A discussion about the ship digital platform as a step forward for digital transformation in the maritime domain

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Abstract. An amazing technological evolution has characterized the maritime domain in the latest decades, toward a strongly digitized ship, as well as systems and services (energy production and distribution, automation services, connectivity with external assets…). The increment onboard of sensors and actuators, the augmented internal and external ship networking capabilities, the advent of enabling technologies in support of a cloud-oriented approach and the huge pervasiveness of AI create the urgent need of designing an effective ship digital platform, to be considered as a whole with the vessel platform. In the paper, a discussion about the ship digital platform will be proposed, with a high-level perspective, identifying the main functionalities and characteristics. It will be illustrated how the digital platform onboard can support and empower the development and deployment of a ship digital twin, from a life cycle perspective at the functional level.

Keywords. Digital Transformation. Digital Ship Architecture. Ship Digital Platform. Digital Twin.

1. Introduction

Originating around the mid-20th century, the digital evolution in the maritime industry, both for merchant and naval ships, has been a transformative journey of technological advancements, culminating in today's state-of-the-art digital-native technologies and innovations. Ship design, construction and operations have undergone profound changes in line with such evolution.

Since the beginning of Internet of Things (IoT) era [1] in the late 2000s, the world has been radically reshaped by its exponential and widespread adoption across various industries. This has acted as a catalyst for a plethora of creative applications, producing a variety of cyber-physical-social smart systems (CPS3) [2]. Information technologies, such as cloud computing, Artificial Intelligence (AI), wireless sensor networks and Big Data, allowed for disruptive advancement in the industry, known as Industry 4.0 [3, 4].

This process yielded new challenges and opportunities also in the maritime and shipbuilding ecosystem, traditionally considered a technology laggard [5]. Opportunities

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arise from the efficient integration of technologies such as IoT, Big Data, AI, Application Programmable Interfaces (APIs), edge devices, and sensors. Combined with the availability of data, these technologies are driving the optimization of vessel operations, enhancing efficiency, reducing costs, and maximizing up time. According to [6], Industry 4.0 digital technologies fuel the disruptive application spread, motivating however the need for the enterprise to put in place strategic responses (digital business strategy and digital transformation strategy) that in turn rely on digital technologies.

At enterprise level, new values can be created, with positive (operational efficiency and organizational performance) and negative (security and privacy) impacts, dealing with structural changes (organizational structure and culture, leadership, employee roles and skills etc.) and organizational barriers (inertia, resistance etc.). The enterprise digital transformation, described above, is a possible pre-requisite and answer, at the same time, to the rapid technological advancements and the digitization/digitalization of the entire world. Nevertheless, digital transformation is a long and hard journey in which technology, culture, leadership and strategy interplay [7].

With a specific focus on warships, in this paper it will be discussed how the innovative concept of Digital Ship Architecture (DSA) can enable effective solutions to ensure the integration of modern Industry 4.0 digital technologies effectively into naval operations through ship digital platform, providing a wide range of functionalities and applications. Namely, effective system integration enables the use of ship data to create an operational and functional framework for the system orchestrator [8], which will then access the aforementioned information via various applications embedded in the ship digital platform. In this context, different benefits to digital twin are going to be put in evidence as well.

2. Digital Evolution in the Naval Ship Domain

The use of digital technology has been rooted in the maritime industry for decades, both in the merchant and naval domain, as already mentioned. The timeline evolution of the digitalization process is briefly outlined in this section. Its importance is outlined in the ship design and construction domain, as well as in the operational context, together with the increasing availability of decision support tools.

