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Industry 5.0: Transforming ship design through human-centered approach

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ABSTRACT

Industry 5.0 heralds a paradigm shift by reinstating the significance of human centricity alongside technology. Incorporating human collaboration into the design methodology aligns with general project management methodology and addresses the imperative of facilitating sustainable goals in the industry. Focusing on human skills and aspirations offers a viable path to expedite the adoption of new technology into the mainstream, aligning with the evolving needs of the shipbuilding industry and green targets of society development. The article delves into the implications of the Shipbuilding 5.0 paradigm to design process and methodology, the potential changes it brings, and the potential benefits it can offer to the evolution of the shipbuilding industry.

KEYWORDS

Shipbuilding 5.0; Human aspects of technology; Digital transformation; Design methodology

INTRODUCTION

The ship design process is often perceived as a primary engineering discipline focused on functionality. There are numerous methodologies and approaches to managing and organizing this process and many forums where such topics are discussed. A recently introduced concept to the shipbuilding world is Industry 5.0. Initially developed by the EU (European Union Publications, 2021), it takes the previous idea of Industry 4.0 to the next level. The levels of the Industrial Revolution are conceptual simplifications capturing the core changes in the social-technology landscapes and related processes understanding. These levels should not be interpreted as an assessment of the technology use, readiness, or advancement in digitalization, as these only indicate the industry's transformation stage and a conceptual framework.

Changes described in Industry 5.0 can be reflected in the evolution of the shipbuilding industry and ship design process. This article explores what changes in ship design can be expected in the context of Industry 5.0. It starts by providing an overview of the Industrial Revolution concepts focusing on ship design and shipbuilding, identifying impact areas, examining each area in detail, and offering a framework approach for considering the human-centricity perspective.

SHIP DESIGN METHODOLOGIES AND HUMAN CENTRICITY

The slow evolution of the ship design activities and methodology development reflects the society and technology development process. Figure 1 presents a very simplified version of the main changes in shipbuilding, primarily triggered by industrial evolution. From sailing ships to steam engines and steel hulls, these changes directly impacted the designs and purposes of vessels. It enabled longer sailing routes and larger cargo holds, and it is impossible to say what the cause and the reasons were

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- the desire for stronger vessels or the enablement of longer sailing due to more reliable ships. Later, CAE/CAD/CAM technology enabled more complexity and opened the doors to robotized production processes. This process is still ongoing; however, hardly any ship design is performed without the involvement of IT technology. Now, we witness the next leap forward with data management systems, advanced simulation, and a human-centricity finding its space in the IT technology serving shipbuilding. The latest stage of evolution, Shipbuilding 5.0, is expected to focus on placing human needs and capabilities at the heart of intelligent IT to take cyber-physical systems to the next level.

