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Mapping 2D midship drawings into a 3D ship hull model based on STEP AP218

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Abstract

Standard for the exchange of product model data (STEP) AP218 has a standard schema to represent the structural model of a midship section. While its schema facilitate the exchange of ship structural models among heterogeneous systems, most shipyards and classification societies exchange information using 2D paper drawings. We propose a feature parameter input method to generate a 3D STEP model of a ship structure from 2D drawings. We have analyzed the ship structure information contained in 2D drawings and have defined a data model to express the contents of the drawing. We also developed a GUI for the feature parameter input. To translate 2D information extracted from the drawing into a STEP AP218 model, we have developed a shape generation library and have generated the 3D ship model through this library. The generated 3D STEP model of a ship structure can be used to exchange information between design departments in a shipyard as well as between classification societies and shipyards.

Keywords: Data exchange; Mapping; Parametric feature; Shape generation library; Ship structural model; Standard for the exchange of product model data AP218

1. Introduction

1.1. Backgrounds

A ship is a durable product with more than 20 years of operation life, and shipyards need a standardized information-processing system in order to maintain the usability of technical data, even with changes of operating system of computer after many years [1]. In the early stages of ship design, functions, *configurations* and rough arrangements are determined, and through various analysis processes, an optimized design alternative is resolved. These results, containing most of the design information, are presented in the format of 2D drawings. These 2D drawings are further analyzed and remodeled in 3D CAD (computer aided design) systems in order to use the information in downstream processes such as NC (numerical control) and robots. Such disconnection in information flow, however, potentially leads to errors in design information and delay in design completion.

The 3D digital model in the shipbuilding industry enables the integrated usage of design information solving problems incurred by the separation of structural design and outfitting design that arise from the differences in the CAD environments. The use of a digital model makes the design environment flexible in areas where integrated information management is necessary, such as structural analysis and approval by classification societies [2]. Standard for the exchange of product model data (STEP) provides an appropriate framework for these industrial environments. The shipbuilding application protocols (AP) of STEP represent and facilitate the exchange of 3D ship models [3].

If a 3D model is generated in an early design stage for the downstream processes such as the structural detail design and outfitting design, the information quality can be maintained during the information flow. In addition,

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inefficiencies in the design process, such as analysis of 2D drawings and manual modeling for a 3D CAD system, can be removed. To capture design intents contained in the 2D drawings of a ship structure, which are the results of early design stages, an information model is proposed. The 2D data structure can store the information represented in the drawings. In addition, a graphical user interface (GUI) that supports the data structure is developed to enable the user to easily input the data represented in the drawings. This 2D design information model is then transformed into a 3D ship model based on the STEP AP 218 standard [4] and the 3D model can be used in the downstream processes.

During the translation process, the mapping relationships between the 2D data structure and the 3D ship model are defined, and the library for 3D information enhancement has been developed. The 3D structural model of STEP format can be generated by these mapping relationships and by utilizing the library. To evaluate its effectiveness the implemented system is applied to a real ship.

1.2. Previous studies on the ship product model

There have been studies regarding the modeling of early ship structural information and 3D model generation from drawings. Yum [5] used an object-oriented concept and proposed a methodology for building an early ship hull model. Park [6] developed a prototype system to support the ship hull detail design and classified features of the internal members in the hopper structure. Nomoto, et al. [7] modeled ship structure geometry using the product model concept and the object-oriented concept. The integration of the ship design process and production process is possible by defining the data structure of the product model. The model can be used to analyze the hull and to implement the computerized model. These studies provide the user requirements and data structures for 3D ship CAD systems.

Shin, et al. [8] proposed a method to reconstruct a 3D model from 2D drawings using feature recognition and heuristic rules. While this approach has succeeded in translating the data in the drawings by feature recognition, it does not employ a systematic data model to represent the drawings and suffers from a low recognition rate. Lee, et al. [9] proposed a data structure that defines the semantic data model of a ship for the early design stage using UML (unified modeling language) for the model. Lee also developed and verified a CAD system that supports the proposed data structure. Lee analyzed 2D data that is generated in the initial ship design stage, and the proposed data structure is used to generate a 3D ship model. His approach is different from the information model proposed in this research in that we store the ship data in the form of 2D drawings whereas Lee used a 3D model. For example, the seam line of a plate is included in the drawing but it is not included in Lee's data structure and the seam line is processed after the 3D model has been created. In addition, since his model does not support an international standard such as STEP problems in data exchanging may arise. The data structure proposed by Lee is appropriate in representing the knowledge of design experts and analyzing the semantics of an object.

In studies regarding the representation of a ship model using STEP, Seo, et al. [10] developed a system to utilize SIKOB [11] arrangement information in commercial CAD systems. Shin, et al. [12] used STEP for the exchange of data between structural design and outfitting design and introduced a sharing method via the Internet. Park [13] studied the interference between hull information and outfitting information using STEP methodology and how to store the data in a relational database. Most of these studies used AP203 [14] of STEP, which is developed for the 3D product information of mechanical parts and assemblies. As APs for the shipbuilding industry are made available, we need to utilize them.

