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Ship design assessment through virtual prototypes

Matteo Dodero[a], Serena Bertagna[a,*], Luca Braidotti[a,b], Alberto Marinò[a], Vittorio Bucci[a]

[a]*Department of Engineering and Architecture, University of Trieste, Via A. Valerio 6, Trieste 34127, Italy*
[b]*Faculty of Engineering, University of Rijeka, Vukovarska 58, Rijeka 51000, Croatia*

Abstract

The traditional design process has been developed, through time, by trial and error, following an evolutive approach. By following this procedure, the design team focused its attention on only one conceptual design alternative at a time, which is perfected step by step until the expected outcome is obtained. Nevertheless nowadays, due to the high complexity of ships and increasingly stringent operational requirements, this approach appears to be obsolete in a market where cost and time reduction is a fundamental parameter. Indeed, to be competitive in the shipbuilding market, very accurate information should be available since the beginning of the process, to allow the design team a 360-degree exploration of a high number of alternatives and then identify the best design solution in no time.
In this paper a new, rational, design process, necessary to raise efficiency and effectiveness of ship design, is presented. By using a multi-purpose design software, the authors were able to create a Virtual Prototype of a case study ship with ease and little training, obtaining, since early-stage design phases, some outputs of interest (such as longitudinally weight distribution of ship structures, preliminary midship section, GZ curves and powering curves) without great computational efforts. The most important benefit of using only one multipurpose software instead of multiple specific ones lies in the elimination of remarking activities for switching from one software to another, reducing loss of data's risks during the process.

Keywords: Ship design, early stage design, Virtual Prototype, Product Model Program,

1. Introduction

The shipbuilding industry, although it has always been strictly related to its past heritage, is in constant, slow, evolution. The growing complexity of ships, due to the increasing of their main dimensions and the stricter regulatory requirements (i.e., anti-pollution regulation's compliance [1] or stability rules [2]), brought shipyard's competition on the market to another level. Green design solutions [3–5], innovative approaches used to reduce production costs [6–8], analysis of multiple design alternatives to verify incremental innovation [9,10] and, in general, performance improvement in all ship's subsystems [11] became the ship-owner's discriminants for selecting a shipyard over another to build his fleet. Therefore, a traditional design approach is no longer enough to assure a certain level of competitiveness in this aggressive market (shipyards must produce more in less time compared to the past). Furthermore, with the entry into force of new preliminary assessment verification for system on-board pax ships (Safe Return To Port requirements [2]), shipyards must find a solution to obtain, since the beginning of the design process, a substantial output to verify. This transition from the traditional way-of-thinking to the new one based on the market requirements, however,

* Corresponding author. Tel.: +39-040-558-3462
E-mail address: sbertagna@units.it

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cannot be done in a single day; the knowledge of decades of history in naval industry must be integrated in the new state-of-the-art methodologies (as seen in [12]), in order not to waste these immeasurable information.

To achieve this goal, in this paper the authors present a new rational ship design approach able to act as a bridge between these ways-of-thinking. This method is based on the use of state-of-the art software since early stage design phases (that includes both preliminary and concept design ones, [13]) and, in particular, on a general approach used to create Virtual Prototypes (VPs). Defined since 2002 [14], the general Virtual Prototyping technique hereby presented has been derived from various approaches (such as object-oriented, modular and multi-disciplinary simulation ones [15–18]). Through the creation of a VP the authors showed how the system's assessment can speed up and how to obtain a high number of outcomes, with major savings in terms of time and cost reduction.

In addition, the Virtual Prototype provides a 3D parametric master model that can be accessible, in the future, through virtual reality, thus enabling rich visualization of design choices and analysis of physical fit of components and creating a training platform for seafarer's formation [19,20].

Nomenclature

AR	Augmented Reality
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CASM	Computer-Aided Synthesis Modelling
CFD	Computational Fluid Dynamics
CIM	Computer-Integrated Manufacturing
CSI	Computer System Integrators
DT	Digital Twin
FEM	Finite Element Method
PLM	Product Life-cycle Management
PMP	Product Model Program
VP	Virtual Prototype
VR	Virtual Reality

2. Ship Virtual Prototypes

Due to the increasing complexity of ships, the shipbuilding design approach has undergone a lot of various changings during the past decades. The traditional ship design approach, whose decisions are taken on designer's experience and intuition, does not explain how to systematically find the best solution for a design problem. In fact, this approach is based on a fixed sequence of design phases (Fig. 1), which are standardised as follows:

