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Digital Shipbuilding – Needs, Challenges, and Opportunities

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ABSTRACT

Ship design firms, shipyards, and ship equipment manufacturers – the shipbuilding industry or just shipbuilding, must adapt their products and services' deliverables to the steadily evolving expectations of the stakeholders in the market.

Digitalization and the use of computational tools have been suggested as the effective means to meet such challenges. However, many anecdotal statements and industry recognitions have expressed concern that such efforts have proven less effective than should be expected and promised, and opposite to what many application suppliers advertise. It is argued by this paper that such a situation is experienced because of, among other explanatory factors, incompatibility, lack of proper protocols for information sharing and isolated implementation efforts in single departments rather than a holistic organizational approach. The lack of full understanding of the ship designer's role and responsibility as the main facilitator of such a change process is also recognized as a clear weakness in the effort of successful digitalization of shipbuilding. It is argued that such a vital transformation process cannot be left alone to the software application providers, despite their size and dominance.

This paper explains and discusses why this situation is experienced and indicates what improvement measures could be introduced to counteract the opportunity loss. The article addresses five potential digital service deliverables that could complement the existing service delivery of shipbuilding operations and thereby increase competitiveness and market attractiveness. These services include a) vessel support and control centres, b) performance monitoring, c) maintenance management, d) spare part handling, and e) life cycle assessment (LCA). The article also reflects on what implications and consequences this development has on the ship designers' work and their firm's adaptation to new services' demand in the shipbuilding market. The paper concludes with some reflections on the actual implementation of these services, highlighting challenges and further opportunities.

KEY WORDS

Digital; digitalization; shipbuilding; ship design; opportunity search

NOMENCLATURE

PLM – Product Lifecycle Management, ERP – Enterprise Resource Planning,

INTRODUCTION

Ship design firms, shipyards, and ship equipment manufacturers – the shipbuilding industry or just shipbuilding, must adapt their data-based deliverables to the steadily evolving expectations of the stakeholders in the market, and adjust their value chain positions and interrelationship with relevant project stakeholders to achieve maximum value creation and competitiveness. This will require going beyond traditional and existing ship design and shipbuilding activities and tools. This is much in line with

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our recent observations that market expectations are quickly moving towards a more integrated demand and supply situation for products and services. Such services are: - environmental performance of vessel; - performance-based and predictive maintenance; -autonomous operations; - sustainability reporting; - green loans, - emission regulations; - real-time performance evaluation and optimization; - recycling of vessels; - reuse of materials, equipment, systems equipment, vessel and fleet traffic and port operations and their complementary product tools. Efficient communication and information exchange channels must be set up between these downstream services and upstream ship design solution work activities to provide continual feedback and feed-forwarding to secure effective operational decision-making support. Hence, the complexity and uncertainty of such decision-making related to shipbuilding – ship design and erection, and ships-in-operation will continue increasing (Brett et al., 2022; Ebrahimi, 2022; Garcia, 2020).

The interrelationships among stakeholders involved in shipbuilding projects, manufacturers, other service providers, work processes and tasks performed by each engaged actor, have become a "spider-web"- type network of information exchanges and transaction-oriented situations to support the identification, collection, collation, storage, and dispersion of such information and or data. Value chain communication needs and appropriate exchange channels, tools, and formats have, therefore, grown considerably – in scope, extent, and use. A worldwide shipbuilding activity exists out there, where owners and financiers can be in one region, the ship designer in another region, the shipyard and equipment supplier in a third or fourth region, and other stakeholders like flag state, class society, and charterers (cargo owners) being in an "opposite direction of the world". There is no doubt that such a dispersed network of project actors and information exchange model could not easily function without the internet and other efficient satellite-based communication facilitating channels.

What a few decades ago was a simplistic discussion between two actors in the value chain about what engine size and type to install onboard – a choice among 2 to 3 relevant options, has today, become a much more complicated and cumbersome multi-stakeholder involved decision-making process where fundamentally different energies (fuels), energy converters (engines, fuel cells), energy storage and transfer systems came into place. Further, varying expectations and regulations as to energy usage and emissions are making the selection of the power plan of a vessel a dynamic, rather than static choice. Most of the vessels being designed today will have to make modifications to their power systems during their operational lifecycle. Similarly, the expectations of the end users of the vessels are changing, requesting much more transparency about the vessels and their operations. Emission reporting has already become a requirement for many vessels. Financial institutions, charterers, and cargo owners frequently request information about the markets within which the vessels are operating, the stature or physical condition of the assets in use, and the economic situation for the vessel and owner - and the list of information users continues. More than ever, operational and performance data and information exchange relating to capabilities and functionality have become a central element of vessels' design, ship erection, and operation, and must be well planned to maximize the benefits.

In shipbuilding, we, therefore, see a rapidly growing tendency of increased interaction among stakeholders in the maritime value chain and the need for improved information exchange. Digital connectivity increases in most organizations due to the pressure outside by customers and other stakeholders. But also, internal needs relating to work process harmonization and enhanced value creation employing new products and services are growing. Looking from a multi-modularity and interdisciplinary point of view, it is crucial to understand how to make seamless exchange interphases and data transfer protocols from one stakeholder to the other and between ship designers, shipbuilders, and system suppliers. Yet, the authors suggest that today, shipbuilding organizations should think about their digital connectivity around the system they are or represent and the new added value activities to be created step-by-step. This will mean that ship designers in their preparation of a ship design solution and the shipyard, must take into consideration these new challenges and promising digital solutions. The appreciation of current data availability, storage capacity and increasing capabilities of software applications are key drivers in opening new business opportunities, and the emergence of big data analyses and artificial intelligence (AI and generative AI) bring them further capabilities that will undoubtedly enhance our understanding of the extended potential. The way we perform design work or ship construction work today, and how we treat and store information, will enable (or constrain) the potential services that shipbuilding companies can perform in the future.

Figure 1 depicts an overall situation of shipbuilding activities, which need to be interconnected and as seamlessly as possible ensure that critical information is relayed among the elements of the digital business model or value chain elements for shipbuilding.

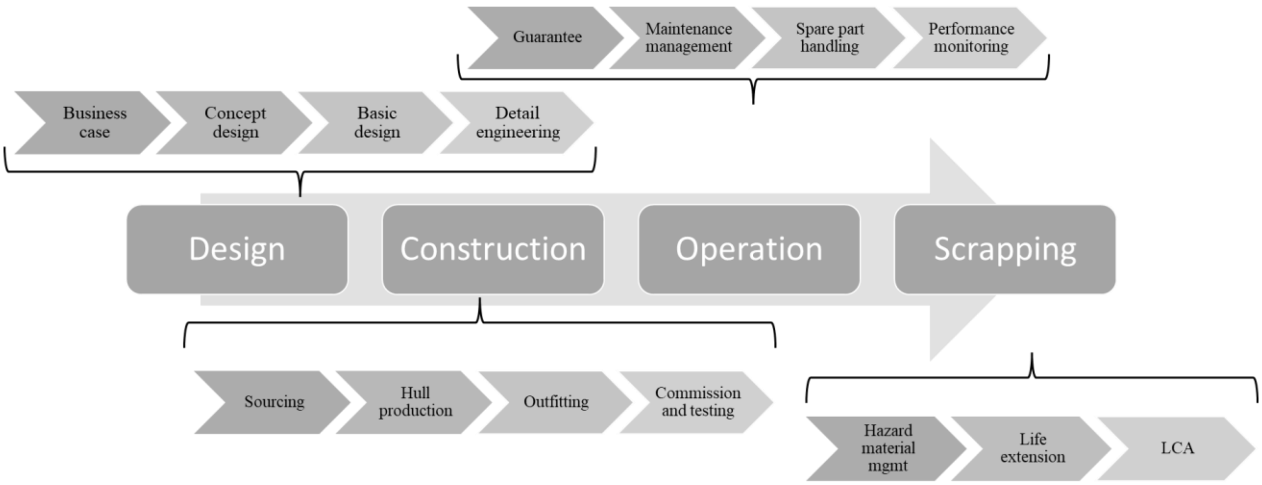

Figure 1. A digital business model for shipbuilding.