1.3. Architecture of the system

We have developed the 3D ship model generation system from 2D design information. The proposed *information*

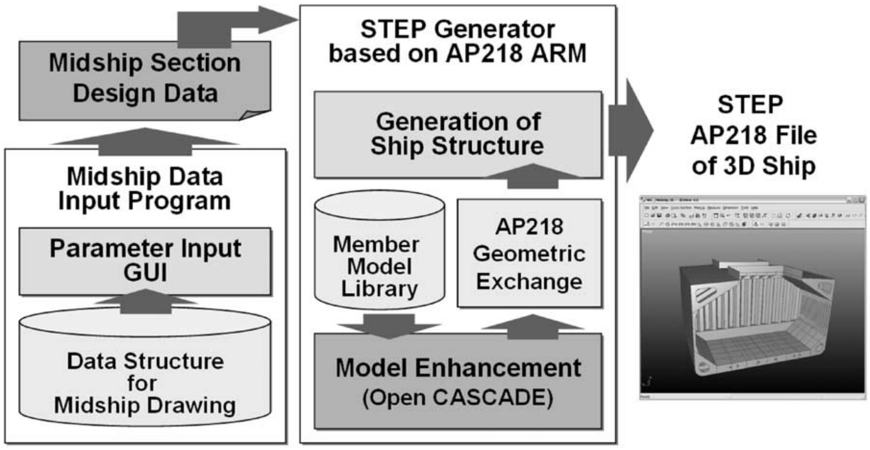

Fig. 1. Architecture of the 3D ship structure generation system.

model of midship drawing can store the information represented in the midship drawings. To transform the 2D information into 3D ship model based on STEP AP218, the mapping between these data structures and the enhancement of information has been developed. Fig. 1 shows the architecture of the 3D ship structure generation system. The system has two modules, the midship data input module and the STEP AP218 generator. The user generates design information of the midship section through the data structure based on the proposed information model of midship drawing and the parameter input GUI that supports the data model. The generated data is then processed by the STEP generator. The 2D design data of a plate is transmitted into the modeling library, which generates the shape of the plate through the data mapping and enhancement processes. The AP218 3D shape of the design data, which is generated by the modeling library, is finally stored as a STEP physical file.

2. STEP AP218

The Standard for the Exchange of Product model data, better known as STEP, is an international standard for exchanging data between different CAD/CAM and PDM systems. It represents a viable alternative to the current chaos of multiple, fragmented standards and proprietary data formats. STEP supports engineering, manufacturing, electrical/electronics, architechture and construction life cycle information such as design, engineering, manufacturing and maintenance. Industry sectors using STEP in production or in pilot tests around the world include aerospace, automotive, shipbuilding, electronics, architecture and the process industries [15].

Ship STEP is an ISO international standard to allow exchange ship product models between heterogeneous systems. It has been developed under the assumption that a ship product model can be divided into separated parts, and each part includes a functional element along the whole lifecycle of the ship. Product model schemas are being developed for each AP [4,16–18]. The reasons for this division are the distribution of modeling work and the need to exchange subsets of the product model between agents in the marine industry, not to mention the practical aspects of exchanging the data associated with an entire ship. To protect against errors where the design information for a ship defined in separate AP's differ from each other, common elements are defined as a ship common model (SCM), and each AP utilizes SCM [19]. The available ship APs are AP215 (ship arrangements), AP216 (ship moulded forms) and AP218 (ship structure).

A ship's structure, including hull structure, super structure and assemblies within the ship, is within the scope of the ship structural model of STEP AP218. AP218 supports the transfer of product model data to support the design, manufacturing and approval of structural systems, plate parts, stiffeners, foundations, and welds, In addition AP218 addresses the preliminary design of the ship structure and detailed design of all kinds of features including profile endcuts and interior, edge and corner cutouts. AP218 covers the following product definitions: the ship's general characteristics, the ship's global coordinate system, local coordinate systems and spacing grids, the geometrical representation, the hull plate and the stiffener profiles, the definition of structural features, the design of the welded connections and joints, the specifications of transverse cross-sections, ship design loads including shear forces and bending moments, the weights and centers of gravity, the materials, the configuration management including approval, and versioning and change administration. AP218 also supports product definition pertaining to the ship's structure at the initial design phase, the main design phase and the manufacturing phase of the ship's life cycle [20]. Currently, AP218 is in the DIS (draft international standard) stage, and the development of AIM (application interpreted model) has been completed. A test case of AP218 is under preparation in Korea and will be published as an attached document of AP218 [23].

Fig. 2 shows a part of the ship structure relationships defined in STEP AP218 in EXPRESS-G [21,22] format. A system is a functional unit on board a ship and is created to represent structural systems, piping systems, or propulsion systems. A part is created by a physical activity and made of material. A *structural_part* is an atomic, in terms of ship structure design, piece of material that is fabricated from stock material mainly by cutting and perhaps also bending processes but not by aggregation processes. An abstract super type *item_structure* has attribute items and entity item as its reference. The entities *structural_system* and *panel_system* that inherit the attribute item_structure and the attribute item

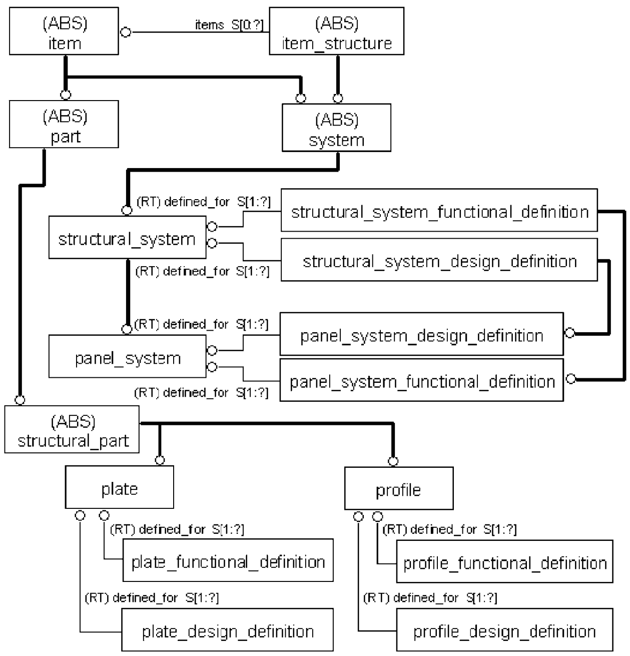

Fig. 2. Partial representation of AP218 structure.