- Concept design: first step of the basic design phase, defines the primary characteristics and an early design configuration of the ship;
- Preliminary design: starting from the results obtained in the first step, it refines the early design configuration enough to obtain an accurate building and operating cost estimate;
- Contract design: the outcomes of this set result in a package of contract drawing and documents, which describe in such an accurate way the ship design and precisely defines acquisition costs;
- Functional design: each system of the ship is fully defined in all its parts. This step ends the basic design phase;
- Transition design: first step of the product engineering phase, the design team decides the zones the ship should be divided into and produces the remaining technical documentation to fulfil the contract drawing requirement list;
- Work instruction: instructions to manufacture the various parts of the ship (in form of drawings and documents) are given. This step ends the product engineering phase.

The traditional approach, therefore, allows the design team to explore only one conceptual alternative at a time. Consequently, if the chosen one is not the best design solution, decisions and modifications need to be performed in the later design stages. These actions, however, are much more expensive and time consuming if compared with the ones made during initial steps (since 70 % or more of the ultimate cost and performance of the final product are essentially "locked in" during early-stage design phases). Therefore, identifying from the beginning the best design solution becomes extremely important to cut costs and delays.

To reach this goal, the design team must analyse a high number of conceptual alternatives since early-stage design phases by using a new and rational ship design approach (e.g., as seen in [21–23]). This new methodology is based on the use of state-of-the-art computer-based tools, which provide from the beginning a large number of accurate information with a high level of reliability.

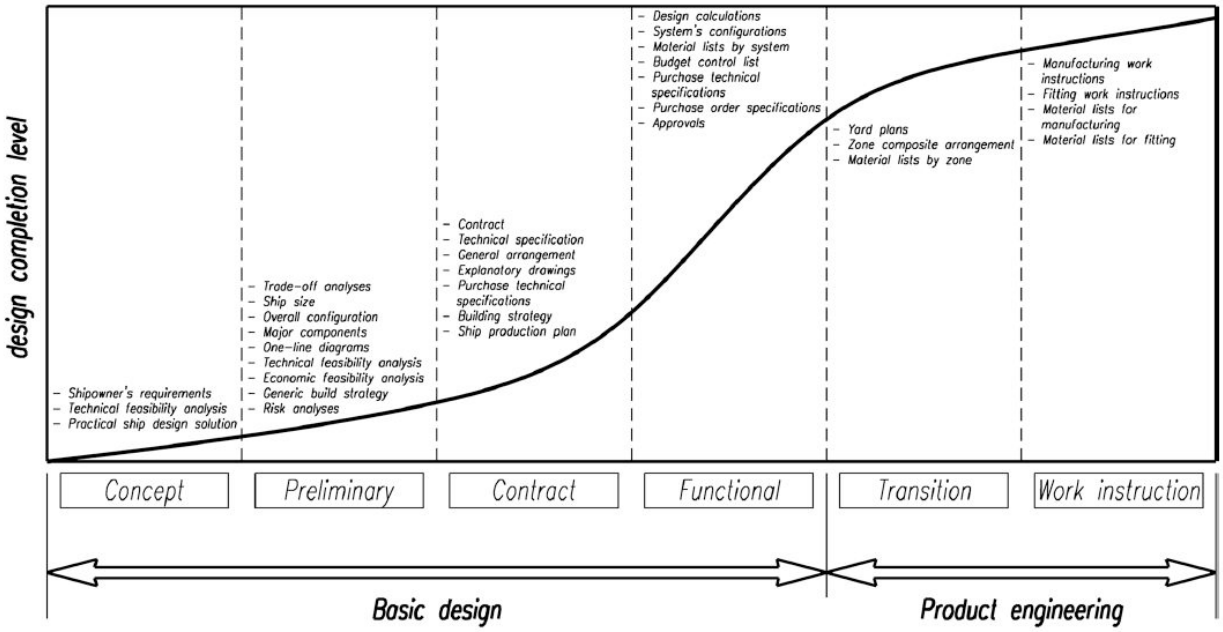


Fig. 1. Traditional ship design approach.

Computer-based tools for design can be divided in four categories:

- Computer-Aided Synthesis Modelling (CASM) programs: by analysing parent/similar ships, they obtain a preliminary design of the vessel;
- Computer-Aided Design (CAD) programs: elaboration of drawings;
- Computer Aided Engineering (CAE) programs: various calculations inherent in the design process (like FEM or CFD);
- Computer-Aided Manufacturing (CAM) programs: transition from the design towards the construction of the ship.

