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Simulation-driven ship design

Rethinking marine design to increase productivity and early insight into vessel performance

Executive summary

This paper examines how an integrated design environment, workflow automation and intelligent design exploration provide the foundation for a new approach to vessel design: simulation-driven ship design (SDSD). Taking a fresh approach to the design process and moving away from the established but inefficient design spiral, SDSD can increase productivity and provide greater insight into, and confidence in vessel performance from the earliest phases of design. This can provide significant cost savings, ensuring profitability for both shipyards and ship owners. The approach also enables naval architects to evaluate many more design variants and focus on improvements and novel designs, giving the potential to meet the ever-increasing demand for greater vessel efficiency.

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Abstract

The marine industry is an integral and critical part of the global transport network, embedded in every facet of global activities from the leisure economy to global trade and naval defense. At the same time, the pressures on this industry have never been greater.

According to Clarkson Research, by the end of November 2019 the global vessel order book had fallen to 2,952 vessels (vessels of 1,000 gross tons or more), totaling 74.3 million compensated gross tonnage (CGT), a 14 percent decline in 2019 in CGT terms, and a 67 percent decline from its 2008 peak. This represented its lowest CGT since 2004.

It seems clear that for long-term sustainability of the business, shipyards need to find a way to differentiate themselves and become more competitive in the market.

To add to this challenge, vessels must now meet increasingly tight regulations targeted at reducing emissions and the impact on global warming. Penalties for missed performance targets significantly increase the risk for shipyards and require completely new mitigation strategies. Ship owners on the other hand require their vessels to be future proof to meet current and expected changes in the regulations.

With this backdrop and these uncertainties, the **only** safe strategy for both shipyards and ship owners is to **design** (and then build) the most efficient ship possible. The less energy a ship requires for operation, the easier it will be to align with any new regulations, whatever energy source or technology is used. The greatest impact on increasing vessel efficiency and reducing building costs can be made during the ship design phase. Figure 1 shows the typical cost build-up for a ship between receiving technical requirements and delivery. Looking at the assigned cost curve, around 85 percent of the final cost of a vessel is determined during the early design phase.

Once the detailed design is started, only minor alterations can be made without incurring huge cost increases. Therefore, to achieve maximum efficiency,

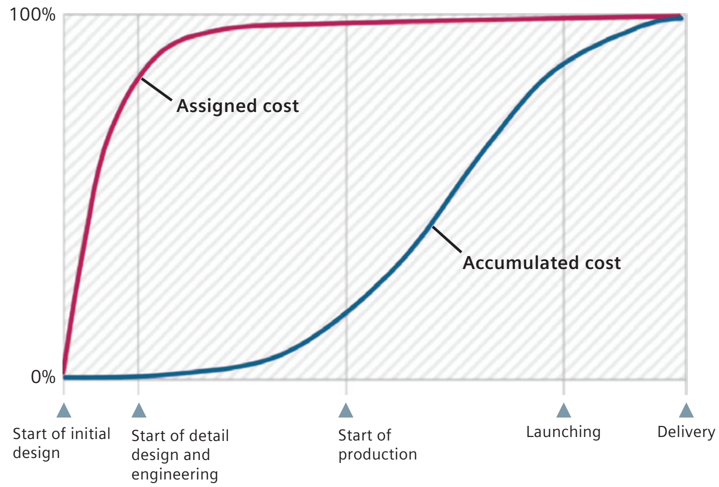

Figure 1: Typical cost build-up for a ship based on work by Fisher and Holbach, 2011.[1] Approximately 85 percent of the final vessel cost is determined during the early design phase.

we must focus the greatest scrutiny on early design. At the same time, by making even a small percentage savings in cost here, the total build cost of the vessel will drop, and profitability will increase.

