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Assessing yacht design processes: a comparison of traditional and integrated methodologies

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Abstract

Yacht design process currently faces challenges as slow data sharing, lack of flexibility in modelling and inefficient optimisation of shapes. This paper assesses the potential of an integrated approach over the traditional one, using a hypothetical industry scenario. The key aspects of data sharing/project management, modelling system, and shape optimization are compared, and new collaborative tools and technologies are introduced. The research reveals significant benefits of the integrated approach over the traditional one highlighting its potential to foster innovation within the industry.

Keywords: yacht design, integrated design, product data management (PDM), topological optimisation, 3D modelling

1. Introduction

Yacht design is a long trial and error process, which consists of refining and perfecting the project through various iterations in order to meet the specified requirements (Karczewski and Piątek, 2016; Liu et al., 2017a). This cycle of continuous improvements is called design spiral (Larsson et al., 2022). Progressively, as the number of iterations increases, the process becomes more and more complete and detailed. The design spiral divides the evolution of the project into several segments, each corresponding to a task performed by a multidisciplinary project team. At the end of each cycle, the compatibility and correctness of the changes made is checked. Through the division into segments, it is possible to systematically cover each aspect of yacht design.
In this context, as highlighted in the literature, the traditional approach could present several challenges, hindering multidisciplinary work, slowing down the design process, and leading to inaccuracies and inefficiencies (Karczewski and Piątek, 2016; Liu et al., 2017a).
The key factors that most significantly impact efficiency include:

- Data sharing and project management - outdated information exchange and storage systems can cause slow data transmission, fragmented projects, and the need for tedious manual data alignment. Stakeholders use software from different platforms across different project phases, which can lead to compatibility issues (Danese and Pagliuca, 2019).
- Modelling system - direct modelling is not flexible and makes it difficult to modify a model's geometry once completed (Hochkirch et al., 2002).
- Shape optimisation - simulation processes require multiple iterations and adjustments are often made intuitively by the naval architect (Kim and Nowacki, 2005). If the results are not satisfying enough or reveal errors, the entire process must be repeated.

In the nautical sector, most of the studies proposed specific solutions for each critical issue that has emerged. The suggested solutions have mainly proposed the use of a collaborative data platform, parametric modelling, and multi-objective optimisation as design-management tools. However, the studies lack an integrated approach that explores the synergies within these three design-management tools. The present research aims to develop and test an integrated approach, evaluating not only the possible synergies in the yacht design process but also the pros and cons compared to the traditional approach.

The paper is divided into seven sections. After an introduction, the second section presents the tools used through a literature review. Then, the methodological framework applied to the research is outlined. In the fourth and fifth sections, the results of the research are presented, respectively for the traditional approach and the integrated approach. In the sixth section, the results of the application of the two approaches are discussed through a comparison. Finally, in the last section, conclusions are drawn.

2. Theoretical background

2.1. Collaborative data platform

Facilitated collaboration among multidisciplinary stakeholders is a topic of great interest within the yacht industry (Liu et al., 2017b). The collaboration involved in the design process can be viewed through two levels. Firstly, it encompasses inter-organisational cooperation, which involves multiple stakeholders participating in the project. Secondly, it involves intra-organisational collaboration, where different divisions within the same organisation work together (Solesvik, 2007).

To effectively support the continual exchange of data in this multi-faceted scenario, a shared platform serves as an indispensable tool in streamlining information sharing, ensuring data accessibility, and promoting collaborative synergies among the stakeholders.

Improving data exchange is not just an issue for the marine industry. Other industries have addressed the problem by adopting cloud-based shared platforms. In the AEC industry, this is achieved through the use of a Common Data Environment (CDE) (RICS, 2014), which collects and manages all project information in a unified model. This model integrates the different project domains, such as geometric, temporal, and economic. One important aspect of such collaborative platforms is that modifications to the project are automatically visible and accessible in real-time from all stakeholders, eliminating inaccuracies and drastically reducing communication times (Liu et al., 2017a).

2.2. Parametric modelling

A crucial aspect for expediting the entire design process is the availability of a versatile approach to create an initial hull design that can undergo subsequent shape adjustments (Vernengo et al., 2020).

