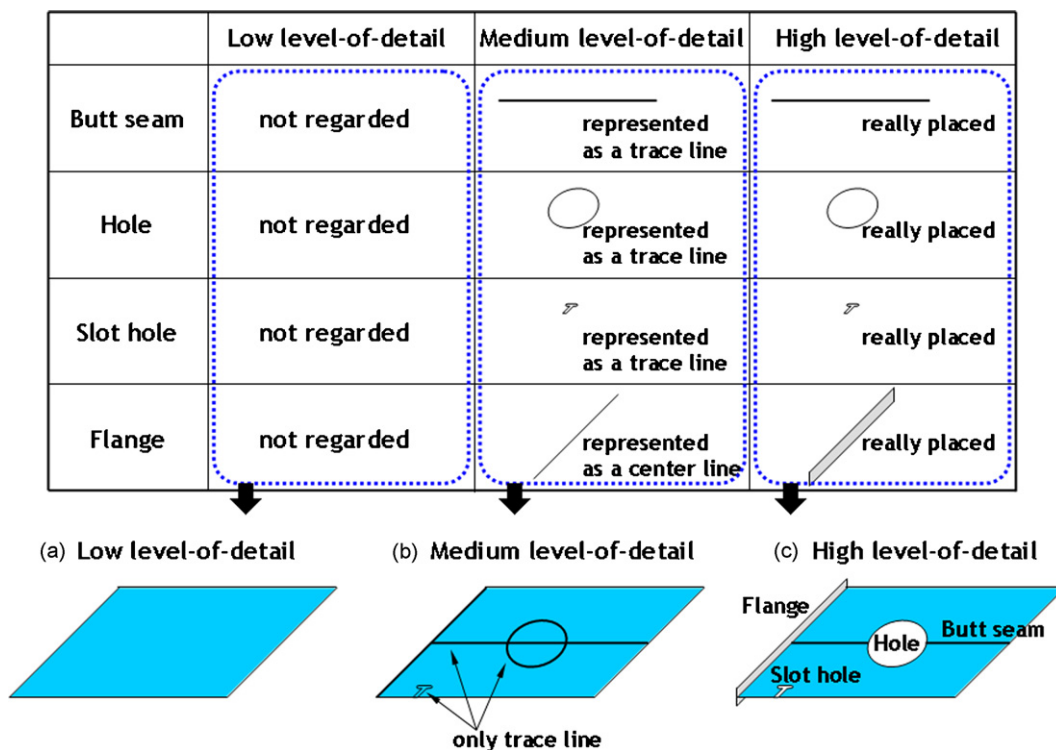


Fig. 15. Representation method of various level-of-details of the elementary hull structural parts.