Unfortunately, there is no general framework or architecture for digital connectivity or data description to be easily enabled and implemented. Such a broader digital generic connectivity system is missing. Shipbuilding is a small and special industry, requiring specific architectures that, due to limited volume sales potential, few are interested in developing. Requiring, therefore, a strong collaboration between ship design software providers, data and document management providers and shipbuilders (Gaspar et al., 2023). Such lack of digital architecture for shipbuilding delimits the overall understanding and opportunity search for the full exploitation of digital ecosystems and their virtual interoperability. An example is the application of virtual reality (VR) tools in early concept ship design, which have been claimed to potentially provide efficiency improvements to the overall process (Schiavon et al., 2019). The author's previous recent research has concluded that the use of VR in conceptual ship design has revealed that very often its application is time-consuming and user-case limited, resulting in an extensive "nice-to-have" feature, and not a means to improve efficiency (Garcia et al., 2020). In the future data economy, the question is, therefore, not anymore who has the monopoly of the data. The question then becomes how to make the organizations interoperable and build new capabilities to exchange the data/information with the domain of their business interoperability (Arola, 2018; Keane et al., 2017).

This article briefly discusses aspects of such a new complex business situation. Certain interoperability aspects mentioned above are deliberately left out of the discussion of reasons for the consequent length and comprehensiveness of the article. This article, therefore, focuses primarily on some of the lifelong data exchange and service opportunities and reflects what implications such new business interoperability can have on the ship designer and the shipyard operations – other aspects of digitalization in shipbuilding are left out in this article. At the same time, it is fully appreciated that the development and implementation of such new technologies will be challenged by high cost, and human-resources consumption, since the industry is characterized by having a fairly short time horizon for their investments, and are deeply conservative when it comes to new ways of doing things (Keane et al., 2017). Considering these premises and difficulties of directly connecting technological developments to growth in revenue and profits - competitiveness, historically it has taken time for such improvement efforts to become realized and derivative effects to come to fruition.

From vessel to "system of systems"- thinking

Given this new situation, it is tempting to make a parallel to what contemporary systems thinkers claim: " that the whole is more than the sum of its parts and that everything is interconnected" (Jackson, 2019). They suggest that you must always start with the whole system because you need to know everything to know anything. Further, unless you know the whole system, you cannot justify acting because you can never anticipate the results. When it comes to digitization of shipbuilding, it is argued in this article that, a similar systemic approach is necessary to reveal as many of the drivers and enablers elements and causal factors influencing.

Hence, expectations and demands from shipping companies as to the delivery of a vessel and the services related to it are also changing. This requires going beyond traditional ship design approaches and traditional shipyard activities and the maintenance and repair work during the lifecycle of the vessel. Market expectations are developing towards a more integrated delivery where aspects such as environmental reporting (environmental footprint in design, production, operation, and recycling phases), performance- and predictive-based maintenance, autonomous/remote operations, etc. A traditional basic design drawings package with complementary outline specifications and supporting analysis reports is simply not sufficient any more as transaction and information documentation between the service provider and buyer. Such needs for increased information exchange and life cycle follow-up possibilities of assets or services being provided over time, must be catered for within the delivery of the vessel in the future, either by the ship designer, the shipyard, equipment supplier and or other third parties or all of them together.

Thus, what is delivered is no longer just a vessel design solution or a manufactured ship, it is a three-level information or data-producing repository: level 1 – the ship as a twin, level II - the ship when in operation and at level III, the ship in operation within the broader shipbuilding values chain model – a system of systems.

What does digital mean?

Digital is a broad term. It is sometimes uncritically used as a badge to represent anything new. Often it is applied to distinguish from other practices, behaviours or products that are simply older (Fletcher & Adolphus, 2021). "A wider appreciation of the increasing scale and wide-ranging impact of digital technology in contemporary economic and social activity leads directly to an acknowledgement of the importance of developing and maintaining a digital presence", they conclude (Dörner & Edelman, 2015) On the other hand, argue for digital to be seen less as a thing and more as a way of doing things. In this way, they argue, "digital is an enabler for action, not a goal in itself". Examples of this interpretation are digital marketing, digital business; e-commerce; or even email. In this article, we address digital as various actions to accomplish improved competitiveness and attractiveness – making a preferred supplier in line with the Dörner and Edelman (2015) interpretation. Thus, we discuss in the further of this article, digital shipbuilding, web-based ship design, and digital ships-in-operation.

Digitalization – a deeper view

What is digitalization? The use of digital technologies to change an organization's business model to provide new revenue and higher value-producing opportunities – the process of moving to a digital business (*Digitalization*, 2024).

It is already well recognized and argued by many that digitalization has and will have a profound impact on how to execute shipbuilding business and create sustainable ship design-related products and services in the future. But it is important to notice that digitalization transforms products from physical goods into tangible services, in many cases into manipulated data and data analyses results as the "product or service". It supports the increased speed at which products and services are being produced and implemented using digital processes, data, and communication channels. Digitalization efforts support viewing work processes, products, and services as a source to generate and collect more information - leading to increased value creation.

There are 12 critical elements of successful digital transformation:1. End-to-end connectivity, 2. Data and work process management, 3. Configuration management, 5. Model-based application structures, 6. A digital thread, 7. Digital twins, 8. IOT and PLM platforms in place, 9. Changing views of product – into servitization, 10. Big data analytics, 11. Data governance and security, and 12. Digital expertise and skills transformation (MacKrell, 2024).

Among the 12 digitalization enablers, the digital thread (6) is looked upon as the most important because it relates to the communication framework that allows a connected data flow and integrated holistic view of the value chain and business concept throughout the products and or the services' delivered lifecycle across traditionally siloed functional perspectives.

Furthermore, digitalization has three powerful implications for product and service development and lifecycle management: - ensuring that all stakeholders and transformation processes are fully accessible with access to all data, - reversion of data files (documents) into data records to unlock them and reducing them as typical stumbling blocks, because nobody remembers where to find them. Finally, big data is at the heart of digitalization.

Digitalization has no "borders"

The pivotal digital technology for realizing all these opportunities is the internet and satellite communication. Without this well-established, open, and global network of computing working under the same protocols and processes, what we now label digital would simply not work. Increasingly the purpose of computers, laptops, tablets, and mobile phones is to have physical touchpoints on the internet (Fletcher & Adolphus, 2021; Gaspar et al., 2014). "Exploiting the unique characteristics of the internet is at the heart of understanding how to create and capture value through a digital presence", Fletcher and Adolphus (2022) state.

This digital mindset must go beyond the traditional digitalization of design and production processes; however, it is here where it should start. The information generated during the design and production phases of the vessel should lay the foundation for the future of digital shipbuilding operations. History, however, shows us that digitalization and the use of computational tools for analysis and drawing production have proven to be less effective than should be expected and promised. It is argued by this paper that such a situation is experienced because of incompatibility and lack of proper protocols for information sharing. The authors of this paper are convinced that digitalization has been performed in silos, one activity at a time, and without an overall holistic plan. Furthermore, overambitious software application development – one system (suites) for all purposes and needs, rather than building up a step-by-step functionality and allowing a robust platform infrastructure. Also, underestimation of the time of populating these new applications and costs of training and start-to-use initiatives have among other factors contributed to the digitalization disappointment, so far. This does not mean gains cannot be met or arrived at, but it will take time, extra costs, and pain to get there.

The toolbox of shipbuilders (incl. ship design companies) typically consists of system platforms, 3rd party special applications, and internal proprietary bespoke software applications. Such systems are normally not developed with effective connection protocols for the exchange of design and production information with external receiving applications. This situation creates significant extra work and costs, deteriorating the competitiveness of the industry. Alternatively, shipbuilders can go in with a full software system supplier delivering all the tools, becoming too dependent on the single software supplier.

This paper explains, discusses, and suggests improvement measures for how to enhance the effectiveness and efficiency of these information exchange processes. Enhancements are closely linked to a better understanding of how the information stream flows among all relevant stakeholders with an emphasis on addressing commercial, operational, and technical matters.
This article discusses the overall competitiveness challenge the shipbuilding industry is exposed to and the need for change to meet present and future opportunities. The availability and use of current computational tools are limiting shipbuilders in expanding their business due to this fact. This article builds on the foundation that the European-funded SEUS project (Gaspar et al., 2023) is building, and will explore complementary digital business opportunities for shipbuilding companies.