In this perspective, parametric modelling can be useful especially when the model is subject to many modifications (Myung and Han, 2001).

Parametric modelling represents a completely different and innovative approach to CAD compared to the traditional tools of 2D drawing and 3D modelling currently widespread.

With this tool, each object is created through a sequence of design parameters, which represent the main features of the model (Khan et al., 2017). Subsequently, these parameters are related to each other through constraints. The first experimentations regarding the use of parametric modelling for hull design were carried out by Kuiper in the 1970s (Kuiper, 1970). Since then, significant advancements have been made in research on the topic. Khan et al. (2017) proposed a parametric modelling framework, dividing the hull into different regions and introducing shape operators. Pérez-Arribas (2023) stated that preliminary parametric hull models enable flexibility and accelerate the design process, facilitating modifications in successive design phases as well.

2.3. Multi-objective optimisation

Designing a hull involves considering a multitude of factors while adhering to specified constraints and meeting diverse requirements. Achieving the optimal design and performance involves a significant amount of manual effort, and often relies on a trial and error approach.

When striving for the ideal solution, various criteria may come into play, leading to conflicts among them (Karczewski and Kozak, 2017). This results in a solution that doesn't fully satisfy each criterion but rather necessitates a trade-off between them. In multi-objective optimisation, the challenge lies in

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identifying and establishing this compromise. One approach to addressing the multi-objective design problem is to pursue a set of Pareto-optimal solutions. These solutions represent a delicate balance where no improvement can be made in one criterion without sacrificing performance in another.
By defining a range of values for each variable associated with the parametric model and simulation data, it is possible to generate numerous versions in a fully automated process, analysing the behaviour of the model in different morphological declinations and scenarios. Each of these variants represents a compromise that closely aligns with the desired objectives. The results obtained are accompanied by reports and graphs that simplify comparison and classification based on compliance with requirements. Research indicates that several studies have already explored the use of these tools within the nautical and shipbuilding industries. Papanikolaou (2010) presented a multi-objective optimisation procedure aiming to assist the designer of Ro-Ro Passenger ships in the preliminary design stage. Liu and Zhang (2022) used this approach to optimise the resistance and sea-keeping performance of the ITTC Ship A-2 fishing vessel. Multi-objective optimisation was used also to improve the hydrodynamic performance of a yacht's hull (Bigini et al., 2023).

3. Methodologies and focus of the research

3.1. Research strategy

The research was conducted by two students specialising in Vessel & Yacht Design at the Università di Genova as part of their master's thesis work. One of them completed an internship at a shipyard, while the other gained experience at a yacht design studio. The diverse backgrounds of the research team provided a well-rounded understanding of the diverse facets encompassed in the yacht design process.
The research followed a comparative strategy between the traditional and the integrated approach to yacht design. A hypothetical professional scenario was then defined within the yacht industry, with the aim of simulating a realistic framework of reference. In particular, a 50-foot long cruiser-explorer sailing boat was identified as a practical case study for testing both approaches, reflecting the growing trends in cruising and charter in the yachting market.

Figure 1. Render of the sailing yacht case study

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The comparative analysis focused on three key criteria for yacht design: data sharing and project management, modelling system, and shape optimisation. For each criterion, the most suitable software and tools were identified and evaluated to effectively test both the traditional and the integrated approach.
Both starting from preliminary 2D waterlines of the boat, the two methodologies were applied sequentially, first experimenting the traditional approach and then the integrated one. Specifically, the team member with shipyard experience addressed data sharing and project management aspects, while the counterpart who completed an internship at the design studio focused on aspects related to the modelling system and shape optimisation.
During the execution of both approaches, the research team members kept track of the timelines for various project phases and reported the results obtained through user observation. Through an unstructured interview, team members discussed to highlight the strengths and weaknesses of each approach. This strategy allowed the research team to systematically evaluate the real potential of the integrated approach.