Nevertheless, the use of different classes of software to elaborate and manage the huge amount of data involved in ship value chain presents some important limitations. First at all, different software often are not integrated with others and need remaking activities to render the data accessible by the specific tool. In addition, due to the complexity of the product, different teams treat each aspect of the whole process independently. As a result, the information generated often are not efficiently related to others.

To solve these problems, some computer companies started to incorporate several categories of software in a single tool thus creating multi-purpose programs. The outcome of these software falls within two categories: Digital Twin or Virtual Prototype.

Digital Twins (DTs) can be described as software representations of physical objects and processes that are used to understand, predict, and optimize performance [24]. A DT is connected with its physical counterpart in both real and later time, to exchange data and information, and in the end allows estimating the expected behavior of a certain object/process.

Virtual Prototypes (VPs), instead, can be described as computer simulations of a physical product that can be analyzed as if it were a real physical model [14] .A VP contains all the information of a certain product necessary for its physical construction and also, using Virtual Reality (VR) techniques, its aesthetic and ergonomic evaluation.

Starting from these definitions, as easily noticeable, both the outcomes need an important initial effort to set up all the necessary information. In particular, a DT requires much more time compared to a VP for configuration setting. On the other hand, results from a DT are much more substantial compared to the ones obtained from a VP.

For early-stage design phases, also in relation to an initial cost-benefits analysis between DT and VP, outcomes obtained from the latter can be considered more than enough in terms of time saving and results accuracy.

2.1. Modeling tools

In the current market of design software, an attractive alternative to the traditional computer-based tools is represented by multi-purpose programs, which include several categories of software in a single tool. A multi-purpose program can be:

- A Product Model Program (PMP), which includes both CAD, CAE and some part of CASM/CAM capabilities;
- A Computer-Integrated Manufacturing (CIM) program, a PMP customised for specific shipyards able to coordinate stand-alone programs linked via a common database;
- A Computer System Integrators (CSIs) program, a software tool for the Product Life-cycle Management (PLM).

For developing the VP of case study ship, in the first instance, some CSIs software were taken into account (Hexagon's Intergraph® and Cadmatic®). However, due to the level of details to be achieved (in terms of software's cost-detail analysis) and its user-friendliness (the training phase for learning how to use a CSI can be challenging), a PMP of the company Qinetiq® named Paramarine® was used. The software is able to study numerous naval expertise areas such as manoeuvrability, seakeeping, stability, propulsion and structural calculations. The programming paradigm of Paramarine® is "Object Oriented" in C++; every geometrical element, physical data and conclusive analysis are contained in objects, which memorised how they were created and how they are linked to each other.

The hierarchical system thus created is able to identify ascending and descending objects (Fig. 2; in Paramarine® placeholders of various colour are used to identify the first level of ascending objects); the modification of the first one directly and automatically modifies the second one.

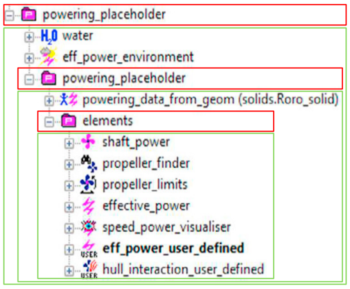


Fig. 2. Example of hierarchical system for powering: ascending (red box) and descending (green box) objects

2.2. Methodology

The construction and testing of VPs transformed the virtual design models in direct design objects. In fact, a VP is subjected to checks, analyses and simulations and comes to coincide in substance with the finished product itself, allowing to extrapolate a high number of outcomes.

In addition, a VP provides a 3D parametric master model that can be accessible through VR, thus enabling rich visualization of design choices and analysis of physical fit of components and arrangements to include verification of intersections between hull, systems and structures. This 3D model can also be used to analyze ship construction, maintenance and repair activities through visualization and analysis of maintenance envelopes and interferences. Furthermore, the inclusion of avatars enables measurement of potential human-machine interface issues. This capability provides the opportunity to make production-related decisions in early-stage design phases and, if connected with VR, allows the fast proof-of-concept of new technologies.

The creation process of VPs begins with a first phase of pre-processing information, obtained from various sources (Fig. 3). This part is very important because allows to link any type of input derived from the shipyard's archives (technical documents such as general arrangements, building plan or mid ship section drawing, CAD 2D drawings or CAD 3D models) to the PMP new project. Nevertheless, if the design team prefers to build the 3D model directly inside the PMP, the software's CASM/CAD part allows to define the hull and superstructure geometry of the ship's VP, along with all the planes necessary to define its internal subdivision.