Digitalization - "raison d'etre"

This article highligths the importance of making connections and building relationships through digital channels is part of the purpose of creating a worldwide presence as a part of competitiveness building, also it emphasizes a mindset of sharing, openness, and transparency so vital for ESG recognition. Digitalization should help us to a) improve profit margins of design, engineering, fabrication and assembly (traditional shipbuilding deliverables), and b) exploit opportunities within aftermarket activities and early design.

Figure 2 shows how the estimated average performance yield of different activities of the shipbuilding value chain for two different periods for a selection of Norwegian firms. The results for 2006/12 are the performance yield during "good market" conditions and the 2016/22 results represent "bad market". There is a significant level difference among the main value chain activities – typically, the upstream ship design-focused business produces acceptable, but low-profit margins, ship erection or hull production notoriously low partly unacceptable profit margins, and downstream "aftermarket" or life cycle-oriented services produce profit margins at encouraging and attractable high levels. When we know that the downstream value chain activities yearly and over the lifetime of the vessel, typically 20 to 30 years, bring in such high-profit margins successfully positioning oneself in that part of the shipbuilding value chain is a "no-brainer", if possible, when, and for how long.

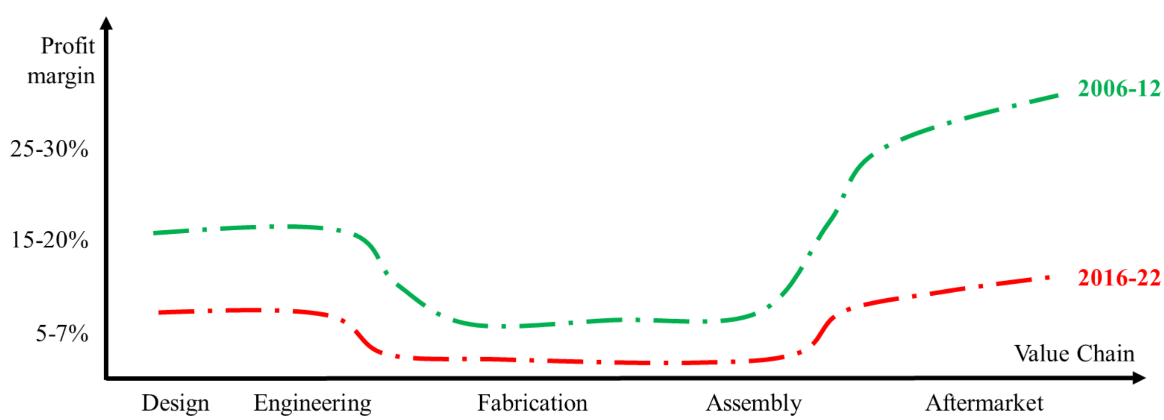

Figure 2. Profit margin of different activities in the shipbuilding value chain.

Many shipbuilding companies are currently in transition wrt to what future avenues to take: i) status quo – stick to what you already are and try to make the best out of it, or ii) adapt to the new demands and transition to digital shipbuilding – develop, expertise and skills to handle a new digital service portfolio. Such a transition will require a fundamental change for most shipbuilders. A new "digital mindset" (Leonardi & Neeley, 2022) must be established to understand how data, information, and digital solutions can enhance the existing business model or completely revamp it.

A DIGITAL FOUNDATION FOR SHIPBUILDING

Product lifecycle management (PLM) is the process of managing product-related design, production, and maintenance information. PLM integrates people, data, processes, and business systems and provides a product information backbone for companies and their extended enterprises. The word PLM is not new in the maritime industry, but to date, its implementation is scarce and to some degree not successful (Recio Rubio et al., 2023). A strong reason for the limited implementation and success is that in most cases a standard PLM structure has been pressed into a ship design and shipbuilding process. Hence, pushing ship designers and builders to change the way they were working, rather than adapting the PLM software to the peculiarities of the industry.

An internal survey among employees of a Norwegian shipbuilding firm identified some key challenges that employees considered as the anchors for further improvements in productivity and process efficiency (NA, 2018). These challenges include: i) product and design data are not organized – because every project has its peculiarities, the same information is not available for all the projects, and if so, it might have a different name or be stored in a different folder; ii) company knowledge is residing in people's heads. The experience and knowledge developed at ship design firms are primarily tacit, hence difficult to store and retain isolated; iii) very limited reuse partly because required information is hard to find. For early concept development, when a project is finished without a shipbuilding contract, the documentation is rarely reviewed and categorized. Thus, the re-use of this information is limited, as people might not be aware of it, or don't have contextual information about the project or the status of the documentation; and finally, iv) multiple specialized software packages model the product from different viewpoints, making difficult and time-consuming the synchronization of design changes. Different areas of a ship design firm and shipyard have their specialized software, which requires either a strong connectivity between software solutions, or manual work to ensure correct product definitions. The structural department might use a different hull definition than hydrodynamics, and the general arrangement might be drawn based on hull lines from the 3D rendering tool. Hence, three hull designs need to be synchronized and calibrated to secure mirror definitions.

A summary of the main challenges identified in the survey is depicted in Figure 3 below.

Figure 3. Challenges identified on current data and project management practices at Ulstein.

Interconnectivity among software utilized in ship design and shipbuilding activities is essential to secure a smooth and effective implementation of PLM. Figure 4 reflects the complexity of software integration. The overview does not include all the functions or software used by a ship design firm or a shipbuilding company, but the most critical ones. The integration of systems/software needs to follow a stepwise approach. Each stage of the implementation process pursues covering one of the expectations and goals defined.

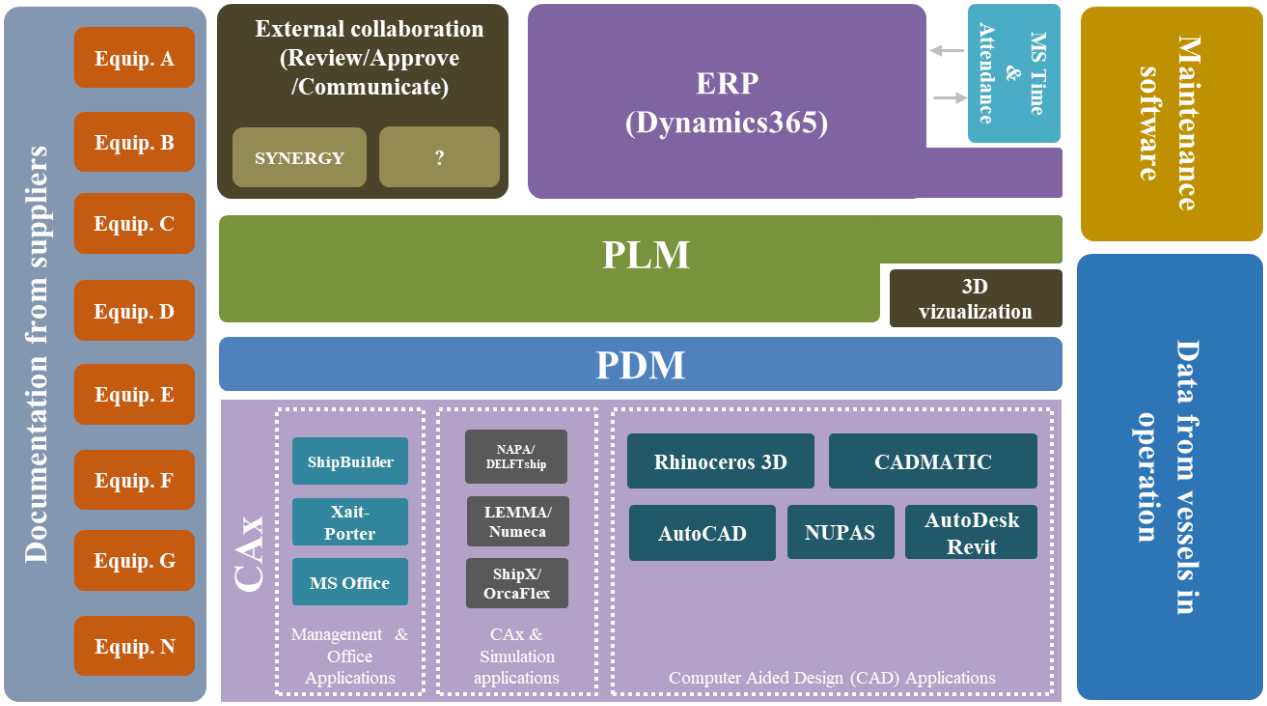

Figure 4. Software integration and complexity of shipbuilding projects.