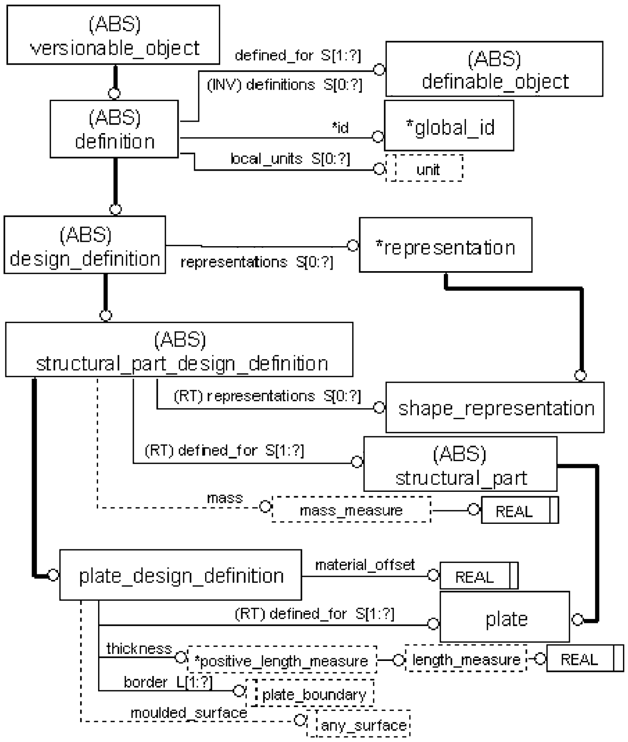

Fig. 3. Entity *plate_design_definition* in EXPRESS-G notation.

are composed according to the structural functionalities. The attribute items of the entity system refers to the entity structural_part and its references are the entities plate and profile. The entity structural_system is composed of several entity panel_systems, and each entity panel_system is composed of several entity plates and entity profiles. Each entity system and entity part references the entity *functional_definition* and the entity *design_definition*.

Fig. 3 shows the EXPRESS-G representation of the entity *plate_design_definition*, which contains the 3D geometric information of plates. The attribute *defined_for* states the geometric information of a plate, and it is an attribute of the entity definition and refers to the entity plate of Fig. 2 as RT (redeclared type). The attribute border specifies a boundary that is made of several pieces. The attribute *material_offset* expresses the offset of steel from the nominal plane. The attribute *moulded_surface* assigns the nominal datum plane. The attribute thickness specifies the thickness of the plate. The geometry information is defined in the attribute representation and references the entity *shape_representation*. A non-manifold surface model is used for 3D shape.

3. Information model of midship drawing

Most product information is defined in drawings. The designer represents the shapes, properties and design knowledge of a ship structure with 2D CAD systems. They usually use symbols in addition to lines and arcs to represent their design rationale. The data represented in the drawings shows conventional or similar patterns for the same ship type. To define the shapes of plates, parameters are used, that depend on the properties of plates [23]. The user designs a ship structure by defining the parameters of the shape patterns of the plates. As the parameters of the ship structure represented in 2D drawings can be analyzed and structured, we use the *feature parameter input method* to allow designers to input drawing information with the user interface.

In the feature parameter input method shapes and properties, which are defined based on the information model and data structure, are described by parameters. The user can represent design intent by setting values into the parameters, which define the shapes of the structural parts.

We have analyzed the design rationale described in the 2D drawings of ship structure and defined the information model of midship drawing. The information defined in the midship section drawings can be classified by the entities general_information, configurations, *piece_definitions*. The entity general_information is basic and common data such as the ship name and its principal characteristics.

The entity configurations describes the arrangement of the ship structures that should be defined to construct the midship section. Fig. 4 shows the entity configurations items of an inner section. The breadth and depth of the ship are defined in the entity general_information, and the information of the inner bottom plate can be calculated from the height of double bottom. The information of the hopper tank plate and side shell plate can be obtained using the *x*, *y* coordinates and the width of the hopper tank. In this fashion, the entity configurations of midship section can be defined by parameter representation in the 2D drawings.

The entity piece_definitions represents detail information of structural pieces. Based on the structural arrangement defined by the entity configurations, the entity piece_definitions describes seam information of longitudinal members,

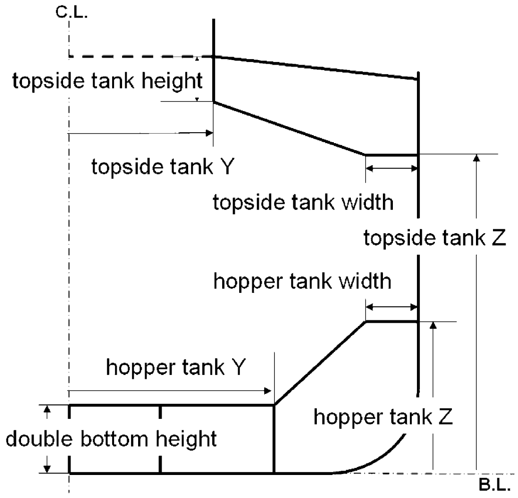

Fig. 4. Entity *configurations* of the inner section.

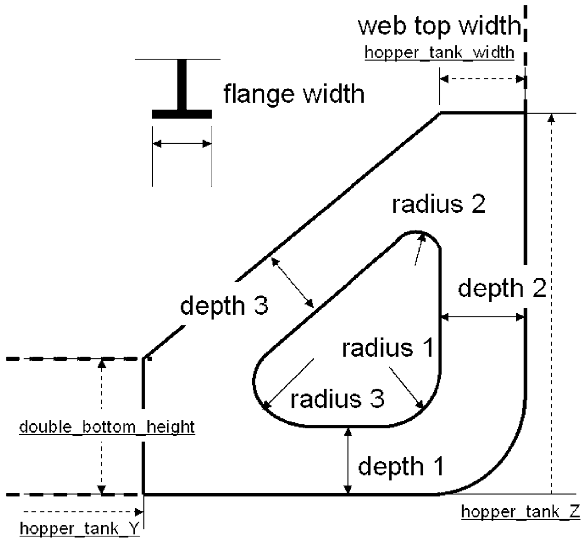

Fig. 5. Entity *piece_definitions* of hopper tank web (transverse members).

shape information of transverse members, and longitudinal stiffeners.