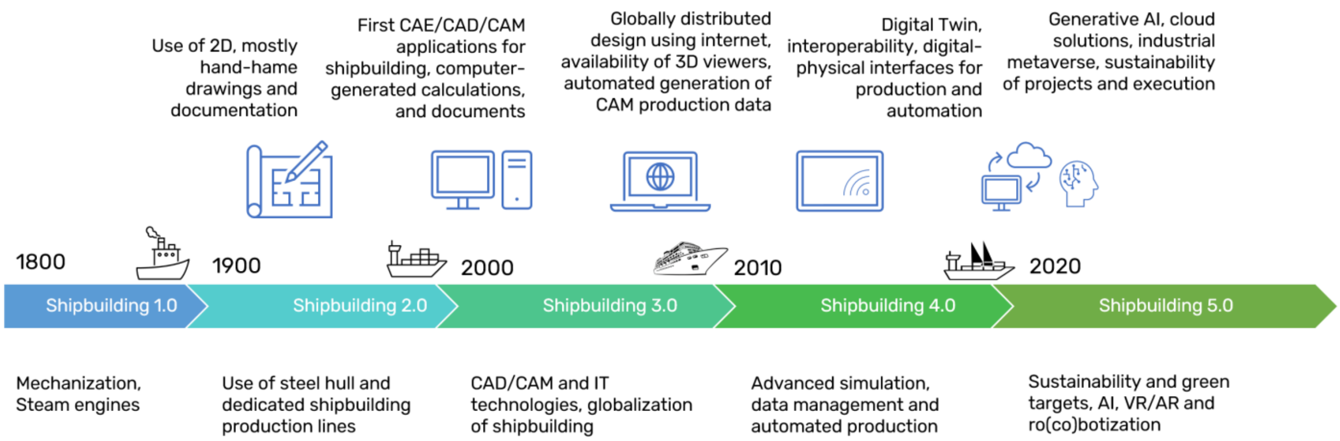

Figure 1: Evolution of concepts towards Industry/Shipbuilding 5.0 and main driving forces behind the concept levels and ship design technology.

For the ship design process, these steps can be described as a change from manually made design to technology-creating design based on human input. Only 30 years ago, it was a mainstream practice to do calculations and prepare all documentation using pen and paper or a calculating machine at best. Some 20 years ago, the first applications for engineering calculations were employed for ship design. At about the same time, the first CAD application provided the possibility to create a digital model and 3D model to evaluate engineering decisions and generate semi-automated output. There are technical possibilities to present the design model in Virtual Reality (VR), use simulation to assess hull forms and propulsion alternatives, and involve any expert anywhere in the world in the design process. These are undeniable advancements of the change that affected the ship design process due to technology and societal evolution. Industry 4.0 emphasizes a connection between digital models and physical products, while Industry 5.0 adds a human-digital-physical layer of complexity. Considering the latest stage, Shipbuilding 5.0, expectations are high with generative AI applications popping up in all areas, the industrial metaverse making its first steps into the industry, and co-bots and robots being employed in many shipyards for various tasks. What makes it unique is its overall focus on sustainability and resilience. It can be expected that the ship design process will be affected by these changes, and the following sections outline some of them.

AREAS OF SHIP DESIGN WHERE HUMAN-CENTRIC APPROACH CAN INFLICT CHANGES

The primary goals of shipbuilding lay in large-scale transportation, with various goals in rivers, sea, and ocean exploration. There are numerous purposes for waterborne transportation and human activities on and underwater. These goals are often substituted in ship design with derived imperatives, such as "delivering value for owners and operators" and ensuring the safety of operations. We must return to the origin and address the initial question - why does society need waterborne transportation and exploration of the rivers, seas, and oceans? While the response to these questions might be obvious, the presentation of the question in this form opens the core of the Industry 5.0 concept, placing human intentions and interests at the core of all processes. Focusing on the core of the initial reason provides a key to evaluating how to fulfill the request. This way, the discussion is taken from the context of shareholders, such as the owner or operator perspective, into a more comprehensive background of stakeholders, such as society goals, regional differences in communities, and people who will operate and use the vessels. This is a primary shift towards human-centricity, which should be performed before functional requirements.

The shipbuilding industry is different from other transportation industries. There are many explanations for this, ranging from the narrow specific expertise required for naval architecture to the complexity of projects closer in scale to onshore production facilities, such as power plants. Additional differences can be found in the methodology approach - product versus project. While most similar industries refer to the end product as a product and hence apply product design and management methodology, shipbuilding often refers to vessels as projects. It is even sometimes said that shipbuilding projects are similar to the R&D process. However, there is no mainstream discussion about applying methodologies from the R&D approach, such as software development, to ship design processes. As a separate industry focusing mainly on shipbuilding-specific needs, there is little cross-dissemination with other industries and practices. On one side, this helps to facilitate a significant amount of complexity and stay in one direction, but on the other hand, this deprives shipbuilding of experiences in similar industries and technologies, as well as general management practices.

To summarise, ship design has the following differentiators: rapid advancement to the functional approach, lack of connotation with other industries, and approaches to design. The next part presents a more detailed discussion about the areas with the most potential to evolve under the concept of Shipbuilding 5.0.