Once completed the external shell in one way or another, the internal subdivision is modelled by defining both on-board partitions (watertight, fire, secondary and capacity compartment) and structural elements (bulkheads, decks and shell plating), as well as main machinery positioning (often presented as 3D building block, with a certain weight and centre of gravity position). It is important to notice that all the geometrical objects thus created are modelled as parametric elements, to allow a 360-degree exploration of design alternatives by changing their inner characteristics (main dimensions, thickness or positioning).

Finally, starting from the complete geometrical definition of the VP, the PMP CAE part can be set to obtain all the information of interest such as, for example:

- Powering calculation;
- Buoyancy calculation;
- Stability calculation;
- Seakeeping calculation;
- Structural scantling calculation;
- Hull girder calculation.

Alternatively, the VP can be exported in other specific CAE/CAD/CAM tools to obtain specific outcomes not available in the in-use PMP, such as CFD and FEM calculation, 2D drawings or 3D for VR. In this case, the outputs have a higher level of accuracy compared to the ones obtained from only a PMP because they were extracted from specific tools, with a higher computational effort. The design team's task was to understand the minimum level of accuracy required and, therefore, which is the best tool to use to reach it. The whole creation process is depicted in Fig. 4.

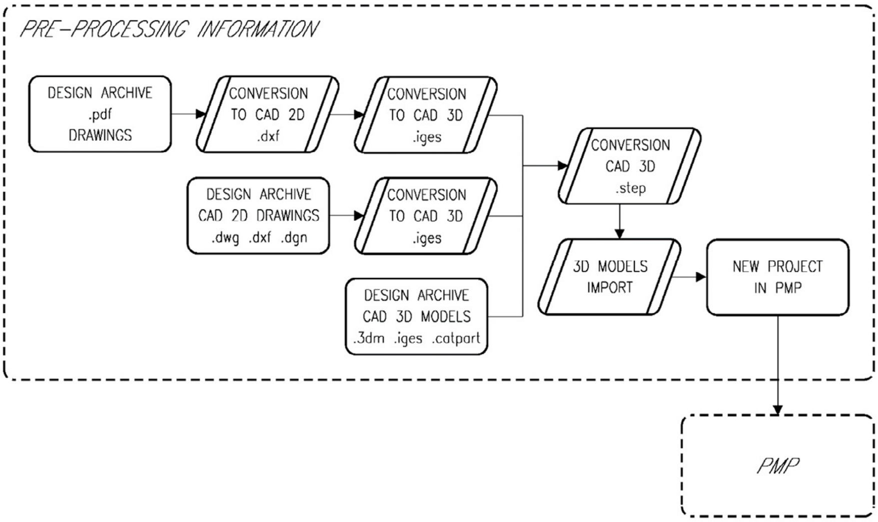