Fig. 5 shows the entity piece_definitions items of a hopper tank web. The layout of the hopper tank web can be extracted from the parameters of the entity configurations for the inner section. The dotted lines show the layout information defined by the entity *inner_section_configuration*, and the underlined texts show the attributes of the entity inner_section_configuration. The information of the entity configurations determines the boundary shape of the hopper tank web. The entity piece_definitions of the offset data from the boundary face (depth 1: offset from inner bottom, depth 2: offset from the side shell, depth 3: offset from hopper plate), and filleting data of the inner hole (radius 1: radius of bilge plate side, radius 2: radius of side shell side, radius 3: radius of inner bottom side). The entity piece_definitions defines detailed shape information of the web plate, and also includes ‘flange width’, a property of a flange.

Fig. 6 shows a partial representation of the information model of midship drawing with EXPRESS-G format. We use VisualExpress of the EDM (Express Data Management) system to generate Fig. 6 [24]. There are STEP standards for the 2D drawing such as AP201 (explicit draughting) and AP202 (associative draughting). These APs define elements used in drawings, such as lines, circles, arcs. These elements have geometric shapes but they cannot represent design features of the ship structure. The information model of midship drawing is different from AP201 and AP202 because the model defines the design rationale of the ship structure described in the midship section drawings. The proposed model of Fig. 6 is not a part of ship STEP either; it is developed to store the design information of 2D midship drawings in

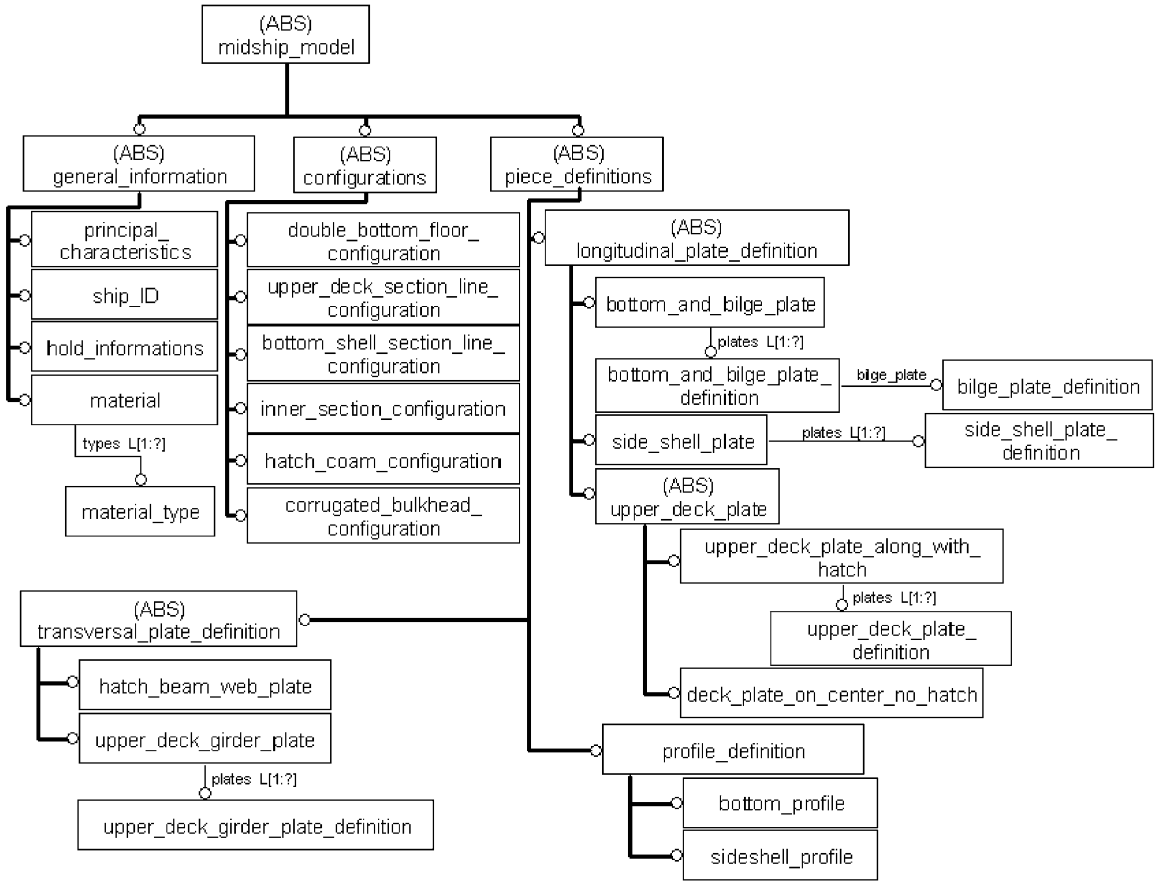

Fig. 6. Information model of midship drawing using EXPRESS-G representation.

a manner similar to the way designers represent their design rationale.