Change of focus from shareholders to stakeholders

The purpose of building vessels should primarily focus on the intention of its use and, consequentially, on human intention. Therefore, decisions made during the design stage should be verified against the design's intended purpose. One might say that ship technical specifications outline all these intentions and purposes, and indeed, this is the expected flow of information—the ship owner would describe in a relatively detailed manner the main expectations and limitations for the future vessel. Ideally, it should incorporate the expectations of people who need to "keep vessel at seas" and those who "need to make it functional" onboard. However, the technical specifications are often copied from previous vessels and projects, and requirements are significantly affected by personal preferences or beliefs. It is a very human way, but unfortunately, such misconceptions placed in the first steps of the design process significantly affect the later stages.

Two examples of the early identification of the end user need tackled early in the process are twin x-stern by Ulstein and double-acting technology (DAT) by Wärtsilä. In both cases, identification of the primary intentions of the vessels and expected operations in the early stages led to an entirely new design. In the case of Twin X-stern, a step away from traditional thinking with one stern, they proved maximum maneuverability and fuel savings, especially for offshore operations requiring a ship to remain in position in rough weather (Ulstein, 2021). In the case of DAT, the new design was identified during tests, leading to a whole new class of designs optimized for bow performance in open water and stern designed to break the ice (Warsila, 2024). Another similar example is a barge and pusher or puller combination, initially created to address the challenges of inland shipping and insurance requirements for unmanned vessels. Instead of having a manned vessel, having an unmanned barge and a pusher tug operating alongside is a more economically feasible solution.

The examples illustrate how addressing human centricity at the very early stages of the design can change the course of the design process and challenge standard practices or intentions to reuse previous project practices. Changing the focus from the shareholders' perspective of the ship owner to stakeholders of the future vessel, such as the primary purpose of the new-build project, its goals, and expectations, might significantly affect the design outcome and the later design stages.

Future use of ships and how to address unknowns

A typical lifespan of commercial vessels is about 20 years, and the navy fleet might be extended to 30 or more years. This means that many unknown and unpredictable factors exist when defining the main characteristics of future designs. Such concerns are repeatedly addressed in the methodology research, and a comprehensive overview is presented in IMDC 2022 (Erikstad, 2022). The questions brought to the discussion are uncertainty when designing for the future and the needed flexibility to meet this uncertainty. Some industry design companies experience the same concerns and look for a methodology to tackle these design aspects (Yrjänäinen, 2023). The approach proposed revolves around a typical engineering approach – to account for the changing factors, such as technologies, regulations, and environmental changes, and integrate these into the operational scenarios accounted for in the design. This approach is propagated to the simulation of operations, and while being a viable alternative, it exercises a linear approach to a complex design problem. One may argue that similar problems are addressed in variant management for a typical PLM approach and scenario-building technique in general and strategic management.

A possible approach to tackling this area would be to employ one or several approaches from other fields of study or industries. The shipbuilding industry often dismisses experience from other fields as distinctively different from its own. However, there might be a suitable methodology for approaching complex projects with high uncertainty levels and multi-stakeholders. This approach can be taken from general project management, where many similar or even more complex organizational, process, and methodology issues are actively researched and tested in industrial settings. A more specific methodology, such as agile development principles (Rigby, 2016), can be adopted, similar to the design spiral approach in an iterative nature of incremental development to handle complexity and uncertainty. Considering the ship design project from a typical research and development perspective, the process outcome changes along the project's progress, and external factors may significantly change the scope and outcome.

Systems thinking (Forrester, 1961) (Ford, 2009) offers yet another way to look at ship design methodology. Currently, it is often applied in a way that limits the scope of functional systems of the ship and system architecture. A broader perspective can be taken to look at a future vessel as a part of the system of stakeholders, such as owner, operator, transportation, or research systems - as a part of the system of shipyards, suppliers network, technology providers, etc. It can offer a more holistic view of design and address human centricity in a large context, leading to innovations, sustainable factors accounted for early, and greater flexibility compared to a standard approach, which gets into the specifics of functional design very early.