The partners in the European-funded SEUS project are working on establishing this platform, integrating a well-established project and data management tool (Contact Software) into a well-established design tool (Cadmatic) (Gaspar et al., 2023). Connecting these two central elements of shipbuilding projects, the consortium targets 30%-time savings in engineering activities and 20% in production and assembly. Achieved by architecting and developing an integrated platform for a combined and open solution incorporating CAE, CAD, CAM, and PDM software and testing it at shipyards. The new platform solution will be built with the best European shipbuilding expertise provided by academic and industrial partners. Figure 5 organizes the value chain activities, indicates from estimates the savings potential in time saved, and suggests by what means these accomplishments will be achieved (Gaspar et al., 2023).

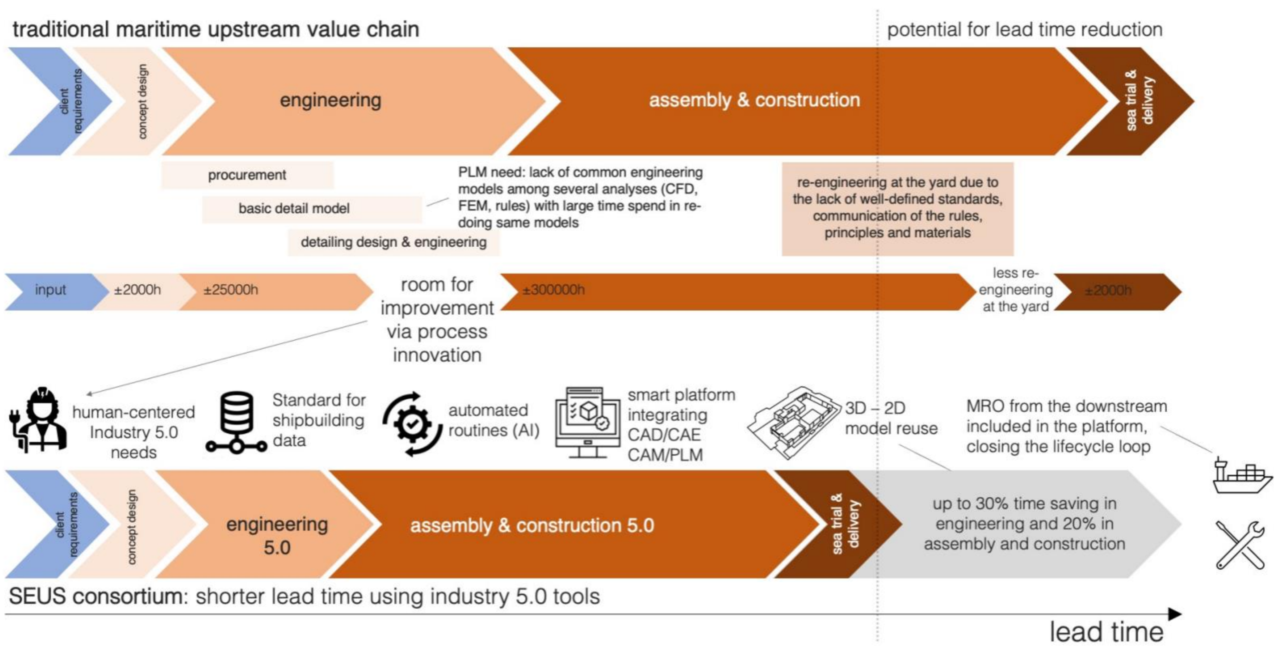

Figure 5. Potential for lead time reduction predicted by SEUS project (Gaspar et al., 2023).

But when all that data information has been generated, captured, structured, and stored during the design and building phases, is there any potential for further value creation during the operational and scrapping phases? What can be done with such information, and who will do it? It is argued in this article that such achievements can be obtained by carefully planning, developing, and stepwise implementing a digital business model for shipbuilding representing the digital thread or electronic communication structure necessary to integrate both upstream and downstream shipbuilding value chain activities.

A DIGITAL BUSINESS MODEL FOR SHIPBUILDING

Business models describe the design or architecture of the value creation, in other words, describe how a firm plans to deliver value to its customers and be left in a position to perform such businesses sustainably, including, but not limited to economic and financial performance (Teece, 2010). The business model of ship design firms relies on the provision of ship design drawings and calculations (Lagemann et al., 2024), while the shipyard focuses on the construction of vessels and integration of vessel systems. As the ship owner takes control of a vessel after delivery, the state of the vessel traditionally transforms information-wise from "as built" to "as is". Thus, from the moment a change is made onboard when the ship is in operation – either by the crew, equipment supplier or by a third-party shipyard, the documentation of the vessel and its systems become quickly incorrect or at worst, obsolete. Hence, as the "ownership" of the "ship description"- specification, drawings and complementary vessel records/reports, changes hands in the value chain, the information and interrelationship interphases are challenged wrt what, when, and which formats shall be used and who is responsible for making the transactions take place. Who is responsible for the updates, collection, and safe and secure storage of this information? During the lifetime of the vessel, typically, this information transfer process can take place several times, when the ships are shifting ownership hands. Over time, it has been experienced that it is difficult if not impossible to start working on the upgrading of the vessels from a re-designing and refit standpoint without updated and "as is" past and present condition status documentation of the ship.

Traditionally, such downstream activities have been carried out by "any ship designer and shipyard" available with the capacity to handle such a particular vessel – not necessarily the ship designer and or shipyard that originally built the ship. Such situations represent very often a major hassle to the shipowner in terms of providing needed original – "as built" documentation of the vessel to be shared with the repair yard. Far too often has the vessel that has been subject to alterations underway – in some cases larger upgrades or conversions have taken place, in other circumstances has the vessel been subject to minor changes of which in many cases, the complementary documentation of these changes is non-existent or at best poorly described and supplied. No doubt, therefore, it is critical to the owner and repair yard that upgrading the information history of the vessel is well documented and preferably can be supplied electronically and efficiently shared with relevant stakeholders. To counteract this lack of "as is" information, many repair yards, and consultants have had to 3D scan the whole ship or relevant parts of it and reproduce 3D work drawings for progressing in the task at hand. Such expensive and time-consuming extra work would be unnecessary if proper digitalization of shipbuilding was in place.

Yet, these "anyone" shipbuilding outfits have no original deep understanding and appreciation as to how and why the vessel was designed, constructed, and equipped the way it was and what are the accompanying operational premisses or/and restrictions. The original ship design firms, designers, and shipyard building the ship, are, therefore, in a much better and partly unique position to take a central role in this integration exercise and required digitization development. They are the ones who know best the original vessels and most likely are best prepared to make changes to the vessel within recognized knowledge boundaries. They know what equipment is onboard, why, how, and where it is installed, and the performance expected of them. This alternative approach can contribute to the development of a successful digital business model (Teece, 2010, Lagemann et.al 2024), since only the designer and builder have this information in their possession, and thereby represent barriers to entry for other competitors. A change in the shipbuilding value chain as suggested, could, therefore, make life easier for most relevant stakeholders in the value chain. This does not mean that the ship owner has to re-position their ships to another place in the world to get the downstream repair work done, but using a properly planned administration of the lifelong maintenance of the vessels and a digital business model for shipbuilding in place, the owner should be able to trigger the original manufacturers of the design and ship, as they do with equipment suppliers today, set up a trusted digital communication and information channel among the original manufacturers and system suppliers, the chosen "any ship designer and shipyard", the classification society and other relevant stakeholders, if any, and the owner himself in a seamless way. Eventually, "everybody" will be a subscriber and supplier to a sort of a new "Open Vessel Description (OVD-DSP)" facilitating and encouraging an all-in-one open system approach. May be very optimistic, but an ideal goal to be reached, by the few or the many…

Ship owners and other value chain stakeholders are dramatically changing and increasing their expectations towards ship designers and shipbuilding companies, as they are required to operate in a more dynamic environment where information flows are increasing and operational information demands growing. Environmental regulations require shipping companies to report their emissions, to qualify the fuels and technologies they use. What is the vessel prepared for… and how future rule-proof is it? Investors require information regarding level 1, 2, and 3 emissions of the vessel – including its production, operation, and scrapping. Charterers demand real-time information on the operations of the vessel. Vessel managers need robust and reliable information about the state of health of the vessel, its systems, and equipment. So, if all this information is required, who will enable it and who will take benefit of it and generate value out of it? Figure 6 depicts a conceptual idea of Ulstein when it comes to what an evolving digital business model for shipbuilding could look like.