Fig. 3. Pre-processing information schema

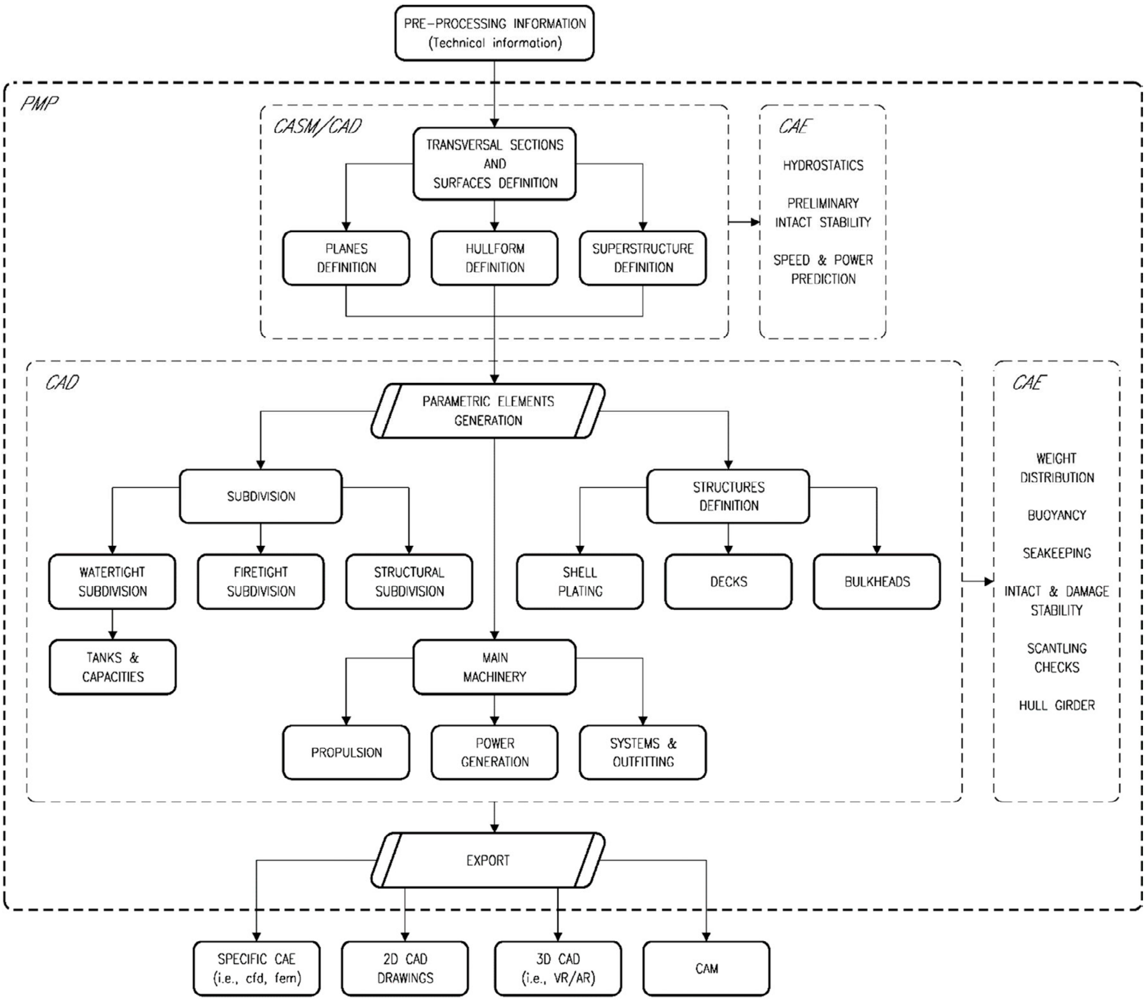


Fig. 4. Block diagram – ideal creation process of a VP

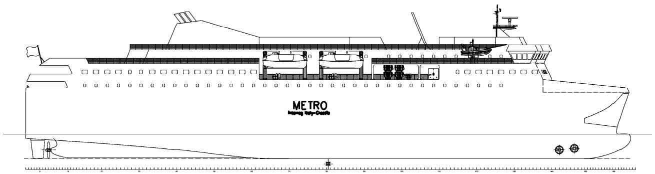
3. Case study

The case study regards a Roll On-Roll Off passenger (RoRo-Pax) ship, a cargo vessel designed to carry wheeled cargo that are driven on and off it on their own wheels, compliant with [2] for Short International Voyages. The vessel is propelled and maneuvered with a twin screw - twin rudder, equipped with two four stroke dual fuel engines coupled with a battery system (for hybrid-electric propulsion) and made of welded construction steel (included superstructure and wheelhouse), with one cargo deck and one hoistable deck for cars.

In Table 1 the main characteristics of the vessel are reported, with a longitudinal view of the ship.

Table 1. Main characteristic of the RoRo-Pax ship case study

Main characteristics	
Length, overall	129.00 *m*
Length, between perpendiculars	123.00 *m*
Breadth, moulded	23.6 *m*
Hull depth to freeboard deck (midship)	8.00 *m*
Draught, scantling	5.6 *m*
Draught, design	5.25 *m*
Deadweight, scantling draught	~ 2240 *t*
Deadweight, design draught	~ 1400 *t*
Speed, service	15.5 *kn*
Capacity	
Max passengers on board	~ 1335 persons
Crew	75 persons
Trailer capacity	631 lane meters
Car capacity, total	350 Car Equivalent Units



After the pre-processing information phase, which allows to import a 3D CAD model in Paramarine®, on-board partitions, structural elements and machinery's 3D building blocks are built (Fig. 5 and Fig. 6).