An additional way of tackling uncertainty would be to employ futures studies methodology. Futures studies is a field of science that researches the uncertainty and complexity of futures. A classic example of this methodology is scenario building, which offers a way to structure unknowns and include unexpected factors. One of the main principles of future studies is to involve stakeholders in the discussion and, through this discussion, to identify possible, probable, and plausible paths. This approach was presented in the research (Jokinen, 2022), where the influence of creativity shaping long-term futures for decisions made about ship design was examined using foresight methods. Looking at the ship design problem as a task to create a design that serves in the future is a novel perspective to ship design methodology.

Change of design process elements: workforce, expectations, tools, and expertise

The third area of the transformation is the process elements affected by a change of perspective. These elements are workforce, expectations, tools, and expertise. The first one is the change in the workforce, which the industry and academia have witnessed already, and these changes are expected to accelerate in the future – changes in the workforce involved in the design process. Generations XYZ engineers gradually replace the stereotypical image of the past with experienced engineers solving challenges and striving for the best outcome. New generations of engineers expect technology to serve their needs and facilitate a significant part of the design process, including encapsulated best industry practices and tacit knowledge to be embedded in the tools. One aspect of this change is accessibility and user experience of the technological tools interactions – instead of the laborious process of creating 2D drawings to use interactive AI-assisted Mixed Reality (MR) headsets and generate engineering output automatically. Software providers continuously fostered this shift of the paradigm process, and expectations often exceeded reality in this area and sometimes even created unrealistic expectations of technology solving all imaginable problems, which remain unsolved for now.

Expectations are another area that can be affected by incorporating human perspective. Based on the human perspective, marketing promises and sometimes science fiction publications often elevate expectations, creating an image from limitless possibilities. Managing the expectations early enough can help allow a realistic approach and leave space for innovation. It requires a conscious and systematic effort to manage this process instead of considering it taken care of by itself.

Tools are arguably the fastest-evolving element of the design. The tools refer to various ship design packages for modeling, simulations, etc. Within the last decade, only the advancements in hardware and software alone have gone that far to take designers from 2D reality with paper drawings into Mixed Reality, where design can be created and designed full scale with immersing experience in 3D. Digital Twin concepts are enabled by the possibility of handling large and increasingly complex amounts of data and connectivity. The original vision of a unified Digital Twin was gradually substituted with a more practical Digital twin for a particular purpose and now slowly moves into the direction of a digital thread or backbone, enabling the storage and use of Digital Models and Twins for specific purposes. Software developers increasingly place User Experience (UX) at the center of the software development process and recognize the importance of technology adaptation instead of focusing on functionality exclusively.

In the previous wave of evolution, Industry 4.0, the main focus was on the connectivity of digital models and the physical world to enable manufacturing and automation. Blurring the borders between the digital and physical worlds provided numerous applications to send ship design data directly to production or machinery. It became mainstream to use general cutting and welding programs automatically based on 3D data and created many automated interfaces and applications for robotic assembly in the industry. Now, attention from the software development teams is dedicated to the usability of the data, tools, interfaces, and user experience. Therefore, the focus is no longer on the tool's functionality; a human-centric perspective is gradually incorporated, addressing the previously described challenges: workforce and expectations. Fully robotized production lines remain a vision for shipbuilding while using co-bots, and AI-generated planning and scheduling are a reality enabled by advanced ship design technology.

Expertise or skills is the last element of the change process. It refers to specialized expertise required for ship design and knowledge management systems facilitation of organizational knowledge management. Modern shipbuilding's complexity exceeds a single person's capacity to handle all aspects or disciplines, elevating the need for expertise management, different teams' involvement, and tacit knowledge facilitation. Newer generations of shipbuilders expect technology to store and offer embedded knowledge, skills, and expertise that previous generations needed years to acquire. Here, technology plays an even more critical role as a storage and facilitator of knowledge.

IMPACT ON SHIP DESIGN PROCESS METHODOLOGY

Based on the discussion from the previous part, the following additions can be suggested to the system-based ship design process methodology. Conceptually, these additional additions are presented in Figure 2 as a development for Levander's illustration (Levander, 2006).