This paper introduces simulation-driven ship design as the new way of thinking about vessel design. This approach makes full use of the digital technology available today. By shifting the design process from a traditional design spiral to a fully integrated design environment driven by intelligent algorithms and automated tools and processes that are all connected throughout the lifecycle via the product lifecycle management (PLM) backbone, you can both reduce costs in the early design phase and increase confidence in performance. This way naval architects can focus on engineering and innovation and add system-level optimization across functions rather than wasting time building disconnected models or communicating information using incompatible data sets and siloed processes. The paper explains how this approach works and gives examples of its use.

The limit of the design spiral

Before introducing simulation-driven ship design, let us look at the traditional ship design process. This is often described as a design spiral, as shown in figure 2. The process typically starts with a mission statement for the vessel, followed in turn by various functional requirements, such as proportions and powering, hull form, general arrangements and then through trim and stability predictions and so on to a final cost estimate. At this point, the design is further refined by running through the same loop again. This cycle is repeated multiple times until all requirements are met and the detailed design can commence.

Figure 2 clearly shows this approach is inefficient. The repeated and rigid process often requires multiple teams working in siloed conditions with unconnected tool sets and minimal communication between them. This leads to a time-consuming process, with little scope for true design innovation: It is often easiest to refine an existing design rather than start from scratch and analyze multiple options for the same mission statement. Sticking to the spiral increases pressure on profit margins as well as the risk to the shipyard. But because this method has existed for many decades it is hard to break. This is where simulation-driven ship design comes in.