We define the root entity of the midship section as the entity *midship_model*. It has three subtypes: the entity general_information to describe general data of the ship, the entity configurations to describe the arrangement and outline of the ship structure, and the entity piece_definitions to describe the detail shapes and properties of the structural pieces. The entity general_information specifies general and common data such as the entities ship_ID, *principal_characteristics*, and *material*. The entity configurations specifies the layout of the ship structure and is defined by the parameters of the shapes and features. The entity configurations specifies the arrangement data as follows: Deck, Side Shell, Bottom, Inner Bottom, Hatch Coam, and Corrugated Bulkhead. The entity piece_definitions specifies the entity *longitudinal_plate_definition* for longitudinal members, the entity *transversal_plate_definition* for transverse members, and the entity *profile_definitions* for stiffener members.

We have proposed the information model based on design data represented in drawings and also have developed a user interface to easily capture the design features. The GUI provides popup windows to express the design information with parameters in a similar manner to the way they are represented in 2D drawings. Fig. 7 shows the GUI expressing bottom and bilge plates with seam information. The user can provide the properties of the plates such as the starting point from the centerline, the width, the thickness, the material of the bottom plates, and the height of the bilge plate. The user can provide the parameter values for the plate in the same manner as represented in the drawings. The design information prepared through the feature parameter input method transforms design rationale represented in drawings into the 2D data structure of Fig. 6.

4. Mapping the information model of midship drawing into AP218

As the 3D data structure of STEP AP218 is different from the information model of midship drawing, we should define the mapping relationship between the two schemas. Fig. 8 shows the mapping between the two data models. The left side of Fig. 8 shows a part of the proposed information model of midship drawing (Fig. 6), and the right side is a part of an AP218 data structure that is formatted according to UML and EXPRESS-G. The upper right side is a UML object diagram for a midship. The object mid_ship of the entity structural_system consists of a deck instance of the entity panel_system that contains the instances of entities plate and profile. The entity plate refers to the entity plate_design_definition to define the geometric shape and the entity *plate_functional_definition* to define the functionality of the plate. To represent ship structures in AP218 such as deck, bottom, inner bottom, hopper tank, the attribute *the_function* should be assigned at the time of instancing the entity panel_system to the type *structural_class_functionality* as deck, *tank_top*, and girder. The information model of midship drawing should be mapped into instances of AP218 schema because a functional attribute is assigned to

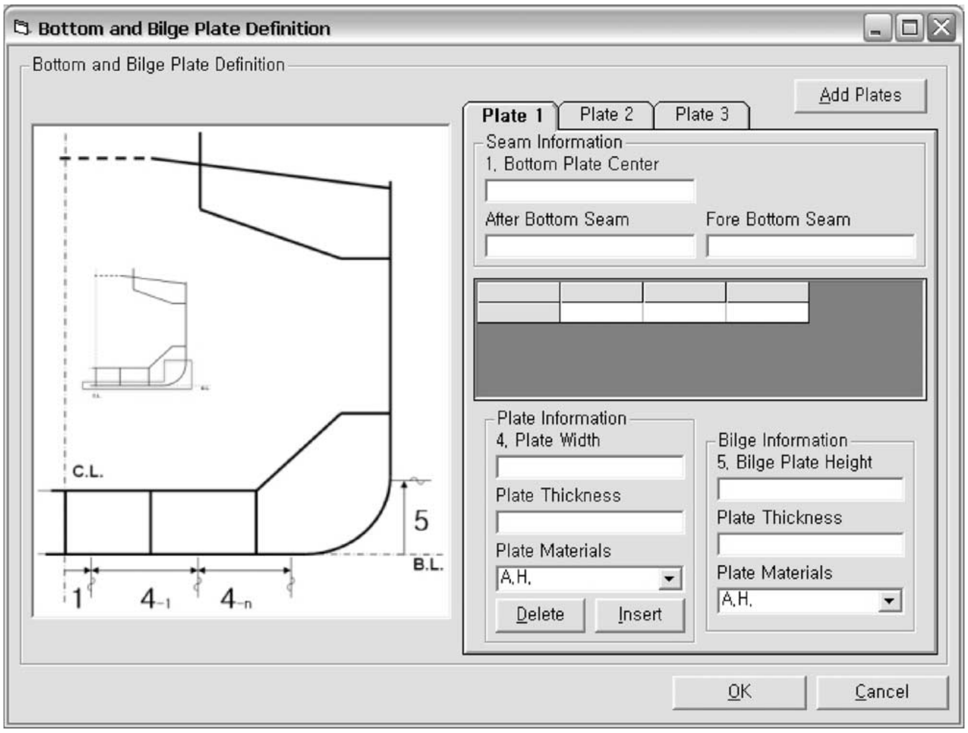

Fig. 7. GUI of bottom and bilge plates.