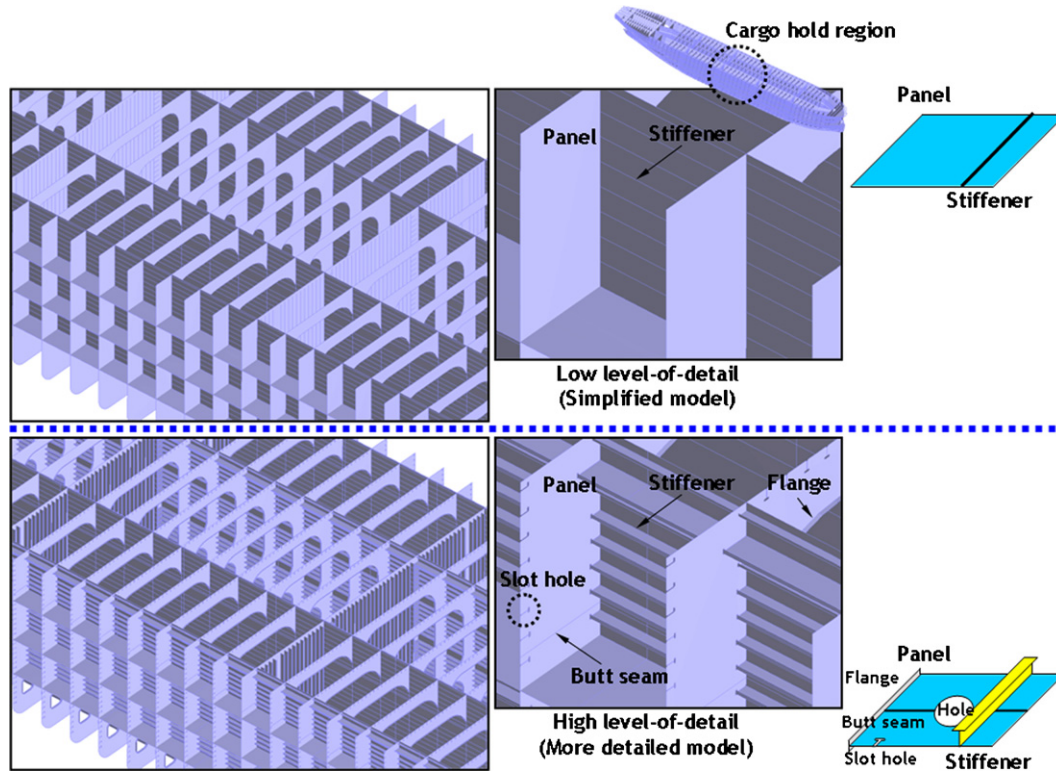


Fig. 16. Example of the generation of the initial hull structural models of various level-of-details of the 300k VLCC.

4. Development of the initial hull structural CAD system

4.1. System configuration

The developed system which was implemented by using the C++ language consists of seven modules. The first module is a data structure for the initial hull structure described in Section 3.1. The second module is a hull structural modeling function. It is a function to generate and store the hull structural information in the proposed data structure. This hull structural information can be given or generated using user input, the data generated from internal calculation such as intersection

calculation, etc. We can state that the hull structural modeling function instantiates the data structure and stores the generated hull structural information in the corresponding position of the instantiated data structure. The third module is a function to generate an initial hull structural model of a whole hull structure using the hull structural information in the data structure as described in Section 3.3. The fourth module is a function to generate the production material information for the initial process planning and scheduling using the hull structural information in the data structure. It generates such information of a building block unit such as the weight, center of gravity, painting area, joint length for welding, etc. The fifth module is a user interface. It is a tool to get input data, which are required

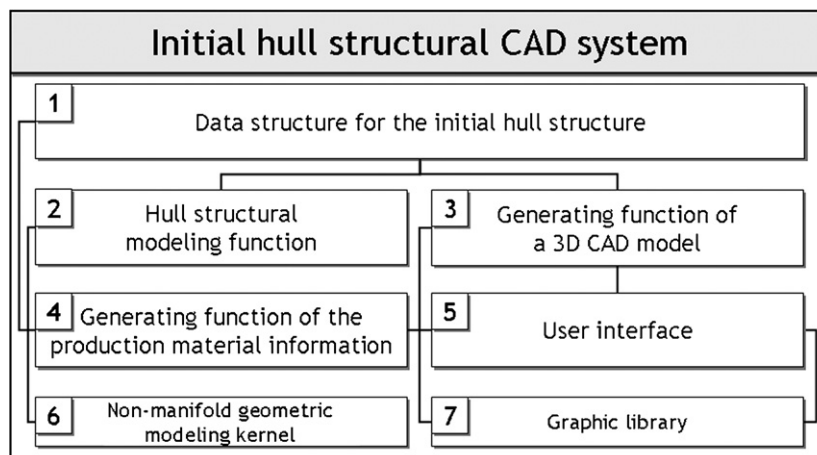


Fig. 17. Configuration of the initial hull structural CAD system.

for generating the hull structural information in the hull structural modeling function, from a designer. The sixth module is a geometric modeling kernel. It is a tool to store the geometric and topological information of the hull structural parts in the data structure through the hull structural modeling function. In this study, a non-manifold geometry modeling kernel [29], which had been developed by us, was used. The last module is a graphic library which is used to visualize the initial hull structural model of the hull structure on the display. In this study, a graphic library [30], which had been also developed by us, was used. Fig. 17 shows the configuration of the developed system.

Below, the details of the hull structural modeling function and generating function of the production material information are described. For details on other modules, please see corresponding sections of this paper or references.