3.2. Scenario hypothesis

The research team outlined a hypothetical professional scenario within the yacht industry to recreate a context based on what commonly happens in this field. This intends to provide guidance for selecting methodologies and tools adopted by the majority of shipyards and design/naval architecture studios.
Within this hypothetical context, the shipyard wants to produce a new semi-custom line of 50-foot long cruiser-explorer sailing yachts. As the shipyard lacks an in-house design and naval architecture department, the preliminary project phase is delegated to external expertise.
The hull must be designed starting from an existing model with similar characteristics, considering that other boats of the same category may be developed in the future with dimensional variations.
The definition of such a professional framework is based on the consideration that this situation is on average the most common in this industry, especially in this size range. The task of designing a boat is often divided between a team of designers, responsible for the aesthetic and functional part of the project, and a naval architecture studio, in charge of both technical and structural aspects.

3.3. Software and tools proposal

The traditional method was approached using the following tools:

- Email and mass storage units - for exchanging information among team members.
- Spreadsheets - used for collecting and organising technical and management data about the project
- AutoCAD and Rhinoceros - software for 3D modelling and drafting.

To test the proposed integrated approach, the Siemens platform was chosen, which offers a comprehensive suite of advanced tools to manage the entire project in a single integrated environment:

- Teamcenter X - cloud-based platform that facilitates real-time collaboration on shared models between the stakeholders involved in the project.
- NX - for parametric modelling and design data management.
- HEEDS - optimisation software that integrates CAD and CAE models, and automatically explores different solutions, generating and evaluating design alternatives.

Program licences were obtained through trial versions or provided by the university.

4. Experimenting traditional approach

4.1. Data sharing and project management

File sharing was commonly conducted through email and mass storage units, leading to the need for multiple copies when several team members had to collaborate on a file simultaneously. Consequently, the coordination of subsequent changes to the source file required manual intervention. Occasionally, the effects of file changes also affected the related documentation, necessitating corresponding updates. Using spreadsheets such as Excel, most of the technical information about the project was collected and organised into different files, e.g., bill of materials (BOM), bill of quantities, and project timesheet.

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In response to evolving developments, document information was regularly updated and synchronised through manual operations.

4.2. Modelling system

The research team used AutoCAD to produce the general arrangement and various technical drawings at different scales of detail, while Rhinoceros was mainly adopted for the 3D modelling of the vessel.
As the project progressed, the use of distinct software for drafting and modelling required manual updates to synchronise changes between the two programs.
To address the requirements of particular variations or respond to unforeseen circumstances, substantial modifications were necessary, including the creation of both 2D and 3D content from scratch in certain instances.
3D models created using Rhinoceros solely represent the geometric characteristics, without incorporating physical properties, temporal aspects, and economic factors. As a result, any alterations to the geometry necessitated manual updates to the associated attributes.

4.3. Shape optimisation

In the traditional approach, shape optimisation predominantly relied on prior experience and, as outlined in the scenario hypothesis, it involved using an existing model similar to the design specifications.
The design process followed a trial and error method. Hull shapes were modified in order to optimise three aspects selected by the research team: hull displacement, internal volumes, and main deck area. These iterative operations were performed manually until the set objectives were achieved. Due to the extended duration of the method used, multiple solutions couldn't be evaluated.

4.4. Project duration data

Traditional approach tools allowed to create a conceptual model of the hull in five hours. Preliminary project phase, which involved a basic distribution of the main interior and exterior volumes and initial project documentation, took 60 hours of work. Final project, with a detailed model and relative documentation, required additional 120 hours of work.

5. Experimenting integrated approach

5.1. Data sharing and project management

In the proposed integrated approach, the use of Teamcenter X as a collaborative data platform ensured that the team members had constant access from anywhere to a unified and up-to-date digital model of the boat containing all project information. In this way, a direct association between the model and its documentation was provided. In addition, documents such as BOM and product sheets were automatically generated by the platform.
Thanks to the collaborative data platform, the research team could work on files that were always up-to-date and aligned. Changes to timesheets and tasks were shared in real-time and integrated with the geometric model.