2.1. Digital Fingerprints in Naval Shipbuilding Industry

The foundation of digitalization in naval industry began with early experiments in digital computation and communication. Notable examples include pioneer projects like DATAR (Digital Automated Tracking and Resolving) [9] and NTDS (Naval Tactical data System) [10] representing early digital systems in the 1950s. Nonetheless, it is the first-generation computer-aided software debuting back in the 1980s, that saw the widespread adoption of computer-aided design (CAD) tools in naval ship design and development that in turn offered naval architects 2D images of warship arrangements, systems and structures. Simultaneously, early computer-aided software engineering tools allowed streamlining workflows and improving design accuracy through automated repetitive analyses like stability calculations, hydrostatics, hydrodynamics, finite element analysis, structural integrity checks etc. Those early digital tools significantly improved individual productivity within specific disciplines by reducing manual calculations and errors; however, they lacked capacity to address the broader challenges of integrating multidisciplinary engineering efforts (i.e., labor-intensive coordination from various disciplines, paper-based processes, change management complexity etc.). These limitations, together with exponential growth in the scale and complexity of naval ship designs, coupled with relentless flow of design changes (iterative nature of ship design, i.e., ship design spiral [11, 12]), drove further innovations in digital technologies, leading to the emergence of a second-generation computer-aided software with broader and more comprehensive solutions in the 1990s. In particular, the very first versions of Product Data Management (PDM) systems were implemented offering more disciplined and automated solutions to change and configuration management [13, 14]. During this period, 2D CAD systems began to be replaced by 3D modeling tools, which enabled Digital Mockups (DMUs) [13] and digital simulations of various processes of shipyard. Even though the combination of PDM systems with 3D modeling tools marked a significant step toward integrating design, engineering, and production processes, they did not fully eliminate challenges in naval shipbuilding of that time, i.e., various setbacks, such as delays, budget overruns, and instances where programs failed to meet requirements or performance expectations. Already then, it was clear that the next generation of digital software technology for shipbuilding would have to be more than an information technology (IT) project, requiring the dedication and commitment from all levels of shipyard leadership [14]. The third millennium brought the concept of performance and fuel consumption monitoring on ships developed by third-party software. These various software solutions could consider the effects of weather, currents, ship speed and trim condition. In 2001, the U.S. Department of Defense launched an unprecedented initiative to develop advanced supersonic multi-role aircraft for its military branches and allied nations, the Joint Strike Fighter program. The program's success relied on secure global collaboration, automated management of configurations and changes for individual aircraft, and modular assembly across multiple locations. A pivotal outcome of this initiative was the Integrated Product Development Environment (IPDE) [14-17], a digital framework that set the benchmark for managing large-scale, collaborative projects. It also drove the rise of “digital shipyards”, powered by third generation of software technologies that provide an open, flexible, and modular suite of tools, enabling quick and efficient upgrades to existing infrastructures while enhancing design and engineering efficiency [14]. The fourth generation of digital technologies in the shipbuilding industry marks a significant advancement in the adoption of cutting-edge technologies and processes, driven primarily by the integration of Product Lifecycle Management (PLM) systems [18]. Emerging in the 2010s, this generation introduced a variety of engineering software, designed to optimize the acoustic signatures of naval vessels to meet critical stealth requirements, specialized tools to reduce noise generated by onboard machinery etc. It also addressed the growing complexity, precision demands, and cost constraints of modern shipbuilding.

2.2. Present and future trends

The recent ever-growing abundance of digital-native technologies and relevant applications have reinforced the warship’s stakeholder attention to in-service operational performance domain. State-of-the-art solutions improving the operational capability of warships, safety, reliability of systems and equipment readiness, endurance, and optimized lifecycle support are continuously under analysis and development. At present, this is mainly supported by data-based and knowledge-based models to assist human decision-making. In the future, the array of new digital technologies (e.g., cloud-based architectures, digital platforms, digital twins, high power computing, Machine Learning (ML), AI, Big Data analytics, edge IoT devices etc.) is expected to significantly upgrade warship capabilities. Recognizing this tendency, in 2021, the European Digital Naval Foundation (EDINAF) [19] project launched the digital revolution for Naval Industry, based on fundamental pillars such as a reference ship digital architecture and a ship digital platform.

3. Digital Ship Architecture and Ship Digital Platform

Modern naval warfare's unique nature spans multiple physical domains - space, air, surface, underwater, and seabed environments, as well as littoral regions crucial for amphibious operations. This multi-domain nature makes it essential to integrate naval combat systems into a comprehensive multi-domain military operations approach (i.e., using data, computing and networks for intelligence, decision-making observe-orient-decide-act loops and platform reliability improvement). Enhancement of ship performance, at both the individual unit level and the entire fleet level, is crucial from a multi-domain perspective. This very large perspective calls for a framework that enables the traceability of computational processes integration, the relevant logical and practical hierarchy, along time at conceptual and physical level. It can in short be indicated as Digital Ship Architecture and it will be based on a coherent set of interconnected systems, data, and processes supporting the digital warships and industrial digital core operations. It encompasses both the creation of physical structures and the design of virtual or immaterial environments within digital media. Moreover, it becomes urgent to identify DSA as able to address effectively the integration of existing legacy systems with modern technologies into naval operations. Furthermore, the DSA will enable a modular approach, where functional components are added as digital capabilities are progressively identified.

DSA is expected to integrate new digital services and solutions by afloat ship digital platform solving an information and operations technology efficient integration. From this perspective, ship digital platform can be defined as an environment that provides a wide range of capabilities (e.g., storage, computing, network, communication, decision support etc.) through services with specific functionalities utilized by applications to deliver functions to the end-user. Therefore, the naval ship digital platform serves as a centralized framework that facilitates the integration, orchestration, and management of information services, data, and applications within the naval ecosystem. It provides the necessary infrastructure and tools to enable seamless collaboration, interoperability, and innovation across diverse naval systems and assets.