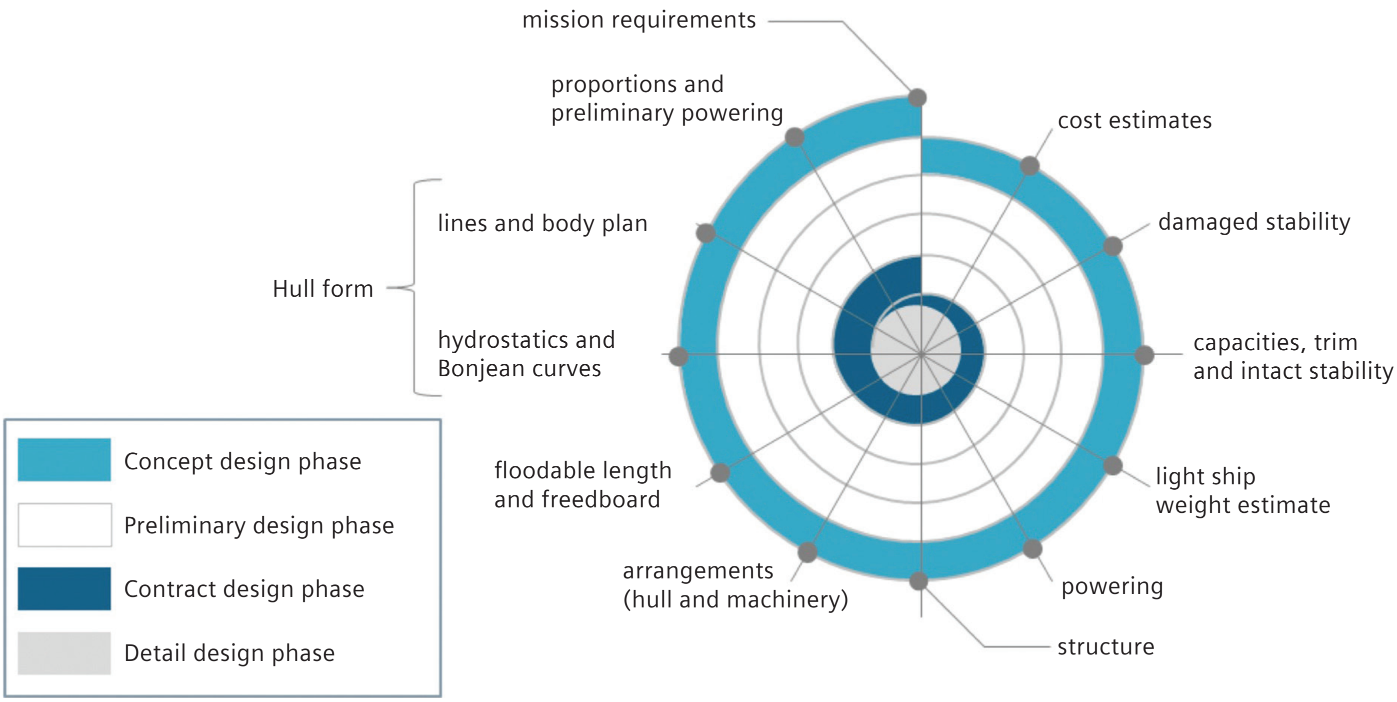

Figure 2: Pictured is the vessel design spiral. Each refinement of the vessel design passes through a sequence of requirement assessments until the final design is reached.

Another way – integrated ship design

Simulation-driven ship design starts from a different viewpoint: what if with the digital tools available today we can streamline the process, get rid of the spiral and combine all design stages together, allowing them to interact with each other seamlessly? In such a streamlined process it will be easier to analyze multiple designs and make rapid changes early in the design phase. This will reduce the assigned cost required (figure 1), while at the same time giving the user confidence their decisions are accurate.

A representation of this fully integrated ship design environment is shown in figure 3. There are still different design stages (initial, basic and detailed), with different levels of information required. But at each stage the spiral is removed: Instead, all aspects of the vessel are analyzed together, with information passed between them as required. Communication between the design levels is also managed via a data backbone in the shape of a PLM system such as Teamcenter® software.

The master model, a single source of data

In an integrated design environment, all data for a given design is stored and linked together. Central to each design stage and linking the stages together is a master model: a single point of reference computer-aided design (CAD) data, which can contain all the information needed, from general arrangement to structural design and marine systems. Different performance analyses can be performed by using only the required data from the master model. For example, hydrodynamic studies using computational fluid dynamics (CFD) require only the hull shape and no internal structure. The results from this analysis and any other analyses are maintained within the data structure and linked to the master model.

As analyses are performed on the master model and give information on vessel performance, the geometry can be updated. At any stage, the master model contains all information related to the most efficient design and can be used as the starting point for more investigations. This master model removes problems with data communication between teams, and lags in design analysis as all engineers can access the same model at the same time.