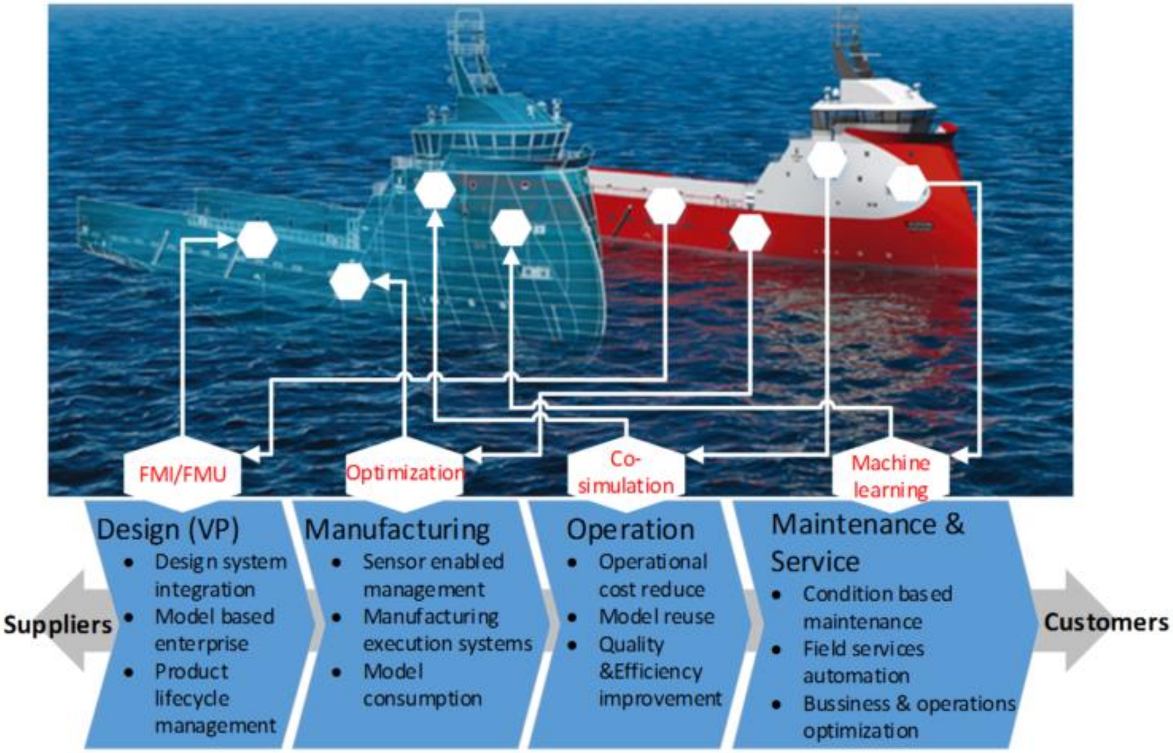

Figure 6: The conceptual idea of Ulstein's digital business model for shipbuilding.

At present, it is experienced by many that there are expectations and deliverables gaps in the way we operate, communicate and exchange information with each other. Some of them are listed here for the sake of good order and make up a list of future "work orders" for the big OVD-DSP initiative – "be aware before you start factors": suppliers will not agree to a single delivery platform being the single source of information. Stakeholders are not able to agree upon an exchange format standard; interphase and systems' architecture standardization is going slow or not there in the first place, initiative-wise; ship design business and work process, as well as ship production workflows, are inherently complex, processes with intricate details, and very often varies depending upon the new building project at hand; different work processes require different software tools and application adaptations – and triggers the "chicken and egg" problem of what comes first – the established work process or the software application way of doing it; different operations have and require different set of tools, machines, facilities, amenities; location, people, knowledge, expertise and skills; domain logic, etc.

Digital shipbuilding is, therefore, all about connectivity – not just the physical and digital ship design and shipyard operations, but also with and among all relevant value chain stakeholders – the future interrelationship "spider-web".

In the following paragraphs, we have summarized and briefly described some of the downstream digital business model initiatives. In this article, we will not repeat some of the upstream digital business model initiatives relating to the existing vessel concept design phase challenges, because these have been revealed and discussed in previous IMDC papers to the extent thought necessary to capture the total digital idea (Brett et al., 2022; Brett et al., 2018; Keane et al., 2017; Ulstein & Brett, 2012, 2015). However, it is stressed that certainly do these upstream and downstream digital model initiatives belong together and should be considered as a whole – the overall digital thread of shipbuilding.

TYPICAL DOWNSTREAM DIGITAL BUSINESS MODEL DEVELOPMENT ACTIVITIES

A: - Vessel support and control centre (VSCC)

The focus on the development of autonomous vessels addresses aspects such as reducing operating costs – primarily linked to manning, but also maritime incidents linked to human error. Partly or fully autonomous ships have attracted a long debate across shipping, with several projects implemented recently to integrate them into commercial operations. However, the slow regulatory framework will likely not allow fully autonomous ships to mature and be integrated into commercial maritime operations for at least another 10 years. Even if we are technology-wise there, we won't be there regulation-wise, as regulation needs to be harmonized all over the world.

Autonomy will follow a step-wise implementation in the shipping industry, and as such, the value chain needs to develop services that support such a development process. Figure 7 shows a plan for how vessel autonomy can be stepwise developed building on the foundations of vessel monitoring and remote control. Such a plan builds on IMO's four degrees of autonomy. Degree one represents the first three stages: availability, monitoring, and decision support, degrees two and three relate to remote control, and degree four for full autonomy. In other words, before we see fully autonomous vessels, we will see a wide range of vessel support and control centres.

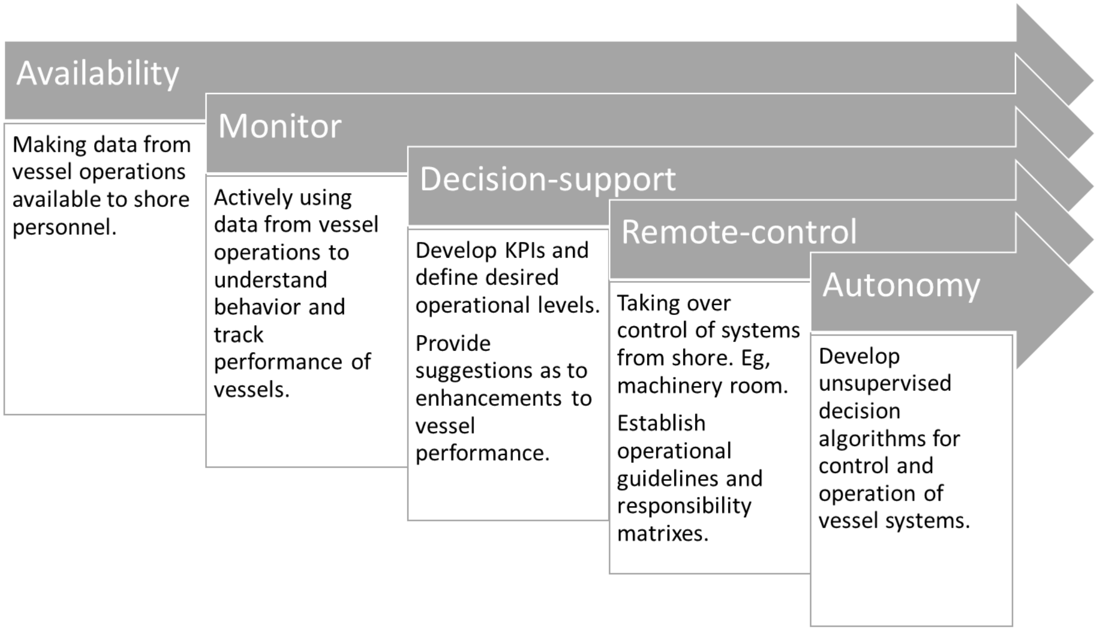

Figure 7. A stepwise implementation of remote-control and autonomy services.