Adding the human-centricity aspects calls for additional points in the "design spiral". These points allocate the space in the design process for analyzing stakeholders, building scenarios for functional design as a representation of alternatives, and similarly for the project's economic feasibility. These might be already accounted for in the other stages of the design process; however, making these steps explicitly visible provides a more comprehensive view of the methodology. It highlights three points where the human-centric approach has the most significant impact and can change the course of the whole design process. Figure 2 shows these additions: stakeholder analysis, scenario analysis for functional design, and scenario analysis for economics design.

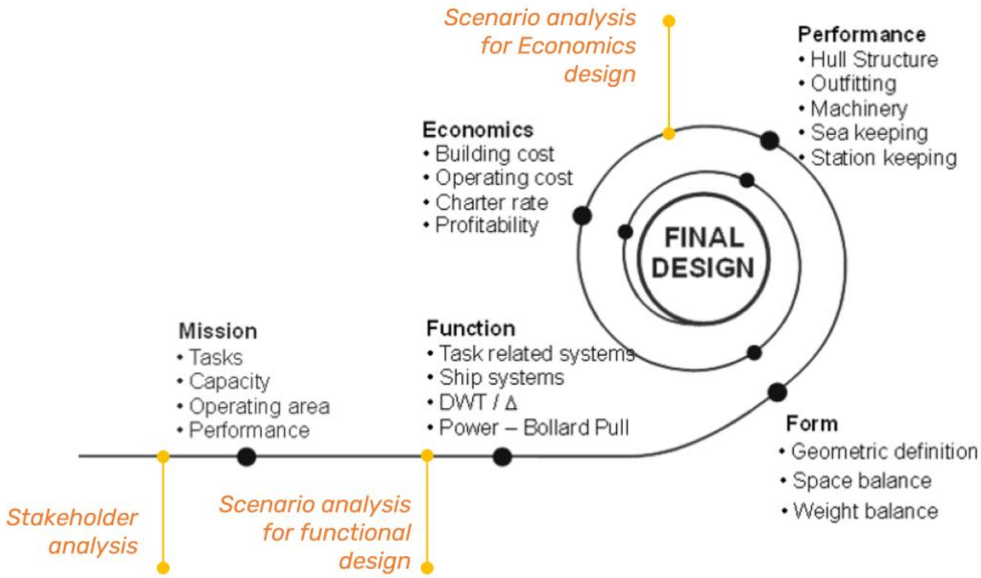

Figure 2: Adapted system-based ship design, a leading figure from (Levander, 2006)**, additional points for stakeholder analysis, scenario analysis for functional and economical design points added based on the proposal from the proposal in the article.**

Stakeholder analysis is suggested as a first step of design activities. Before defining the mission parameters, the initial question should be how and who will benefit from the future vessel. This way, the focus will shift from stakeholders to stakeholders. Analyzing stakeholders can provide insights into the differences between involved groups and potential conflicts of interest among these groups. It would help to map potentially conflicting expectations and also identify sustainability characteristics. As in the examples used above, it can lead to innovative designs and more tailor-made solutions where challenging stereotypes or previous designs have significant potential to offer radically new approaches to design. Such analysis can be arranged as one or several workshops, including as wide a range of shareholders as possible. Ideally, it should include ship owners, naval architects, building yard representatives, and any other potential stakeholders, such as local authorities or local communities that will exploit the potential of a new build.

Scenario analysis (Ramírez, 2016) for functional design is another step after the main characteristics are defined in the two previous steps – stakeholder analysis and mission identification. It should precede the functional design stage and can serve as a foundation for developing several alternative design variants. There are many possible techniques to perform scenario building and analysis. It can be an elaborated process with several workshops, steps, and a thorough study of alternatives, or it can be a simple identification of the central axis for differences and main different scenarios. For example, one axe can be GHG emissions (extremes can be a traditional heavy fuel engine and methanol engine), and another axe can be the shape of a bow

affecting cargo capacity and stability. The natural objection here would be that typically, in the design, there is a multitude of parameters and variations significantly exceeding 2 or 3 extremes, which would lead to the exponential growth of a number of scenarios – 4 in the case of 2 axes, 16 in the case of 3 axes, and so on. To avoid this unnecessary complexity, previous steps from stakeholder analysis and mission clarification can help identify the most valuable criteria for design and focus on these. The outcome of this activity would be a set of distinctively different scenarios for discussion and selection of 1-2 for further development. It can provide a structured way to manage innovation and avoid opinion-influenced decisions.
Scenario analysis for economics design, similar to the functional analysis scenarios, economic scenarios can be built to evaluate the financial feasibility of the project. It can be performed for one functional design or for a set of designs and can include known economic characteristics and future.