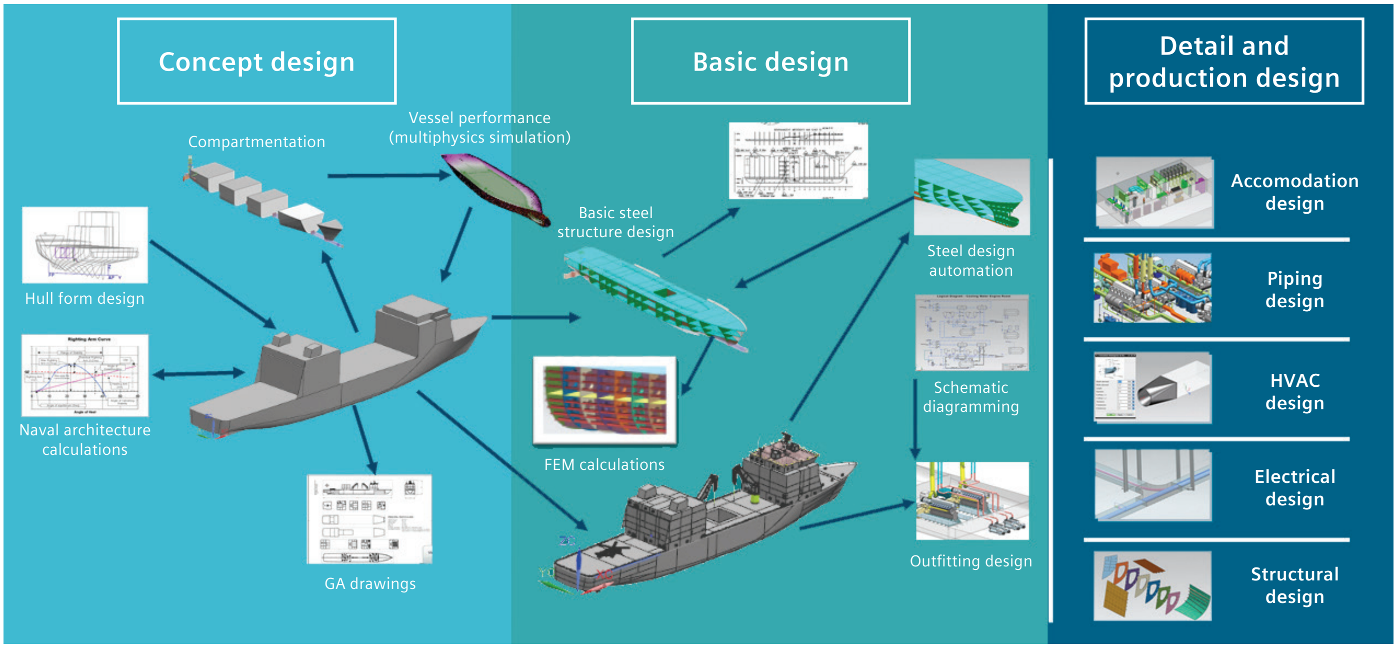

Figure 3: Integrated design environment, with communication both within and between design stages.

Simulation-driven ship design

Although moving to the master model will bring benefits on its own, the true increase in productivity comes with a shift to simulation-driven ship design. This combines the master model with automated simulations and intelligent design exploration, reducing manual intervention during simulations and increasing the range of designs that can be analyzed.

The standard process for CFD simulations when part of the design spiral is highly manual and intensive in terms of man-hours. It starts with designing or importing CAD, and perhaps repairing it before moving to meshing, then setting up the physics and conditions for the test and running the analysis. Once results are available, they can be checked to see if the design meets the expected performance requirements. If it falls short, this process is repeated, starting by altering the CAD and moving on through the stages. Much of this work is repetitive and because of its labor-intensive nature only a few designs can be analyzed in detail.

Simulation-driven ship design moves away from manual interaction and shifts to automated, computer-driven processes. The key parts of the process are:

- Parametric CAD
- Automated geometry repair and meshing
- Templated, pipelined repeatable solutions for physics and parameter setup
- Multiple analyses running concurrently in parallel
- Intelligent design optimization using automated tools

A schematic of this process is shown in figure 4. Following this procedure, we can run as many simulations as we want by simply changing any of the CAD parameters and rerunning the automated process. Once all the simulations have been completed, we can look at the consolidated results: For example, if we have prescribed a sweep through different velocities, we can look at the power speed curve, or if we run a design of experiment (DoE), we can look at the influence of various parameters on the key performance indicators.

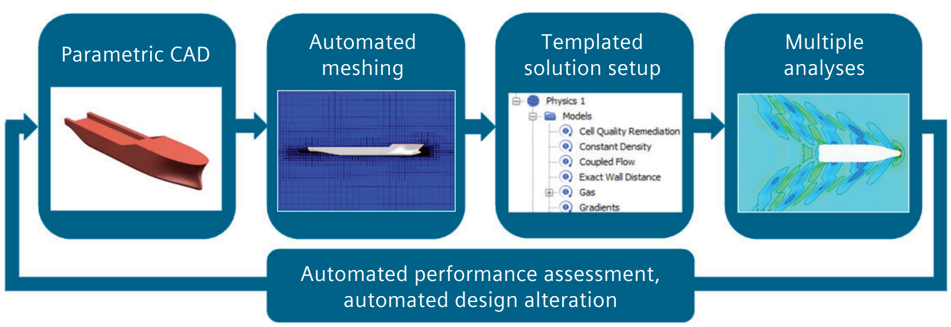

Figure 4: Automated simulation process. Any changes in CAD can be rapidly assessed and the user isn't required to set up models.