5.2. Modelling system

The model was configured to have its primary geometric features, such as hull length, max beam, and depth moulded, regulated by editable parameters. By acting on the control points of specific cross sections, more targeted changes could be made. Thus, by adjusting the parameters, the hull shape dynamically conformed to specified changes. Parameterisation was also applied to the other yacht parts. This tool facilitated the creation of a digital object library of reusable for future projects.
As shown in Figure 1, the hull model sourced from the library can generate diverse versions through parameter modifications. The integration of NX software with the collaborative data platform seamlessly propagated changes not only to the model but also to associated documents. Finally, the use of NX as modelling and drafting software, alongside its integration with the collaborative data platform, ensured to seamlessly transmit the effects of the model's modifications to both 2D and linked documents.

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Figure 2. Modifications of the parameters associated with the model

5.3. Shape optimisation

The team optimised the hull shape by importing the parametric model into HEEDS. The multi-objective optimisation was set up to take into account the three aspects also considered in the traditional approach. Based on this, the software automatically generated 50 Pareto-optimal hull versions by modifying the model parameters. The research team was therefore able to quickly explore a wide range of alternative solutions by analysing the results through reports and charts generated by the software, as shown in Figure 2.

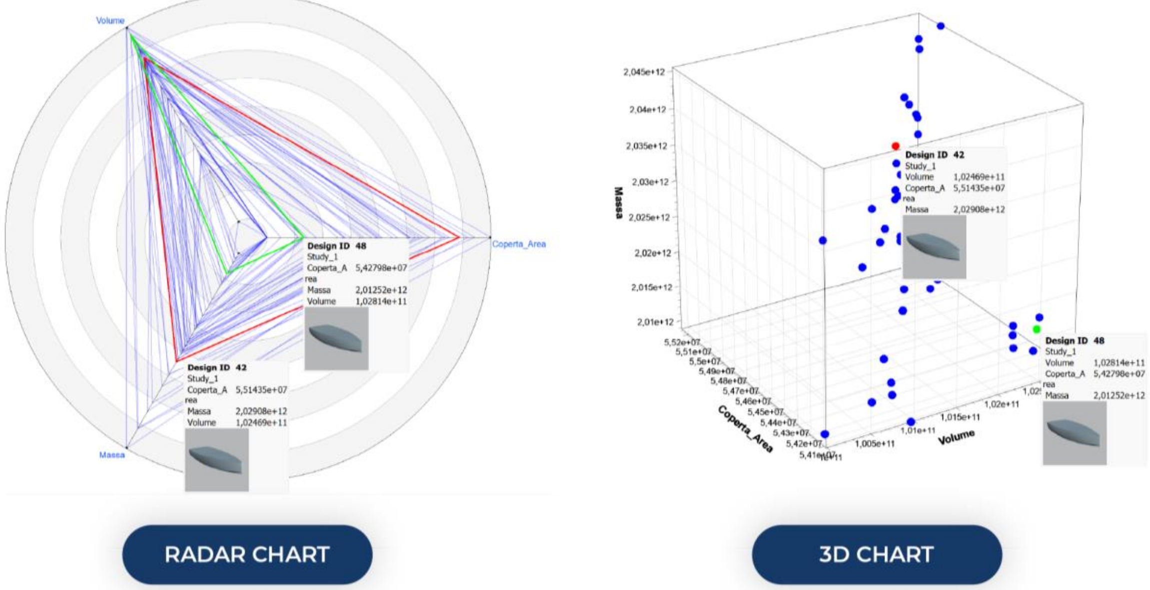

Figure 3. Comparative charts of the results

5.4. Project duration data

By adopting an integrated approach, a conceptual model of the hull could be created within 24 hours. The preliminary project phase took approximately 60 hours to complete. An additional 80 hours of work was required to finish the final project.

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6. Results discussion

6.1. Data sharing and project management

The implementation of a collaborative data platform brought significant benefits in information exchange, project management, and collaboration among team members.

User observation demonstrated that the conventional method of file exchange through email and mass storage units posed challenges for collaborative work on a single document, as it hindered simultaneous contributions from multiple individuals. This resulted in the generation of numerous copies that later required synchronisation, causing significant delays.

In contrast, the use of Teamcenter X allowed the research team to access a single, up-to-date digital model at any time, directly from the cloud-based platform. Therefore, all operators could work effectively on the same data, viewing the changes made by other team member in real-time. As emerged from the unstructured interview, both researchers reported an improved productivity.