Both of the previous steps offer not only a framework to consider different variants and specs of the designs but, most importantly, a tool to address uncertainty in the future. Scenario building is a method in strategic management and futures studies that facilitates the exploration of alternative futures by constructing plausible and consistent narratives of potential developments (Schwartz, 1991). It helps to think systematically about uncertainties, test assumptions, and consider the implications of different future contexts. All of these can enhance design decisions and help avoid design mistakes by providing a structured way of evaluation in complex projects. Along with the scenario methodology, many other tools, such as systems thinking and foresight techniques, can be employed. These can offer a more holistic setting to address the growing complexity of ship design projects, uncertainty of future requirements and regulation changes, and provide a sustainability focus to the maritime industry.

The overall change of the perspective based on human centricity impacts the whole design process. The steps discussed above are explicit actions that can impact the methodology. Besides the methodology, the overall process and its parts are gradually changing. Societal and technological changes impose a significant impact on these. Slow changes from a hierarchical management style in organizations give way to a more flexible way of working, which impacts how decisions are made and how innovations are fostered, allowing the creation of new designs and unleashing human imagination and creativity. Society's goals change from continuous economic growth to sustainability and green targets, giving a prevailing imperative to all activities. Generations of designers change and bring differences in how work is done and what parts are perceived as the most critical. Technology develops fast, allows us to benefit from the digital twin, and opens possibilities for the use of virtual possibilities in simulation, harvesting operational data, and creating an immersive experience in visualization. The whole separate area of potential development is related to Machine Learning (ML) and Artificial Intelligence (AI) applications for ship design and digital twin data management. In addition to the above steps, the design process itself evolves. The management process for ship design as a project, the effect on tools UX or expertise management, including HR aspects or knowledge management systems in organizations—all of these changes will take place gradually in the future and result in updated methodology and, hopefully, the enablement of better designs.

As discussed above, the influence of human-centricity on design process management provides an exciting area for research and application. Ship design methodology can benefit from adopting selected practices from project management – agile methodology, stakeholder and impact analysis, systems thinking, and foresight techniques. This cross-use of methodology from other fields can enrich the narrowly focused ship design process with human-centricity and a broader interpretation of stakeholders' intentions and tackle the uncertainty of future changes. An alternative possibility for such an approach is a service design methodology, with the first research of its application presented (Kim, 2024).

CONCLUSIONS

This article reviewed some aspects of the evolution of the ship design process and methodology based on the framework of the Shipbuilding or Industry 5.0 concept discussion. Without being exhaustive, the main paradigm shift for human centricity was presented as an influential factor in ship design, and possible results of such a shift were discussed. The main areas where the changes can be expected are a change of focus from shareholders to stakeholders, the inclusion of the future uncertainty element in the design decisions, and a change of several aspects of the process: workforce, expectations, tools, and expertise management. Possible impacts on the ship design methodology are identified as three additional steps in the commonly used methodology based on design spiral – stakeholder analysis, scenario analysis for functional design, and scenario analysis for economic evaluation. The expected implications are identified as a structural approach for uncertainty, innovations, and expectations management. The potential benefits include a higher degree of alignment between stakeholders and with the society goals, expectations of new designs and applications of waterborne transport in maritime industry.

The future is not carved in stone, and while some of the implications of human centricity appear most likely, some might take a completely different turn or unexpected directions. While predictions were never the intended outcome of this article, the discussion about Shipbuilding 5.0 and its effects on the ship design process should positively impact the industry overall.

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