Simulation-driven ship design case study

Simulation-driven ship design enables rapid analysis and optimization of vessel designs by integrating parametric CAD and simulation, automated processes and intelligent design exploration. In this section we examine results from an example case based on a multi-role vessel (MRV). The geometry for this case is shown in figure 5.

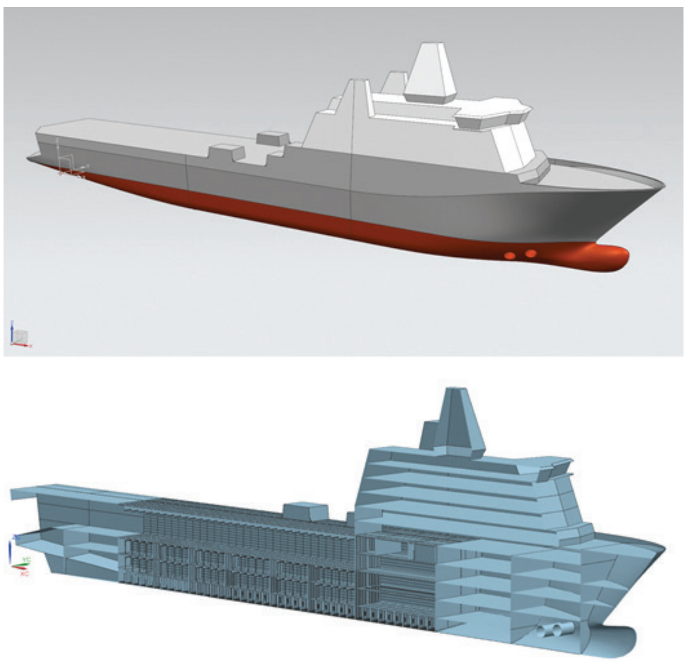

Figure 5: Parametric CAD model of the Siemens MRV.

The goal of this case study is to design a better, more cost-effective vessel. There are two ways of increasing cost-efficiency: reducing the capital expense (CAPEX) of building the vessel, which would benefit the shipyard, and the operational expenses (OPEX) throughout its lifetime, which would benefit the owner. With the simulation-driven ship design approach, we can choose to optimize either one or investigate which design balances both requirements.

The goal of reducing both CAPEX and OPEX should of course not affect the performance; in other words, the mission statement should not be affected. For the MRV the mission statement can depend on its planned use. In this case, the mission statement is to deliver a prescribed mass of goods meeting or exceeding prescribed efficiency targets. To meet this mission statement, we need a certain deck space as well as a certain displacement equal to the mass of the goods. These become our constraints.

Let us now look at the workflow for this MRV example:

1. The CAD (figure 5) master model is stored in NX™ software, from which we can directly derive the general arrangement drawings. Note that because the general arrangement is directly connected to our master model in NX, the drawing will always remain up-to-date. In this case we chose to define eight independent variables (parameters) that can be used to modify the baseline design vessel's hull shape. From the CAD we can also measure the deck area (one constraint) and all other surface areas.
2. Calculate hydrostatics and intact stability using the prescribed constraints to ensure a stable vessel. In this example, we used Simcenter™ STAR-CCM+™ software, the multiphysics CFD solver from Siemens Digital Industries Software, but other stability tools can be used instead. Calculations are automatically performed on the most up-to-date version of the design.
3. Perform a virtual towing tank simulation (hydrodynamics) using Simcenter STAR-CCM+: Analyze the geometry at full scale and calculate the hull resistance.
4. Analyze results based on our required goal. Based on this, make a design change to the geometry by altering the parametric CAD data.
5. To explore multiple designs and move to a simulation-driven design approach, we now drive this complete process via HEEDS™ software. All combined, we now have a truly powerful solution in which HEEDS is directly modifying all design variables, generating all the necessary input files

for Simcenter STAR-CCM+ and running the simulation, while intelligently searching for the best trade-off set of designs (for there may be more than one) that minimize both CAPEX and OPEX. During this process, HEEDS is using all hull shape variables from the original virtual prototype concept stored in the master model without reducing them or using any surrogate modeling.