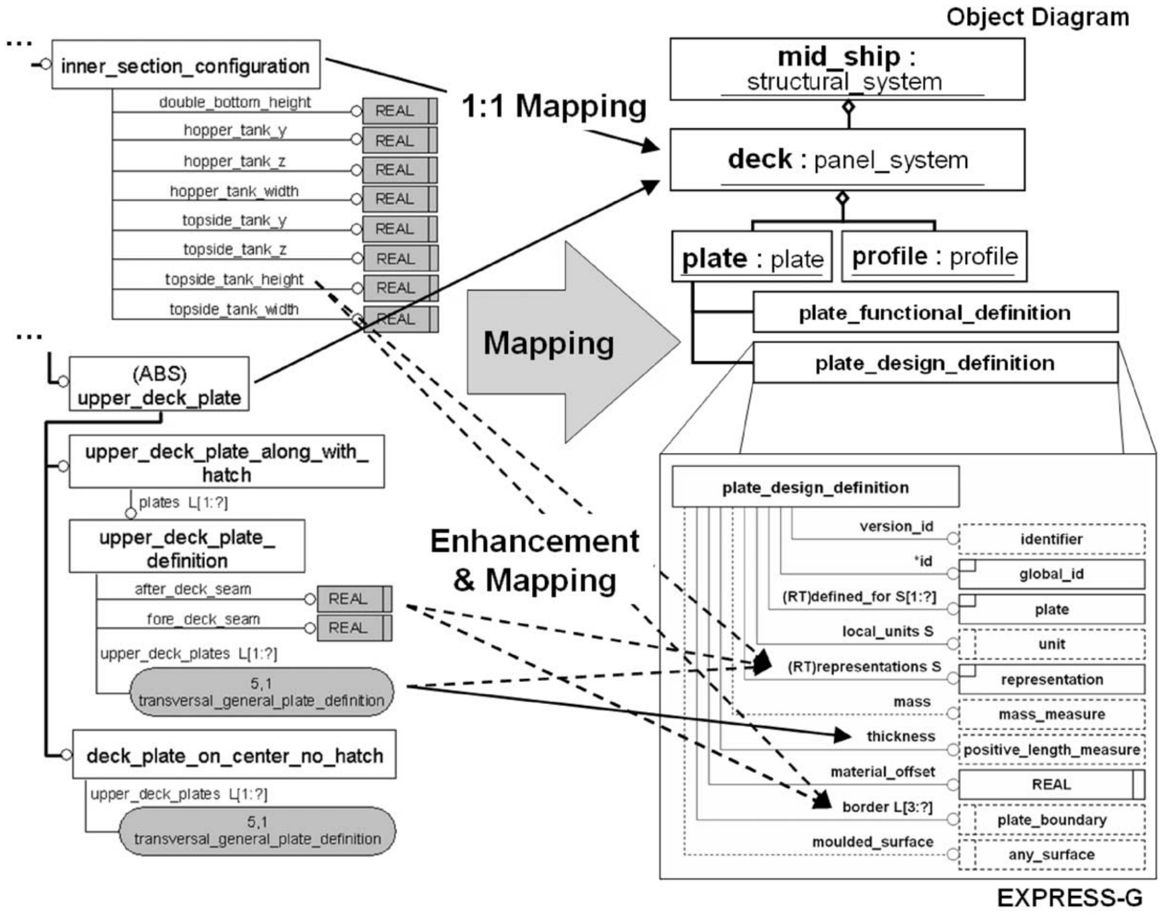

Fig. 8. Mapping the information model of midship drawing into STEP AP218.

an instance to hold the semantics of a ship structure such as the deck. The lower right side of Fig. 8 shows an EXPRESS-G representation of the entity plate_design_definition defined in AP218 and expresses all the inherited attributes from the parent class.

The information of the entities inner_section_configuration and *upper_deck_plate* are extracted and mapped to the deck instance of the entity panel_system. The attribute *general_plate_definition.thickness*, which describes the thickness of the plate, can be mapped one-to-one to the attribute plate_design_definition thickness in AP218. Not all of the mappings between the two schemas are mapped via one-to-one mapping, however. One item can be represented by various methods or multiple information. Most non-geometric information (thickness, material properties) can be one-to-one mapped. The information related to shape (e.g. 2D contours) should be enhanced into 3D shapes. Because the width of a plate is represented by a parameter instead of the global coordinate system, the implemented system calculates the global coordinates by combining relevant parameters. In this process, we need enhancements of 2D information to define these mapping relationships. The attributes representation and border in AP218 can be mapped into the entity inner_section_configuration of the entity configurations and the entity *upper_deck_plate_definition* of the entity piece_definitions of the proposed information model. The data enhancement means operations such as ‘addition’, ‘division’, ‘modification’ of data, and data mapping to exchange information between different data structures. The ‘addition’ enhancement adds data, for example, sweeping or making surface based on 2D contours. The ‘division’ enhancement modifies the existing data through actions such as the division of a 3D plate by a seam line. The ‘modification’ enhancement changes existing data such as the shape change of the floor plate by inserting a hole in floor plates. Fig. 9 shows three enhancement types.

The ‘addition’ enhancement to transform a 2D entity into a 3D shape by sweeping is an example of data enhancement. Fig. 10 shows an example of the data enhancement of hopper tank web plates. The geometric data of the plate boundary can be calculated from the entity inner_section_configuration. The boundary of the web is determined by properties defined in the entity configurations, such as *moulded_breadth*, *hopper_tank_y*, *hopper_tank_z*, *hopper_tank_width*, *double_bottom_height* and *bilge_radius*. The information of the hopper hole is calculated from offset and fillet information of the entity *hopper_tank_web_plate* by the following process. Offset lines are generated with the given offset values from

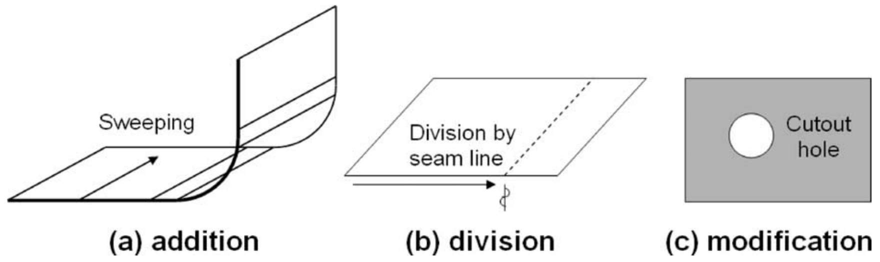

Fig. 9. Types of enhancement.