4.2. Hull structural modeling function

Various hull structural modeling functions such as generating functions of a panel, stiffener, etc. are used to perform hull structural modeling and generate the initial hull structural model at the initial design stage. A suitable modeling function for generating each structural part is required because a modeling method is different for different hull structural parts. Thus, in the developed system, many modeling functions for various hull structural parts, which are based on detailed modeling methods of design experts, were implemented. Fig. 18 shows an example of the hull structural modeling function for generating a stiffener ('Stiffener') on the panel ('Panel 1'). In this figure, we can see how the modeling function stores the hull structural information of the stiffener in the data structure. That is, the data structure becomes equal to that of Fig. 13 after performing this modeling function.

As can be seen from this figure, this modeling function undergoes three steps. First (Step (1)), the data structure is generated to store the hull structural information of the stiffener such as the design attributes of the stiffener. Next (Step (2)), the topological entity is generated to represent the geometric and topological information of the stiffener. Lastly (Step (3)), the relationship information between the panel and stiffener, that is, the fillet seam ('Fillet seam') is generated.

4.3. Generating function of the production material information

At the initial process planning and scheduling stages, designers of a shipbuilding company normally determine the work sequences and methods, necessary resources, work duration, etc. based on existing enterprise resources. To perform these tasks, the production material information of a building block unit must be given. On the other hand, at the initial design stage, the initial hull structural model of a whole hull structure is generated through hull structural modeling of a structure system unit. Thus, a block division method, with which the initial hull structural model can be divided into a number of building blocks, is necessary because the requirement unit of the production material information at the initial process planning and scheduling stages ('building block') is different from the hull structural modeling unit at the initial design stage ('structure system'). In this study, we developed two kinds of block division methods: one uses a rectangular solid while the other uses a subdivision plane.

Fig. 19 represents the overall process of the generating function of the production material information by using a subdivision plane. As shown in this figure, this process consists of four steps. First (Step (1)), a subdivision plane is generated to

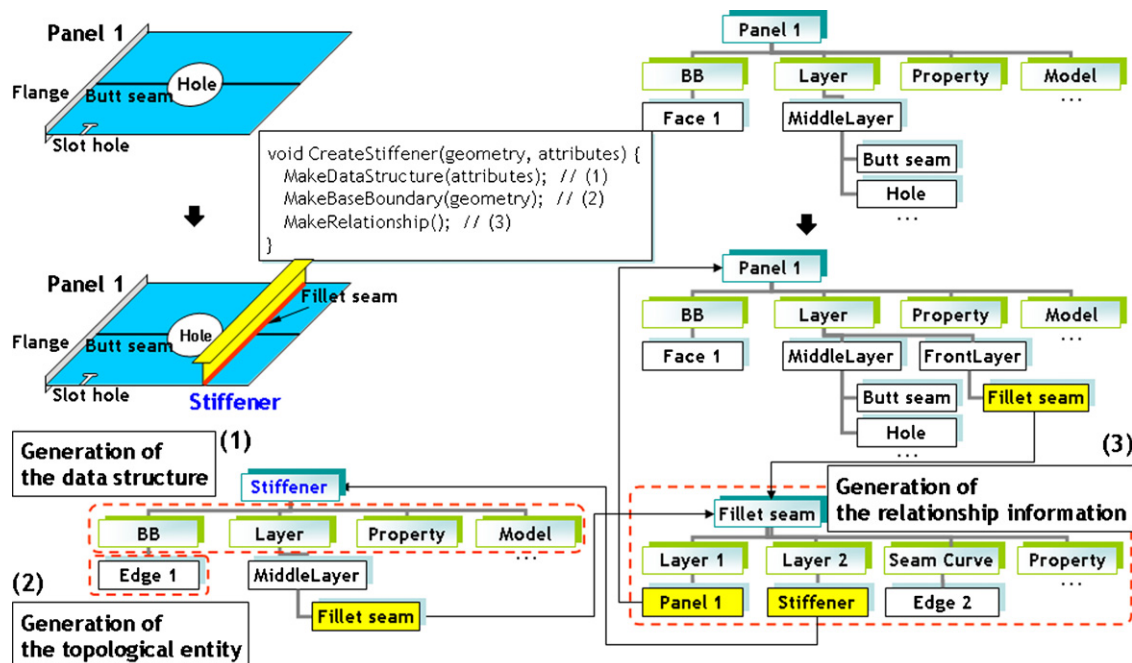


Fig. 18. Example of the hull structural modeling function for generating a stiffener on the panel.