Since documents such as BOMs and product sheets were automatically generated and linked to the model, no manual updates or alignments were needed, signifying remarkable progress beyond traditional spreadsheets.

Thanks to the ability to work on up-to-date information, inefficiencies caused by receiving old versions of documents and aligning changes were eliminated.

Furthermore, the seamless incorporation of timesheets into the cloud environment has significantly enhanced efficiency in managing project timelines compared to conventional methods.

6.2. Modelling system

From the user observation, it was pointed out that the use of traditional software such as AutoCAD and Rhinoceros for drafting and 3D modelling led to considerable difficulties in managing changes to models. In addition, directed modelled components proved ill-suited for the creation of a digital library.

On the other hand, the team noticed a great improvement on these critical aspects through the introduction of parametric modelling. By creating the 3D model of the boat using adjustable parameters, it was possible to cope with unforeseen changes during the project and was able to easily modify the geometry even in the most advanced design phases.

Furthermore, the integration of NX with the collaborative data platform automated the propagation of changes in the parametric model to all related documents, avoiding manual updates. Automated drafting has demonstrated significant advantages over manual alignment between model and 2D drawings, eliminating inconsistencies and reducing errors.

Thanks to these capabilities, design flexibility has increased exponentially, significantly reducing design time.

6.3. Shape optimisation

As emerged from the data, the trial and error method adopted in the traditional approach resulted highly time-consuming. Due to the continuous manual modifications to the 3D model, it was not possible to explore a significant number of alternative solutions before achieving the desired objectives.

By merging the parametric model with HEEDS, the integrated approach allowed the team to overcome these limitations. Compared to the slow manual iterative process, the synergy between parametric modelling and multi-objective optimisation accelerated the search for the optimal solution, while exploring many more design alternatives in reduced time.

6.4. Project duration data

Based on the time tracking data collected, some key observations can be made regarding the times taken for the two approaches tested. For the conceptual hull modelling phase specifically, the traditional approach resulted in faster completion times. However, during the preliminary project phase, the times required were essentially equivalent for both methods. Nevertheless, the integrated approach, due to the high level of automation, greater flexibility and facilitated collaboration, allowed an overall reduction

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in project time of almost 20 hours. In addition, the integrated digital model, due to its versatility, allows easier reuse and adaptation of its components for future projects.

7. Conclusion

As emerged from the research, yacht design practices currently face a series of barriers that hinder processes efficiency. The paper proposed an integrated approach for yacht design and compared its effectiveness with the traditional approach, examining the three key aspects of data sharing and project management, modelling system, and shape optimisation.
The implementation of new tools and the synergy between them have led to significant benefits in nautical design processes:

- Increased collaboration through a cloud-based platform.
- Improved access to project data thanks to a unified digital model.
- Reduced inconsistencies and errors thanks to up-to-date and aligned data.
- Flexible modelling achieved through parametric design.
- Time savings and process efficiency as an overall result.

Since this research was conducted by a team of two university students, financial resources and time spent on design activities may differ from an established professional setting characterised by extensive experience and greater economic capabilities. Future research could explore the practical implications of the proposed methodology in diverse nautical scenarios, such as small design studios or large companies, as the economic and efficiency outcomes are likely to exhibit significant variations based on the professional context in which the integrated approach is implemented.
Moreover, the shape optimisation aspect was examined only by evaluating three criteria among the various requirements present when designing a boat. The inclusion of further physical and structural simulations such as CFD and FEM could provide a basis for future research into integrated design.
Another area of interest for further studies could be the implementation of an integrated approach using software platforms other than Siemens to broaden the perspective and assess the versatility of the proposed approach in broader contexts than the current research.
The research suggests that the implementation of integrated design approaches can be a key to the future of yacht design, promoting innovation, increased efficiency, and continuous quality improvement in the nautical sector. In fact, the benefits from adopting an integrated approach have been well documented in other sectors, such as automotive (Ma et al., 2021), aerospace (Shrivastava et al., 2018), and AEC (Collins, 2023; Garyaeva, 2018). However, translating this great potential into real benefits will require a significant collective effort by professionals and companies to overcome the technological and organisational challenges that still stand in the way of the full digital transition of the yacht industry.

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