Remote support and control of ships (as a stage towards full autonomy) is growingly becoming a reality. Remote control technology is increasingly seen as a game changer for moving some crew onshore, rather than developing a completely unmanned ship, and at the same time, increasing the visibility of vessel operations. Intelligent software systems and enhanced ship-to-shore connectivity have laid the groundwork for the growth of remote solutions and autonomy in shipping. These control centers have as natural first step the machinery systems of the vessel. In other words, the establishment of the engine control room of a vessel ashore. This will require changes in maintenance procedures, as maintenance of systems might be performed only when the vessel is ashore.

B: - Performance monitoring

Vessel performance monitoring is the process of collecting and analyzing data related to the operation of a vessel. The data collected typically includes information on fuel consumption, engine performance, navigation, and other factors that affect the vessel's efficiency and environmental impact. The type of data and the factors that are relevant to monitor will change from case to case, strongly driven by the type of operation the vessel is designed to perform. For a work vessel, it will typically, include power generation, propulsion, environmental forces, and control system dynamics. With these insights, the performance monitoring system helps operators to achieve reductions in resources and materials consumption, fuel, emission, and maintenance costs, without compromising vessel redundancy margin or operating efficiency. Based on analyses, operational advice is provided to managers, and officers onboard and onshore on what work processes or machinery can be stopped to run the ship operations more efficiently. This type of advisory service is dynamic – if a change in the production level falls or w*eat*her conditions, power plant system, or DP system settings are detected, the performance monitoring system recommendations will change accordingly.

Performance monitoring involves the measurement of performance over time against index indicators of performance or key performance indicators (KPIs). Thus, it helps in identifying performance gaps and therefore be used to improve performance on a continual and or continuous basis. It provides an opportunity to exploit the full potential of optimizing the commercial, and technical operation of and the navigation and control of the vessels when at sea. Monitoring the performance helps the organization and ship in providing accurate, objective, and balanced feedback to the ships, management and anyone involved with the upping of operational performance.

Performance monitoring is often broken down into five basic steps: i) Definition of performance objectives (or KPIs), ii) communication of objectives with vessel crew, iii) planning and defining operational guidelines, iv) monitoring operations and work progress, and v) correcting or rewarding performance.

C: - Maintenance management

Vessel maintenance ensures the safety of the vessel, its crew, passengers, and cargo. Regular inspections and upkeep prevent accidents and mitigate risks at sea, minimizing the potential for undesirable events. Furthermore, vessel maintenance is vital for operational efficiency, but also the development of the 2nd hand value of the vessels in case a sales and purchase situation should pop up.

In the maritime world, a well-maintained ship is a happy ship - and a happy ship makes a successful business! Ensuring that vessels are in top condition isn't keeping them afloat; it's about safety, efficiency, and, of course, profitability. A well-maintained ship is a safe ship. Efficient ship operations depend on well-functioning systems and machinery. Routine maintenance checks and timely repairs help prevent breakdowns and reduce the risk of costly delays. After all, time is money in the maritime industry, and every day spent at the quayside or dock instead of at sea can have significant financial implications. With the growing emphasis on environmental sustainability, effective ship maintenance plays a crucial role in minimizing a vessel's ecological footprint. A well-maintained ship is a comfortable and enjoyable workplace for the crew. Good living and working conditions on board can boost morale, leading to better productivity and crew retention rates. A ship is a significant investment, and proper maintenance helps protect its value. So, how to ensure that a vessel is well maintained without overinvesting in preventive maintenance? How to ensure a homogeneous maintenance plan across a fleet of vessels? And how to evaluate what is good enough when considering a maintenance plan?

Preventive, predictive, and corrective maintenance are the 3 main forms of maintenance strategies of which time-based, condition-based, or health monitoring philosophies are derivatives of preventive or predictive maintenance. Time-based preventive maintenance is a method relying on fixed intervals maintenance intervals. This can either be related to time (days, months, or years), or cycles (system starts, running hours, accumulated cycles). Intervals are typically defined by the original equipment manufacturer (OEM), or defined in the guidelines of the shipping company. Most of these intervals are defined based on very risk-averse profiles. In other words, they suggest maintenance or replacement of components way before the system degradation would otherwise require. This approach is the most common in the industry. Condition-based maintenance is a further development of preventive approaches where maintenance periods are driven by the condition of a system. This requires the definition of performance factors and thresholds to which maintenance is required. An example is RAM and CPU utilization (%) for computers onboard.

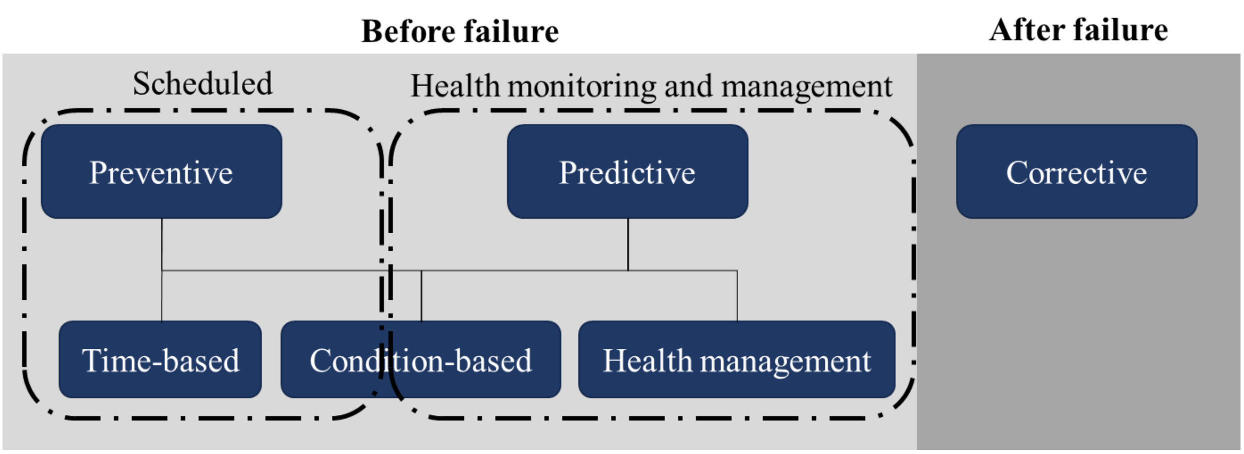

Figure 8. Classification of maintenance strategies. Adapted from (Montero Jimenez et al., 2020).

Predictive maintenance is a further development of condition-based maintenance involving systematic measuring, monitoring, and evaluation of equipment conditions across time. The condition evaluation that results allows for the forecast of the remaining life for components. Predictive maintenance is applied when mechanics or software can be examined for the health of equipment before it breaks down, this is also called proactive maintenance. Health management is a variant of predictive approaches focusing on the performance of the vessel and its systems as a totality, and not on single-equipment isolated. Corrective maintenance, on the other hand, is introduced when the upkeep is relatively straightforward. When anything goes wrong the mechanic, software or hardware needs to be repaired. Figure 8 describes the various maintenance strategies commonly practised in shipbuilding.