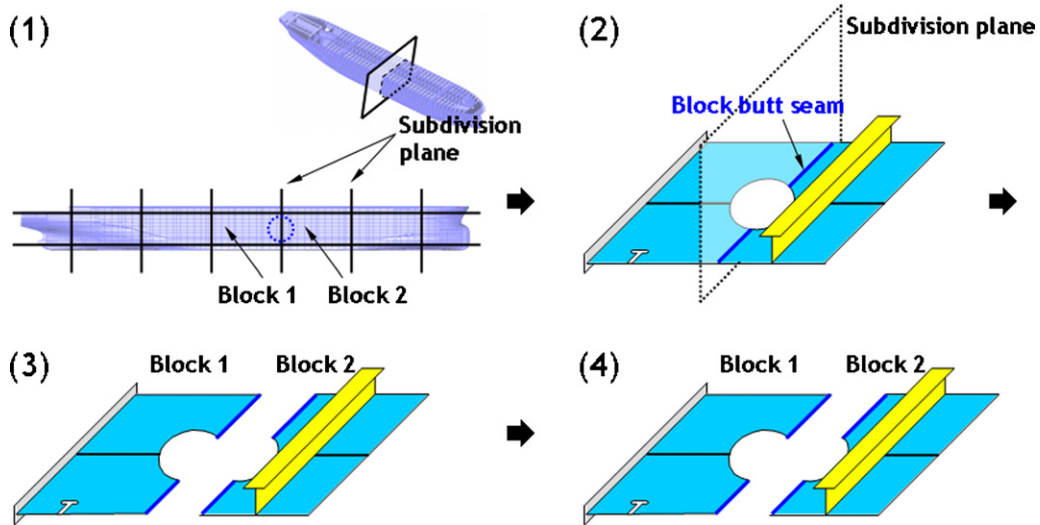


Fig. 19. Overall process of the generating function of the production material information of a building block unit.

divide the initial hull structure into a number of building blocks. Next (Step (2)), block butt seams are placed on the hull structural parts through the intersection calculation between the subdivision plane and all hull structural parts. Then (Step (3)), all hull structural parts are grouped into a building block unit using the block butt seams. Lastly (Step (4)), the production material information of each building block is generated from that of all hull structural parts existing in the corresponding building block.

4.4. User interface

A user interface is a tool to be used for gathering input data from the designer. These data are required for performing the hull structural modeling function. For example, if a designer places a stiffener on the panel, the designer must input information such

as the panel for the stiffener, the placing position of the stiffener, and design attributes of the stiffener such as the section type, material, etc. The user interface does not have important meaning in itself. However, the modeling time may differ depending on the usefulness of the user interface to be designed. Fig. 20 shows the script file-based user interface developed in this study. As shown in this figure, the hull structural modeling procedure of the developed system is comprised of three steps using the script file-based user interface. First (Step (1)), a designer generates a sketch section of the hull structural part to be generated using the intersection calculation between a ship compartment model and infinite plane. Next (Step (2)), the designer generates the hull structural part as if making a 2D drawing using various commands for a script file. Lastly (Step (3)), the designer inputs design attributes of the hull structural part.