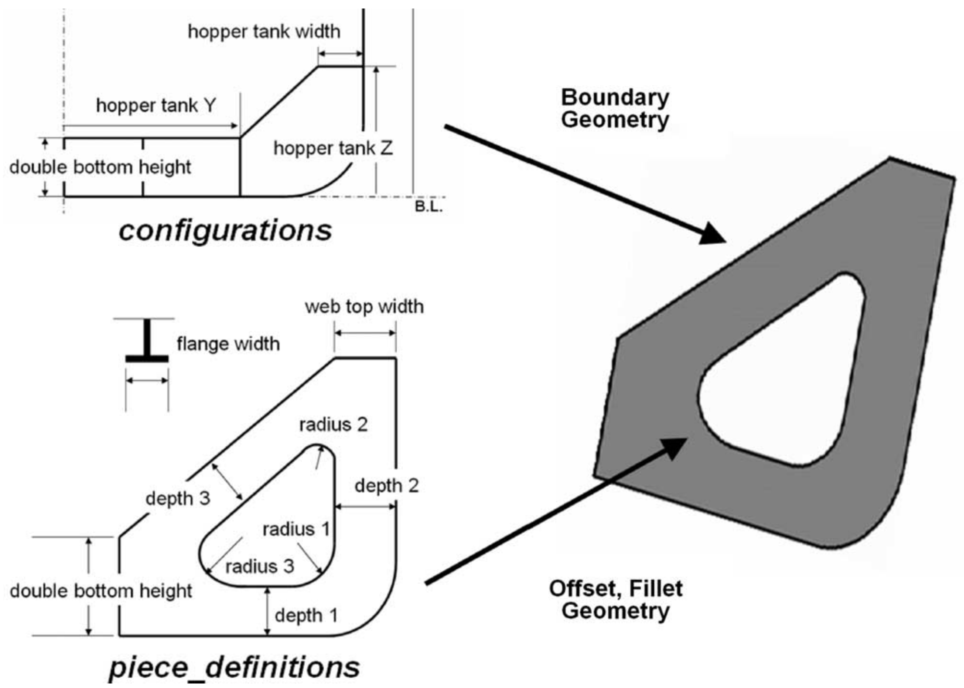

Fig. 10. Enhancement of hopper tank web plates.

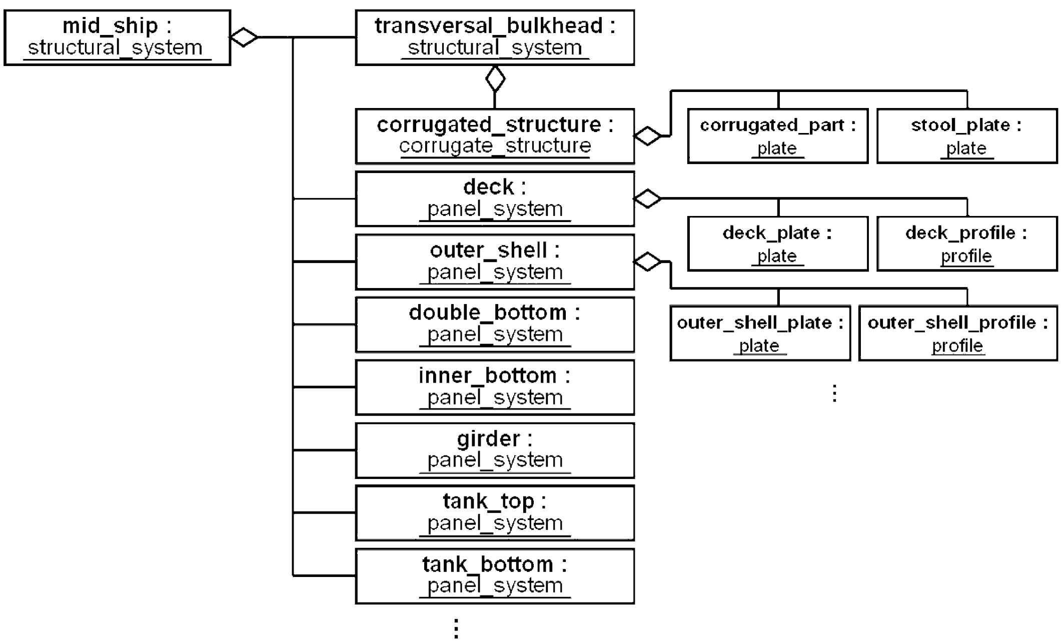

Fig. 11. UML object diagram of midship structure.

```
MIDSHIP_INPUT_DATA_SPECIFICATION_FOR
 BULK_CARRIER;

PRINCIPAL_CHARACTERISTICS;
  LENGTH_BETWEEN_PERPENDICULARS : 216000
  MOULDED_BREADTH : 45000
  MOULDED_DEPTH : 23800
  DESIGN_DRAUGHT : 13896
  BLOCK_COEFFICIENT : 0.8300
  HOGGING_AMIDSHIP : 1577800
  SAGGING_AMIDSHIP : 1460200
  SWSF_POSITIVE : 0
  SWSF_NEGATIVE : 0
END_PRINCIPAL_CHARACTERISTICS;

INNER_SECTION_CONFIGURATION;
  DOUBLE_BOTTOM_HEIGHT : 2500
  HOPPER_TANK_Y : 16600
  HOPPER_TANK_Z : 8400
  HOPPER_TANK_WIDTH : 0
  TOPSIDE_TANK_Y : 10000
  TOPSIDE_TANK_Z : 16710
  TOPSIDE_TANK_HEIGHT : 600
  TOPSIDE_TANK_WIDTH : 0
END_INNER_SECTION_CONFIGURATION;
```

Fig. 12. Sample midship data from the feature parameter input method.

each line of the boundary face of the hopper tank web. The shape of the inner hopper hole is formed by a sequence of filleting operations with corresponding fillet values.

We define the sequence or algorithm for the mapping and data enhancement as the geometric library of structural pieces. The library allows the generation of 3D shapes from pieces and it can be extended with definitions of new structural pieces. The geometric library is a set of predefined sequences of geometric modeling operations, and it consists of a set of APIs (application programming interface) to generate the 3D shape with provided parameters and design information.