This workflow is shown schematically in figure 6. This simulation-driven approach removes the design spiral and provides a framework for rapid investigation of multiple designs driven by the design exploration software.

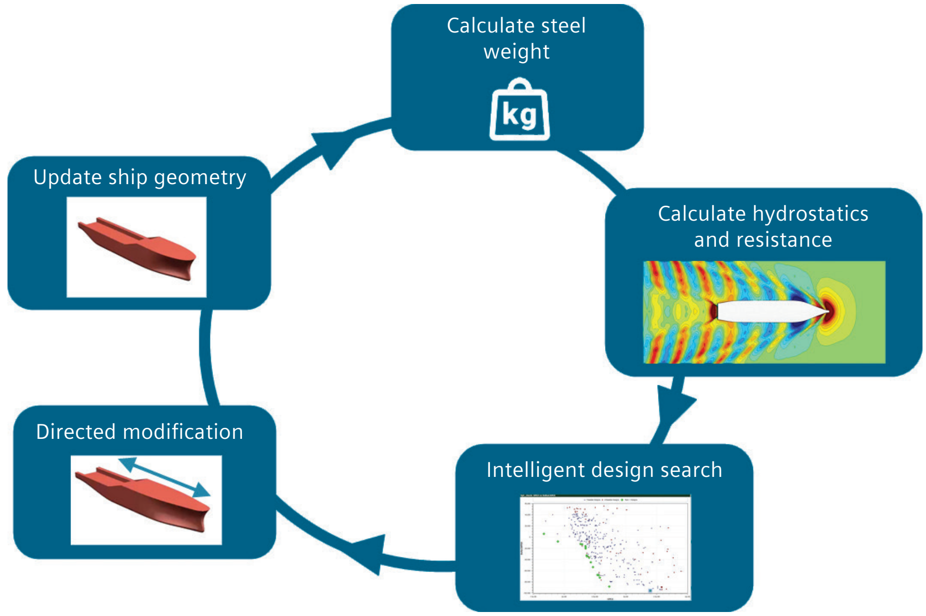

Figure 6. Simulation-driven ship design.

Case study results

For an example case like the MRV, we can evaluate 500 designs in under four days, using a Linux cluster with 24 cores per CFD simulation. This is approximately two hours of computing time per design. Note this is computer time, not person-hours. Once the initial setup has been done the process is driven automatically by HEEDS, working within the design constraints specified by the naval architect. This automated, simulation-driven approach frees up naval architects to work on designs and insights rather than manually setting up and running simulations.

Understanding 500 designs is not trivial, but the results can be analyzed in different ways to see the overall effect of different constraints, as well as examine individual designs in more detail.

Figure 7 shows an example of a summary plot for all design variations, with their relative CAPEX and OPEX predictions. All blue dots are feasible, but the best designs (those which meet the mission statement with lowest values of CAPEX and OPEX) are highlighted in green. For each point on this plot, the complete simulation results are available so the naval architect can select which designs to look at in more detail. This can help the architect understand why certain designs are feasible or infeasible, or what parameter combination makes some designs better than others.

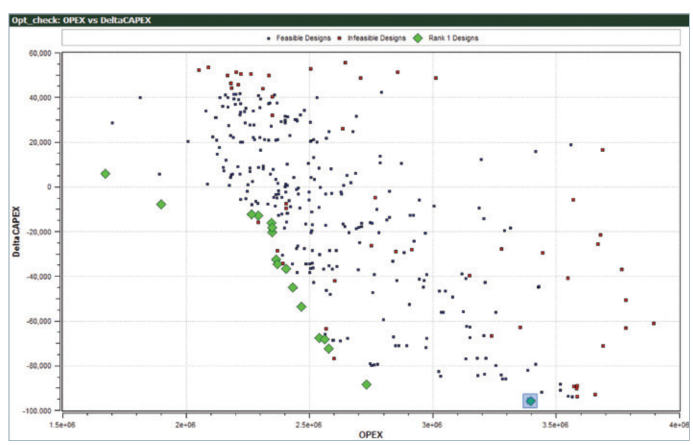

Figure 7: Overview of all investigated designs, with relative CAPEX and OPEX. There are a range of feasible designs (green) that meet the design constraints.