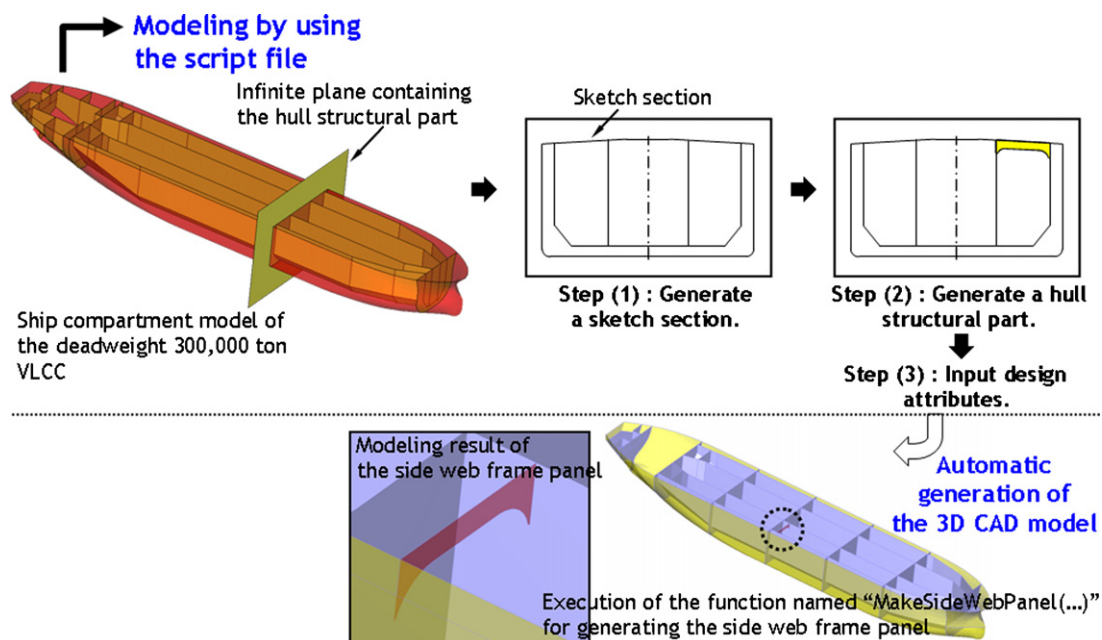


Fig. 20. Example of the script file-based user interface developed in this study.

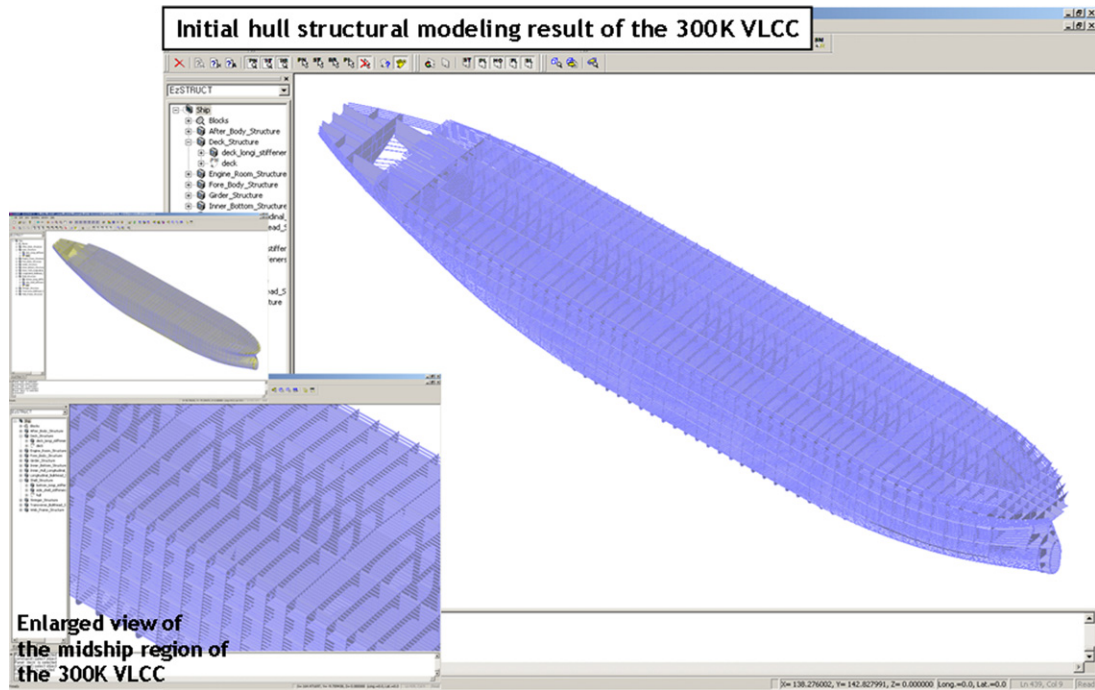


Fig. 21. Result of the initial hull structural modeling of the whole hull structure of the 300k VLCC.