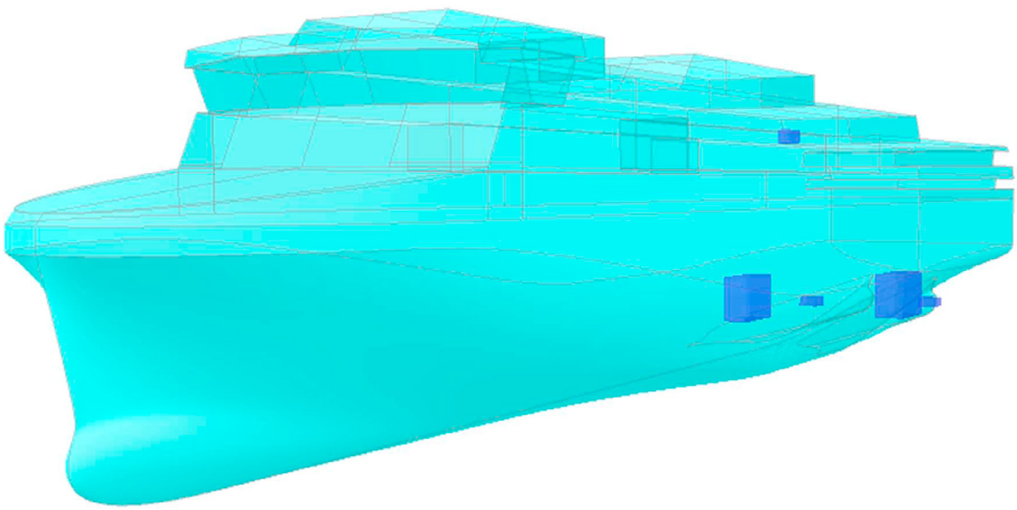


Fig. 5. Machinery's 3D building blocks

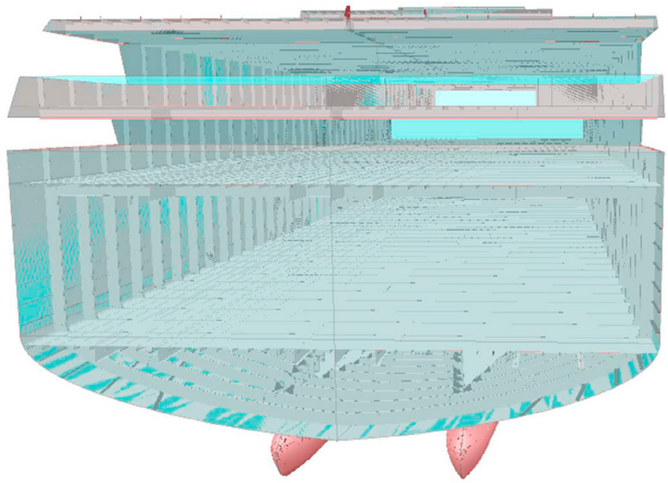


Fig. 6. Structural elements – decks and frames (observer's point of view: from bow to stern)

In Fig. 7 and Fig. 8 some CAE results relating the structural point of view are presented. In particular, in Fig. 7, the longitudinally weight distribution (from bow to stern) of ship structures (such as shell plating, bulkheads, girders and stiffeners) and, in Fig. 8, a preliminary midship section are reported.