Real-time data available from vessel operations measuring events, such as running hours for engines, or start-ups for pumps, are a first step for health monitoring that can enable efficient predictive maintenance practices. Fatigue measurement is a natural next step, which involves the measurement of vibrations in critical components such as propulsion lines or electrical motors. Operational data from the vessel coupled with performance thresholds defined during the design or production phase (sea trials) are also meant to evaluate the health of components and to consider maintenance actions. In any case, health monitoring requires the definition of a threshold and the association of a vessel component or system. To monitor the health of a main engine, for example, it is required to have access to detailed data from the engine and to have a deep understanding of when a component of the engine starts deteriorating and risk increases for breakage. Such information needs to be identified and structured during the design and construction phase, so it can be used during the operational phase and the final recirculation of the vessel. Without a data structure of vessel components and their characteristics, the shipbuilding industry will not be able to go beyond traditional preventive or corrective maintenance.

D: Spare parts handling

Vessels need to replace some of their components over their lifecycle. This includes everything, from critical components such as electrical motors, anchors and chains, or switchboards, to minor components such as doors, tables, or TVs. What seems an easy task can become very complex when relevant information about the system to be replaced is not available or has become obsolete.

For shipping companies handling components that need to be replaced onboard can represent a significant load of work. Identifying the component and its characteristics, identifying and requesting quotations from relevant suppliers, evaluating quotations and technical feasibility, purchasing, coordinating shipping, reception and installation. It sounds like the day-to-day job of a purchasing department at a shipyard, rather than a shipping company. So, why aren't shipyards offering this service to their customers? Is it because they lack an information system to manage vessel components after the delivery of the vessel? Shipyards could make available a list of all the components installed on their vessels, with characteristics, and contact details to the supplier. Hence, when needed, a new component could be ordered "almost" automatically. And probably at a better price than what the ship owner could, as the yard will probably buy larger volumes.

E: Life cycle assessment

Life cycle assessment (LCA) is an approach and very often complementary analysis tool to assess potential environmental impacts throughout a product's life cycle, i.e., from natural resource acquisition, via production and use stage to waste management (including disposal and recycling). New national and international regulations require shipping companies a detailed report of emissions related to their operations. Investors and charterers go, in many cases, one step further, requiring Level 1, 2, and 3 emissions. In other words, emissions relating to the entire lifecycle of the vessel involve production, operation, and scrapping.

The emissions related to a vessel start with its production. The production of steel as raw material, its manipulation and integration in a complete hull. The production of pipes, cables, pumps, isolation, and other materials runs in parallel with the production of the hull. All need to be transported to the outfitting yard and integrated into the vessel. So sea trials and the operational life of the vessel start. Here is primarily energy consumption and the emissions related to it. Figure 9 showcases an LCA evaluation for a commissioning service operation vessel (CSOV).

Sooner than later, lifecycle emissions will impact the selection of a vessel design and the location where it will be built. For ship designers and builders, this means that LCA methodology needs to be integrated as part of their design decision-making toolbox. For us is still unclear how and when LCA should be integrated in the design process, but what is clear is that it needs to be integrated somehow.

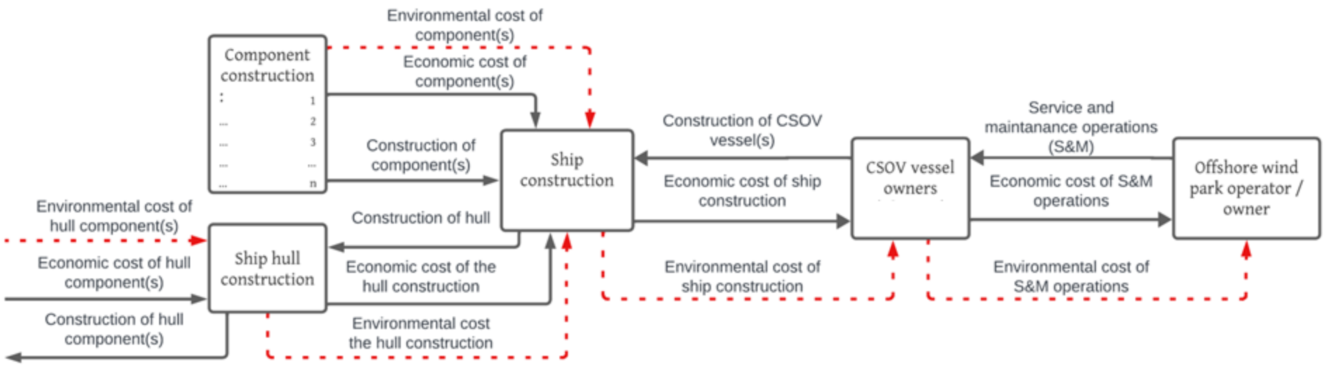

Figure 9. Example of an LCA evaluation for a CSOV vessel.

IMPLICATIONS TO MARINE SYSTEM DESIGN

For various reasons being addressed in this article, information, and data sharing from and between all these downstream services and their need to receive correct information from the upstream digital thread activities (ship design and ship production and equipment systems' integration) needs to be managed efficiently. It is obvious to the authors that all this intra- and inter-activity communication is simply not possible without a new overarching vessel digital business model for shipbuilding. Without it, necessary fidelity, and accuracy in providing better and robust management and operator support will suffer. It is, therefore, timely and important to address and start a sincere discussion as to how we can proceed from here.

The implementation of a digital business model like the one discussed and proposed in this paper has significant implications for the expertise, the processes, the tasks, and the activities carried out by ship design firms. Extracting the value of data and information collected during the design process, construction and operation of vessels will require a mix of mathematical and statistical knowledge, programming skills and ship design expertise. The latter is abundant in ship design firms, but the former are scarce and need to be recruited or trained. New processes need to be defined for the additional deliverables, and existing processes, related to traditional ship design and ship production activities, must be revised. As an example, the delivery of maintenance procedures – preventive or predictive – will require the definition of maintenance periods or performance levels. Today this information is not collected in design processes nor during the construction of the vessel. Rather, it is available on user manuals provided by equipment suppliers. Thus, new processes must reflect activities where such information is identified, collected from suppliers, and integrated into the PLM system. A similar example is the delivery of life cycle assessments for vessels, reflecting the emissions related to the design, production, operation and scrapping phase. Such deliverables, which are already being requested by shipping companies operating in the offshore wind market, will include an additional optimization goal, a Design-for-X (Papanikolaou et al., 2009). Targeting low emissions during the overall lifecycle of the vessel, as opposed to during the operational phase alone, will add a complexity layer for ship designers. But will also require the identification, capture and storage of emission information related to the production of equipment, systems, and vessels.

CONCLUSION

This article argues that digitally linking data and processes streamlines shipbuilding activities, and can bring ship designers and shipyards back into a more central position in the coordination of the overall digitalization efforts of the marine industry. However, to take on such a challenging endeavour will require determination, financial strength, patience, expertise, collaboration and a bit of luck to become successful. Competition about the position-taking in the shipbuilding value chain is unavoidable, but, everyone can participate in contributing proportionally to the digital thread and establish themselves within the overall vessel digital business model for shipbuilding in an open and orderly fashion thereby creating a "win for all" situation ahead.

In this way, tedious and manual operations can be partly eliminated and sometimes minimized to those that add specific value. Business relationships can become more sustainable by removing ambiguity and misinterpretation, compliance assurance, and allowing controlled changes and better handling of business operation dynamics over time. Flexibility in digitalization systems' building is a must and should allow process variation, without having to use extra resources to manage and operate digital infrastructure. So far, the experience is that well documented, and controlled digitalization business processes are easier to sustain. It is expected that upstream digital twins of products, production, and downstream services will eventually lead to new value-creation opportunities. Digitalization efforts, so far, have shown potential for improving collaboration and innovation throughout the ship's lifecycle and should be further motivated. Fragmented and experimental digitalizing has anecdotally, proven beneficial to ship designers, shipyards, suppliers, and owner/stakeholders and improving their overall chain value. Particularly digital twins and various integrated and partly disjointed digital thread elements in operation have been documented to positively impact ship-lifecycle performance. In Ulstein, we have also found increased digitalization to contribute to more sustainable product and service development and more transparent administration of shipbuilding projects. But, so far, not as a surprise to us, for uncertain reasons, more qualitative gains are registered, than quantitative ones, like for example economic results of our operation.