5. Application to hull structural design of the deadweight 300,000 tonne VLCC

The developed system based on the proposed data structure was successfully verified by application to hull structural modeling and generation of the production material information of various ships. This section presents a portion of the verification process. Figs. 21 and 22 present results of the initial hull structural modeling of a whole hull structure and the inside

of a cargo hold region of the 300k VLCC by using the developed system, respectively. Using the developed system, it took one designer about 2–3 days to generate these results of the level-of-detail required at the initial design stage. However, in the case of the TRIBON system, it takes one designer about 1 week to perform averagely the production modeling of only one building block. Of course, the modeling time may differ depending on the complexity of the building block to be modeled. In the case of the IntelliShip system, it takes one

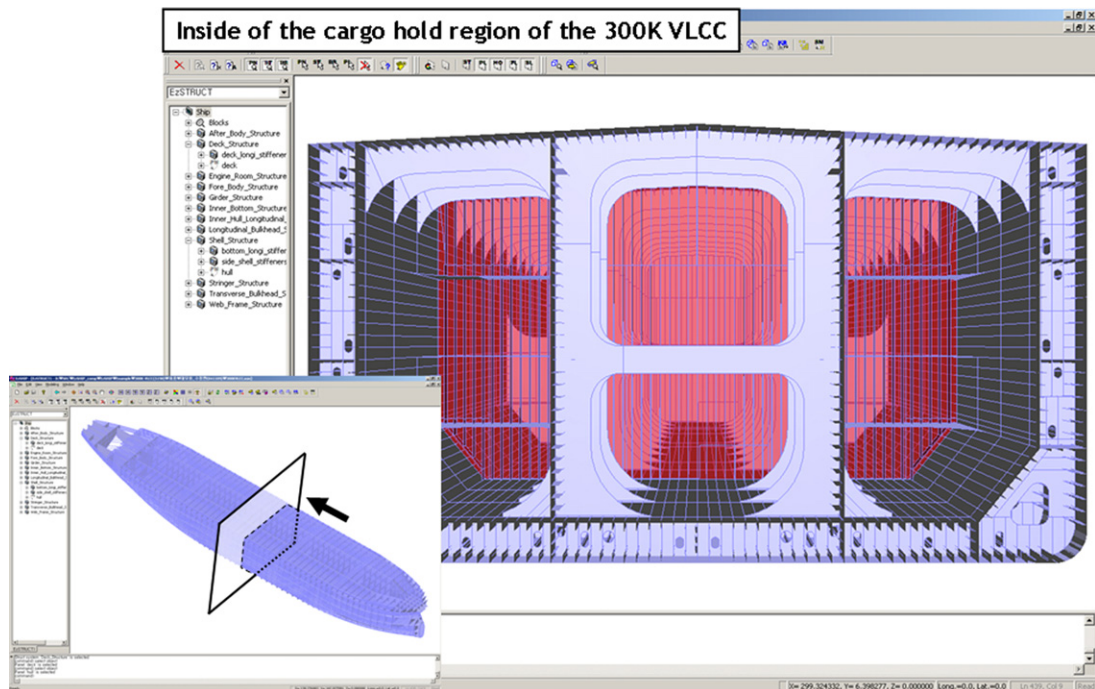


Fig. 22. Result of the initial hull structural modeling of the inside of the cargo hold region of the 300k VLCC.