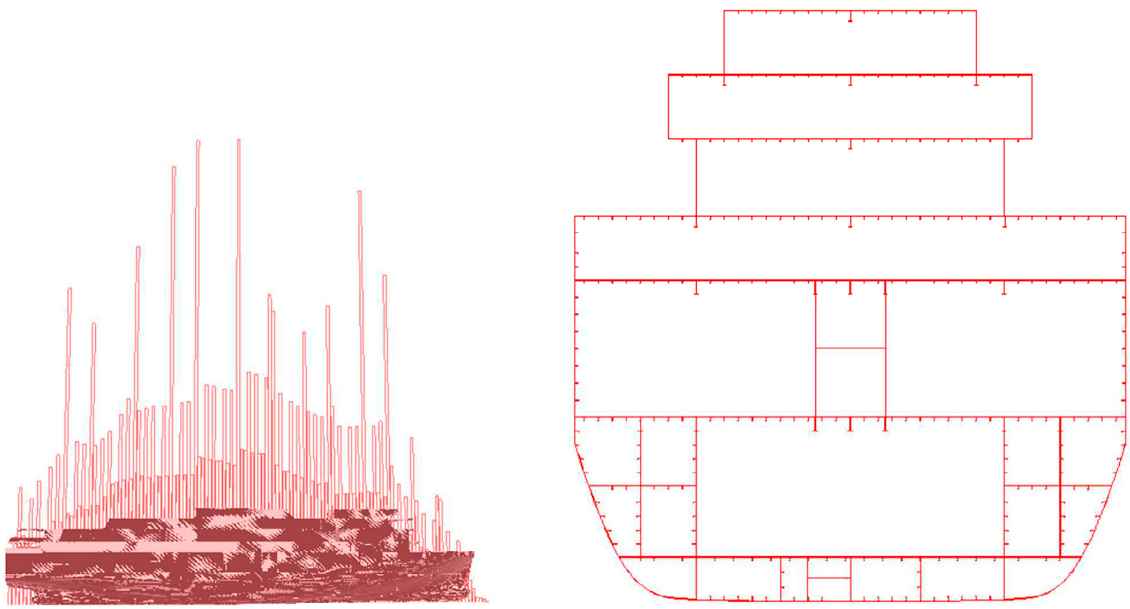


Fig. 7 and Fig. 8. Structural weight distribution and midship preliminary section

In conclusion, in Fig. 9 and Fig. 10 the last CAE results related are presented. In particular, in Fig. 9, the ship speed – engine effective and shaft power relation graph and, in Fig. 10, the righting arm GZ – heel angle relation graph (GZ curve) are reported. The first one allows the design team to estimate the power necessary to move the vessel under consideration at a certain speed, the second one to estimate the intact stability features of the vessel under consideration.