We can also compare the effect of the different design constraints: parallel coordinates (shown in figure 8) show which combination of parameters are responsible for a given trend and can be shared in discussions with the customer. For example, if the operator requires more deck space, the best ways to achieve this and the corresponding changes in other design constraints can be shown in one plot.

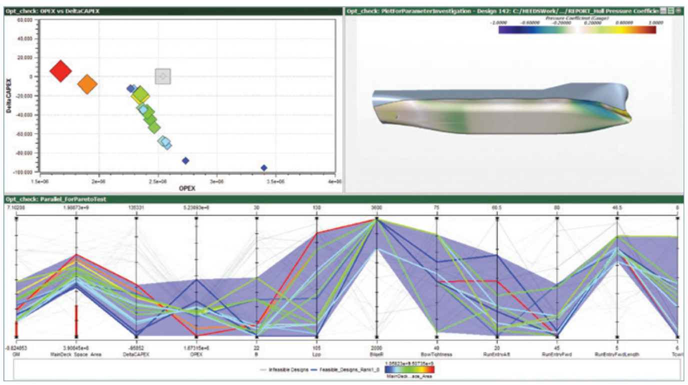

Figure 8: Comparison of contributions from the design constraints for the range of designs highlighted in the upper left plot: size of the deck space small(blue) to large (red).

Thus, the data enables us to understand which parameters are responsible for:

- Expensive to build but cheap to operate designs
- Cheaper to build but expensive to operate
- Designs that fall in between those categories

This information can be used both to target development plans, but also to discuss with the owner at the early stage of the design. And this greater level of information and understanding can influence the design from the very earliest stages, allowing for much better tailored and thus competitive bids with reduced cost and performance uncertainty.

Of course, not all 500 designs are feasible. In this study, approximately 20 percent of the designs were infeasible, violating at least one of the defined constraints. By analyzing the frequency of these constraint violations, naval architects can gain a picture as to how difficult they are to satisfy and why. This could show if the constraints are too rigid: In some cases, relaxing these constraints by just a fraction could lead to finding a more efficient design.

Conclusion

This paper describes a new approach to vessel design: simulation-driven ship design. By moving away from the established but inefficient design spiral, this approach can increase productivity and provide greater insight into, and confidence in vessel performance from the earliest phases of design. The case study example has shown how this approach enables naval architects to evaluate many more design variants, giving the potential to meet the ever-increasing demand for greater savings in vessel efficiency. Simulation-driven ship design can provide significant design cost savings, ensuring profitability for both shipyards and ship owners. The highest relative cost is now computing time, not the engineer's time.

Siemens already has in place the necessary technology framework to manage simulation-driven ship design and all the tools required to use this approach. This is demonstrated in the case study. By embracing the power of digitalization, the marine industry can meet the economic and environmental challenges head on and ensure both profitability and innovation going forward.

Reference

1. Fischer, J.O.; Holbach, G. *Cost management in shipbuilding*. GKP Publishing, 2011.

Siemens Digital Industries Software

Headquarters
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 972 987 3000

Americas
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 314 264 8499

Europe
Stephenson House
Sir William Siemens Square
Frimley, Camberley
Surrey, GU16 8QD
+44 (0) 1276 413200

Asia-Pacific
Unit 901-902, 9/F
Tower B, Manulife Financial Centre
223-231 Wai Yip Street, Kwun Tong
Kowloon, Hong Kong
+852 2230 3333

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