Fig. 11 is the UML [25] object diagram of the 3D ship structure model which is generated by data mapping and enhancement. The midship object of the entity structural_system is composed of a transversal bulkhead object of the entity structural_system and multiple objects of the entity *panel_systems* of the deck, *outer_-shell*, *double_bottom*, and so on. The transversal bulkhead object of the entity structural_system has an object of the entity *corrugated_structure* that contains a *corrugated_part* and *stool_plates*. Each object of the entity panel_system has objects of the entities plate and profile.

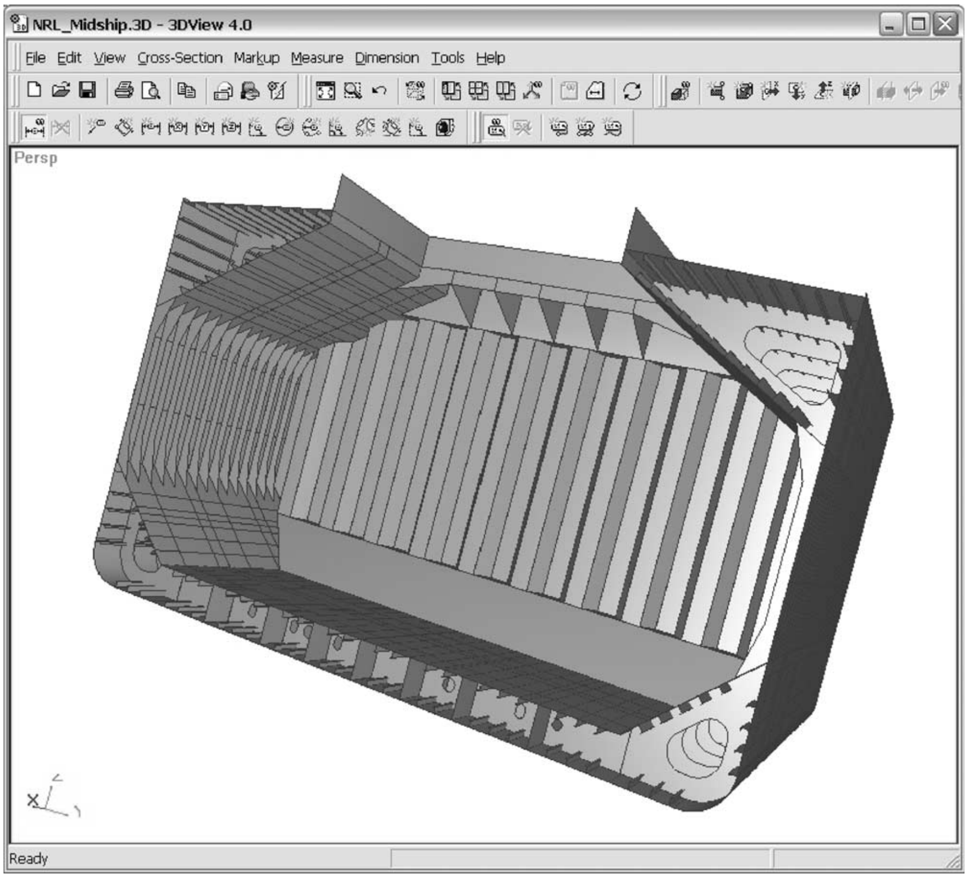

Fig. 13. Visualization of the 3D ship model.

5. Implementation and experiment

We have implemented the STEP physical file generation system from 2D data structure of which data is provided via the GUI and based on the information model of midship drawing as shown in Fig. 1. The system has been implemented in a Windows NT environment. We have used the EDM system of EPM to prepare EXPRESS-G diagrams. ST-Developer 9.0 of STEPTools [26] has been used to compile the AP218 EXPRESS schema. We have also used MS Visual Basic 6.0 for the development of GUI, and MS Visual C++ 6.0 for the development of the module to generate the midship structural model and to store the 3D ship model as a STEP physical file. To generate shape information, the OpenCASCADE 4.0 [27] kernel has been utilized, and we have modified the exchange module of OpenCASCADE to support AP218 shape information. To visualize the STEP ship model, 3D View from Actify [28] has been chosen.

The developed system has been tested and verified with real ship data from a Korean shipyard. The midship of a bulk carrier has also been used in experimentation. Fig. 12 shows an example of the ship structural model generated by the feature parameter input method and based on the information model of midship drawing. The 2D midship data of the bulk carrier are provided through the GUI and enhanced into a 3D ship model.

Fig. 13 shows the structural model constructed from the physical STEP file generated by the developed system. The figure is one hold of a bulk carrier. The generated STEP physical file can be used in downstream applications such as the structural analysis system or the ship CAD system for detail design. This file can also be used to exchange information between design departments in a shipyard as well as between classification societies and shipyards.

6. Conclusion

The design information and design intent contained in a 2D midship section drawing which is the result of the initial structural design stage, are defined as the 2D data structure of the midship drawings. The information model of midship drawing contains geometric information such as points, lines and symbols of structural parts. Most of this information can be represented by parameters. These parameters are systematically classified and are represented together with the hull functional elements. Based on the developed information model, a GUI is developed to ease the user process of design data input, and the acquired information is then enhanced into a 3D model using STEP AP 218. During the translation process, the mapping between the 2D data structure and the AP218 model is defined and the geometry is enhanced to build the 3D model. For this purpose, geometric libraries for each structural part have been developed. Using these mappings and the geometric libraries, the translator has been implemented and is verified by its application to a real ship.

The proposed method to model the information contained in 2D drawings and to define a data structure can be applied to other drawings that have similar patterns. The method can be used for the drawings of different types of ships as well as for other industrial domains that mainly use 2D drawings such as construction and civil engineering. In this research, the information model is defined and the libraries are developed for bulk carriers.

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