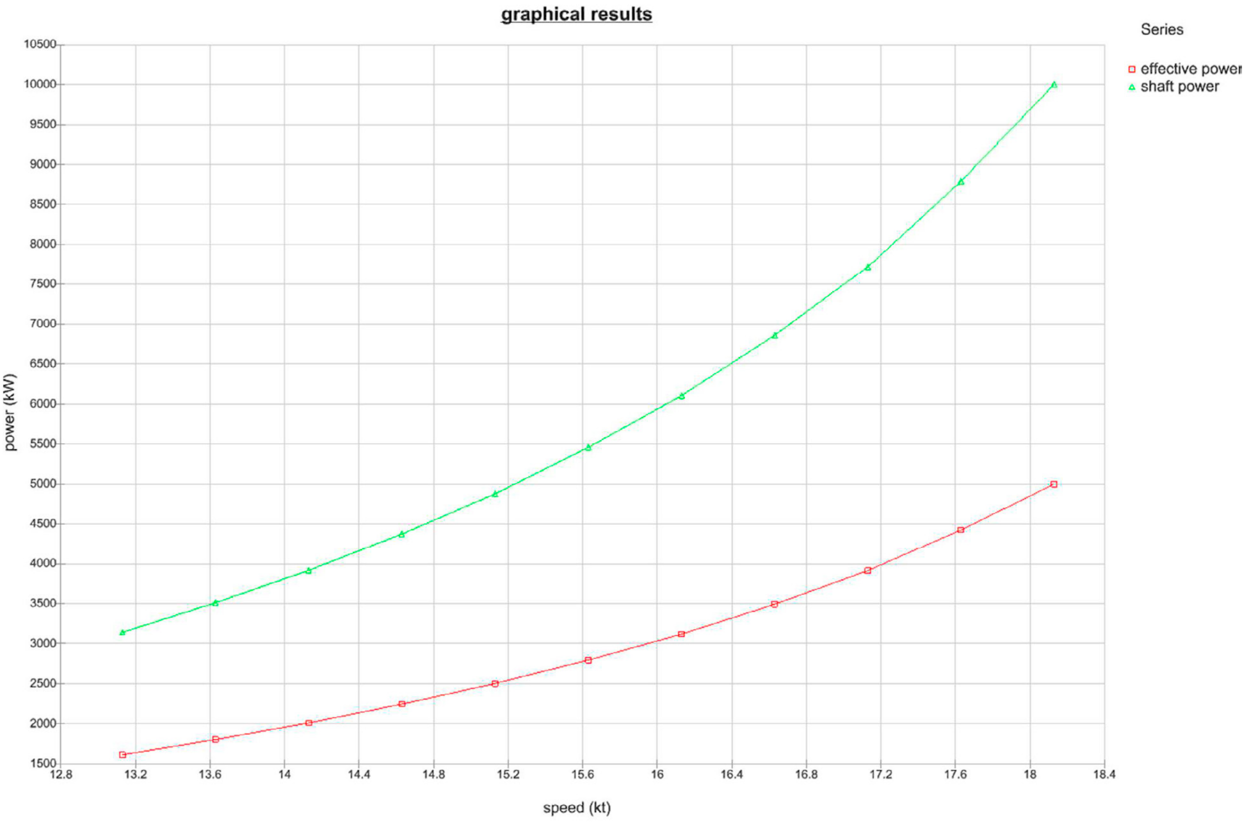


Fig. 9. Powering curves

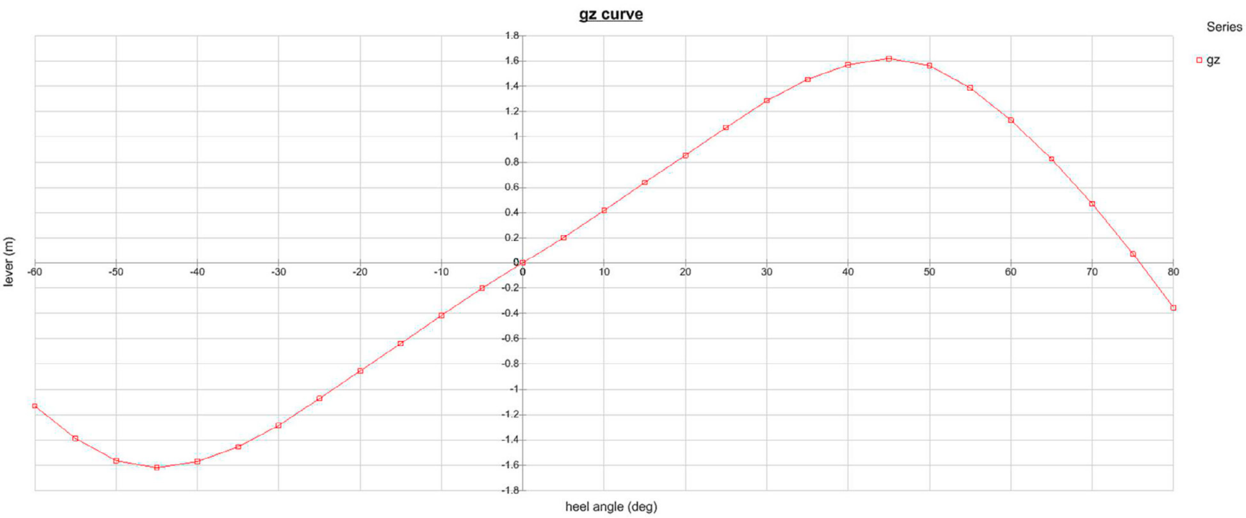


Fig. 10. GZ curve

The results hereby presented, attained by using the CAE part of Paramarine®, represent quickly-obtained consistent and reliable data. Thus, the VP becomes suitable for rapid quality check with the real product built, allowing to save time and quickly identify discrepancy. Besides this, it is important to note that remarking activities required for software switching (i.e., from only CASM to CAD to CAE software) are deleted if a PMP software (such as Paramarine®) is used, reducing in the meantime loss of data and consistency's risks.

4. Conclusions

In this paper Paramarine®, a PMP, was used to create a VP of a case study ship, in order to obtain some outputs of interest (such as a first structural weight estimation) since early-stage design phases.

By using this multi-purpose software, all the remarking activities necessary to software switching are deleted. Besides this, even the time necessary for the transition from a design phase to another is drastically reduced; for example, in a traditional design process, the passage from preliminary to functional design requires at least two months. By using a rational design process (and a PMP tool) this time is basically equal to zero (the level of details of a VP is comparable with the ones obtained from a functional design). In addition to these considerations, it is important to note that a multi-purpose software such as Paramarine® allows to build a high number of design concept in no time, in order to focus from the beginning which are the most interesting design path to follow for fulfilling shipowner's desires.

Even if the obtained outputs can be considered consistent and reliable data to use for starting the real shipbuilding process, difficulties in exportation to other CAE programs was found at the end of the design process (Paramarine®, specifically, can be defined as a stand-alone software, that hardly interacts with other programs). These last steps are very important for achieving a higher ship's level of details; for this reason, in the future, an in-depth cost-benefits analysis must be carried out before deciding which multi-purpose software is more convenient to use.

Despite these software limitations, some future development of this work will be carried out. For example, it is under consideration a VR implementation inside the VP created; thanks to this evolution it can be verified if space arrangements of all ship's elements are being studied properly to let seafarers doing their works or, complementarily, it can be created a Virtual Environment to use as a safe training platform for young seafarers.

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