While agility and innovation are key to success in a rapidly changing business landscape, there is no excuse for not preparing your organization. Digitalization helps achieve agility, innovation, and new business developments. The march of technology, digitalization included, is widely recognized as unstoppable. Today we see only the beginnings of the connectivity that will be required and imposed by competitors. Digitalization is a journey – where to go and what roadmap to follow.

The marine industry is conservative – tend to be late followers in all things digital except for automation and navigation. The adoption of CAD has been focused on being followed by PDM and gradually PLM. Paper drawings do still have a central role – especially in production. Although urgency is written all over digital shipbuilding advancement, we expect this digitization transformation still to take years or decades before full adoption of evolving digital technology is in place and full competitiveness power benefits from it.

It is also concluded that a new effective digital business model for shipbuilding is strongly needed to more efficiently be able to administer the rapidly growing information exchange among stakeholders in the shipbuilding value chain. It is argued that an effective digital business model for shipbuilding development can only take place if all the prime actors in the value chain are participating in the development sufficient data handling rigour is secured, and at the same time, flexibility is allowed in the development process to include the existing, but only compatible myriad of applications, out there. Yet, it is important not to exclude new ship design, ship construction, vessel automation and control and logistics-related, and other business administration-oriented applications. Proper interfacing protocols must be developed internationally and discipline amongst the developers of useful applications must be motivated. At present, it is primarily, the larger ship equipment manufacturers and suppliers, and classification societies that have taken on the spearhead position for these developments. Many smaller and less powerful application outfits, like software provers of administrative software for shipping and independent consultancy firms, are also a part of the group of new business adventurers. So far, these small actors are struggling to establish a critical mass in the market and are notoriously searching for extra funding for their initiatives. Only to a small extent have ship design firms and shipyards seen their natural expanded value chain position opportunity and prioritized sufficient time, money, and expertise to support such a strategic initiative. Not, diminishing the importance of the efforts already realized in building up a full complete digital shipbuilding platform, that goes far beyond today's "ship twin" and "remote inspection" experiments, it is paramount to the authors and argued herein the need for a reorganization of who should take the lead for this development in the future. Although their stature (economics, expertise and recognition) is not an encouraging one, compared to the well-established large and rich equipment manufacturers and classification societies, still will, collaboration and smartness can get them there…

There might be natural and unfortunate reasons for this asymmetry in the lead position of the development and the very late involvement of shipbuilding. If we go back to Figure 2 of this article, it is a fact that shipbuilding is the value chain element actors that have over a long time, yielded the least performance, and thereby have put themselves in a bad position financially, geographically, and expertise-wise to take a lead position in the digitalization project. On the other hand, we can observe that the shipbuilding downstream actors –equipment manufacturers and suppliers have been and are in a different positive and more appropriate position to take on larger and demanding digitalization efforts…

The efficiency of the new "Open Vessel Description (OVD)" digital platform is secured if the ship owner and shipbuilder take the lead together in such a bold endeavour. We recommend that the ship designer – the new naval architect and marine engineer - the business developer, must lead such an effort with the firm and looser inclusion of all relevant suppliers and information takers (users). Since this means that much of the present initiatives and firms' involvement will be challenged a broader type of interest group must come together to coordinate both the standardization work and guidelines for the individual complementary partial software application work. The digitalization efforts will cost money and resources…

CONTRIBUTION STATEMENT

Jose Jorge Garcia Agis: Conceptualization; data curation, methodology; writing – original draft.
Per Olaf Brett: Conceptualization; structure and argumentation; supervision; writing – review and editing.

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REFERENCES

Arola, T. (2018). Towards Maritime Data Economy Using Digital Maritime Architecture. *Proceedings of the 13th International Marine Design Conference*.

Brett, O., Garcia, J. J., Ebrahimi, A., Erikstad, S. O., & Asbjørnslett, B. E. (2022). A Rational Approach to Handle Uncertainty and Complexity in Marine Systems Design. *14th International Marine Design Conference*.

Brett, P. O., Gaspar, H. M., Ebrahimi, A., & Garcia, J. J. (2018). Disruptive Market Conditions require New Direction for Vessel Design Practices and Tools Application. *International Marine Design Conference (IMDC)*.

Digitalization. (2024). Gartner.

Dörner, K., & Edelman, D. (2015). What 'Digital' Really Means. *McKinsey & Company*.

Ebrahimi, A. (2022). *Handling Ship Design Complexity to Enhance Competitiveness in Ship Design* [PhD Thesis]. Norwegian University of Science and Technology.

Fletcher, G., & Adolphus, N. (2021). *Creating a Successful Digital Presence: Objectives, Strategies and Tactics*. Taylor & Francis Ltd.

Garcia, J. J. (2020). *Effectiveness in Decision-Making in Ship Design under Uncertainty* [PhD Thesis]. Norwegian University of Science and Technology (NTNU).

Garcia, J. J., Brett, P. O., Ebrahimi, A., & Kramel, D. (2020). The Potential of Virtual Reality (VR) Tool and Its Application in Conceptual Ship Design. *Conference on Computer Applications and Information Technology in the Maritime Industries*.

Gaspar, H. M., Brett, P. O., Ebrahimi, A., & Keane, A. (2014). Data-Driven Documents (D3) applied to Conceptual Ship Design Knowledge. *Conference on Computer Applications and Information Technology in the Maritime Industries*, *May*.

Gaspar, H., Sepalla, L., Koelman, H., & Garcia Agis, J. J. (2023). Can European Shipyards be Smarter? A Proposal from the SEUS Project. *22 Nd Conference on Computer and IT Applications in the Maritime Industries*, 406–416.

Jackson, M. C. (2019). *Critical Systems Thinking and the Management of Complexity*. John Wiley & Sons Inc.

Keane, A., Brett, P. O., Ebrahimi, A., Gaspar, H. M., & Garcia, J. J. (2017). Preparing for a Digital Future - Experiences and Implications from a Maritime Domain Perspective. *International Conference on Computer Applications and Information Technology in the Maritime Industries*.

Lagemann, B., Lunnan, R., Brett, P. O., Garcia Agis, J. J., Solheim, A. V., & Erikstad, S. O. (2024). What is a ship design firm, really? *Proceedings of 15th International Marine Design Conference* .

Leonardi, P., & Neeley, T. (2022). *The Digital Mindset: What It Really Takes to Thrive in the Age of Data, Algorithms, and AI*. Harvard Business Review.

Montero Jimenez, J. J., Schwartz, S., Vingerhoeds, R., Grabot, B., & Salaün, M. (2020). Towards multi-model approaches to predictive maintenance: A systematic literature survey on diagnostics and prognostics. *Journal of Manufacturing Systems*, *56*, 539–557. https://doi.org/10.1016/j.jmsy.2020.07.008

NA. (2018). *Internal PLM Survey at Ulstein*.

Papanikolaou, A., Andersen, P., Kristensen, H. O., Levander, K., Riska, K., Singer, D. J., McKenney, T. A., & Vassalos, D. (2009). State of the Art Report on Design for X. *International Marine Design Conference (IMDC)*.

Recio Rubio, L., Martin Mariscal, A., Peralta Alvarez, E., & Mas, F. (2023). A Process-Oriented Approach for Shipbuilding Industrial Design Using Advanced PLM Tools. *IF19th IP International Conference on Product Lifecycle Management*, 144–154.

Schiavon, M., Keber, M., Cossutta, A., Zini, A., Jez, M., & Ambrosio, L. (2019). Virtual Reality in Shipbuilding: Three use Cases in a Cruise Ship Design Process. *International Conference on Computer Applications in Shipbuilding*.

Teece, D. J. (2010). Business Models, Business Strategy and Innovation. *Long Range Planning*, *43*, 172–194.

Ulstein, T., & Brett, P. O. (2012). Critical Systems Thinking in Ship Design Approaches. *International Marine Design Conference (IMDC)*.

Ulstein, T., & Brett, P. O. (2015). What is a Better Ship? – It all depends …. *International Marine Design Conference (IMDC)*.