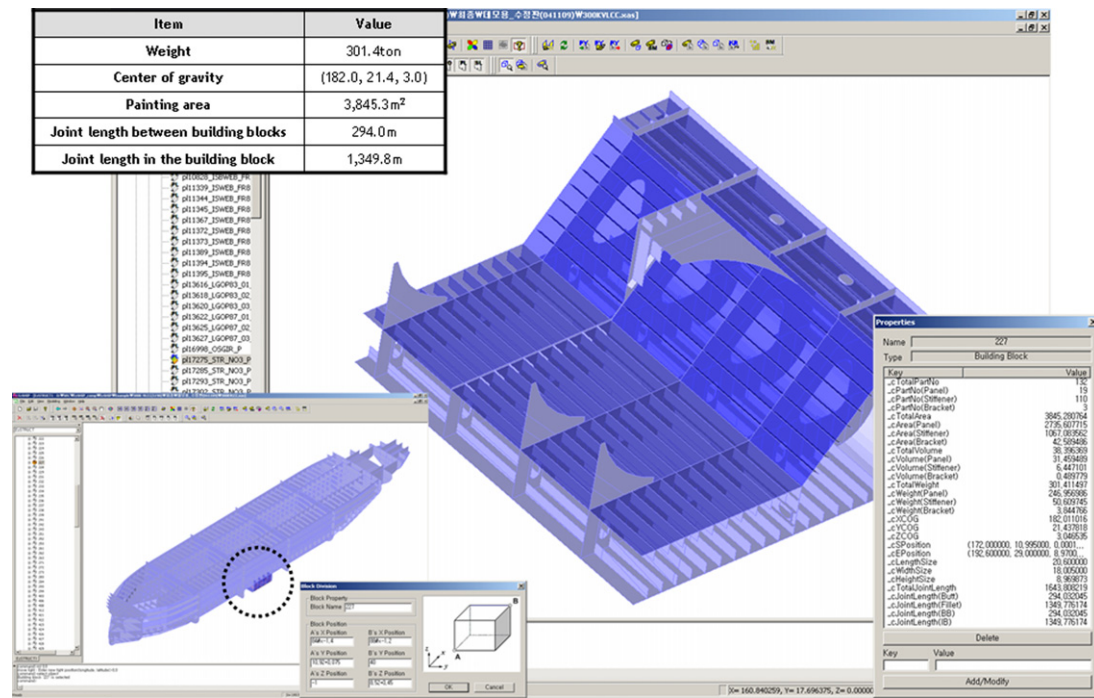


Fig. 23. Result of the generation of the production material information of the building block in the bottom region of the 300k VLCC.

designer about one month to perform the detailed modeling of the whole hull structure.

Fig. 23 presents a result of the generation of the production material information of a building block in the bottom region of the 300k VLCC by using the developed system. As shown in this figure, the joint length between building blocks (‘erection material information’), which is required for the block erection, and the joint length of a building block (‘assembly material information’), which is required for the block welding, as well as the weight, the center of gravity, and the painting area can be accurately generated using the developed system. On the other hand, the TRIBON system can generate only the weight and center of gravity of the building block after performing the production modeling of a building block unit at the production design stage. The IntelliShip system can also generate only the weight and center of gravity of the building block after performing the detailed modeling of the whole hull structure at the detailed design stage and performing the block division at the production design stage.

6. Conclusions

So far, a designer has defined all design information of a hull structure on 2D drawings at the initial design stage and shared these drawings with others of the following design stages. Thus, other designers must undertake the arduous task of translating design semantics defined on the 2D drawings. To solve this problem, in this study, a data structure for shipbuilding CAD systems was proposed to support the digitalized hull structural design by not the 2D drawings but the 3D CAD model at the initial design stage. Using the proposed data structure, the designer can define all design information on the 3D CAD model having shipbuilding design meaning, that is, the initial

hull structural model. Moreover, an initial hull structural CAD system based on the proposed data structure was also developed. The applicability of the developed system was demonstrated by applying it to hull structural modeling and generation of the production material information of a deadweight 300,000 tonne VLCC. The application result showed that the developed system can be efficiently used at the initial design stage.

Acknowledgments

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Myung-II Roh is currently a lecturer in the Department of the Naval Architecture and Ocean Engineering at University of Ulsan, Korea. He holds a BS, MS, and PhD in naval architecture and ocean engineering from Seoul National University, Korea. His research interests are in ship design, CAD, CAM, CAE, CAPP, optimization, robotics, and CAGD.



Kyu-Yeul Lee is a professor of naval architecture and ocean engineering at Seoul National University, Korea. He holds a BS in naval architecture and ocean engineering from Seoul National University, an MS and PhD in naval architecture from the Technical University of Hannover, Germany. His main areas of teaching and research interests include CAD, CAM, CAE, CAGD, optimization, and robotics. He has worked as research engineer and lecturer at the Technical University of Hannover and as a principal research and project leader on “Computerized Ship Design and Production System” at the Korea Research Institute of Ships and Ocean Engineering.