4. Functionalities and Characteristics of Ship Digital Platform

The ship digital platform is made of software and technology used to unify and streamline operations and IT systems. It serves as a backbone for operations and customer engagement, easing stakeholder users and entities in goods, services and information exchange while enhancing connections, collaborations and mutual interactions. The ship digital platform is envisioned to *provide a wide range of services through API-enabled applications*, incorporating features of cloud computing models such as Infrastructure as a Service (IaaS) and Platform as a Service (PaaS). These capabilities will cover various technical domains and operate across multiple levels, from managing low-level infrastructure (e.g., virtualization, storage etc.) to providing advanced digital services such as AI, data analytics, and streaming solutions. Possible examples of technical domains include data, Identity and Access Management (IAM), analytics, digital twinning services, ML services like speech to text, Development-Security-Operations (DevSecOps) services for continuous integration and delivery of applications, IoT services for secure communication of IoT devices etc. Many of these technical domains are bound to mutual interaction.

Given the inherent complexity of warship domain - which involves multiple stakeholder users and entities with diverse priorities - three contexts can be envisaged:

- *Onboard Environment*: on vessels, the digital platform is expected to play a crucial role in supporting navigation and onboard decision-making, facilitating communication and coordination with other vessels or land bases.
- *Shipyards Environment:* in shipyards, the digital platform could enable the testing of onboard components through digital twins and data collected from onboard sensors. This capability allows performance prediction, optimization anf assessment about integration of new components on the vessels.
- *Navies and MoDs Environment:* This environment will include services related to the lifecycle of the units: operation, support, maintenance.

The digital platforms referred to different contexts shall be able of mutual communication and interaction to support the collaboration and the exchange of information across different stakeholders. Considering the Onboard Environment digital platform (i.e., ship digital platform), at the deployment phase, an instantiation of the applications and models may be installed on the ship digital platform, after Navy approval. Depending on Navy or MoD restrictions, (near) real-time connectivity, intermittent connectivity and batch upload, or no connectivity at all, will be configured. Maintaining the perspective of the same environment, a generic data flow for a ship digital platform could be a layer of devices and external systems generating the data, to be ingested and integrated with simulation models (e.g., digital twin etc.) and other information services deployed in the platform (notification services, event-driven transformation, storage services, big data analytics, ML, etc.). The information services process the data and organize it to be exposed and presented to applications and visualization services which will be consumed by the end users. Transversally, security, IAM, development, monitoring, policy, backup and network management services are shared across the platform.

It is evident the importance of identifying services and to effectively manage them. Pertaining to this matter, a typical digital platform structure is described through following layers of services, regardless of the specific environment to be deployed in:

- *Infrastructure Services:* this foundational layer serves as the backbone for the rest of the services providing IaaS capabilities by virtualizing fundamental hardware components (e.g., computing, storage, networking services and virtual machines/containers, SDN).
- *Information Services:* basic IT infrastructure components for data storage, monitoring, transformation, and analytics, pivotal for efficient integration across various naval operations. These services form the backbone of the platform, enabling efficient communication, data management, security and operational capabilities (e.g., IAM, security, database, data lake, data

monitoring and management, data transformation, data analytics, digital twinning, ML and deep learning).

- *Application Services:* this layer represents advanced methodologies for transforming data extracted and pre-processed, into actionable insights (e.g., PLM, AI).
- *User Applications Services:* all information acquired from the previously described infrastructure is made accessible to the end-user through this architectural layer facilitating tasks related to navigation, communication and combat.
- *Security and Compliance Services:* features integrated throughout the architecture to ensure the confidentiality, integrity, and availability of data and services. This includes IAM, encryption, audit logging, and regulatory compliance controls to mitigate cybersecurity risks and regulatory requirements.

Although a variety of services will be tailored for specific environments, many core functionalities (i.e., Information Services) will be common across all deployments.

In the context of mutual interactions, we can speculate that the successful integration of a digital twin with the ship digital platform can improve efficiency, reduce costs and improve decision making. In particular, development and deployment of the ship digital twin can find robust support in the ship digital platform when the following actions are necessary:

- to store and process large amounts of data, a paramount requirement for the most accurate digital twin model.
- to perform analysis and post-processing of digital twin data, with the aim of identifying trends and patterns.
- to simulate digital twin behavior helping in better decision-making process.
- involvement of different teams and departments, thereby enhancing communication and coordination.

In support of this speculation, in [20] important aspects are discussed about composition of a digital twin, that in turn, evidences the need for the four foundational infrastructure technologies, i.e., *data storage and curation*, *computing*, *communications*, and *software platforms and frameworks*. In fact, when considering the composition of the digital twin, important building blocks from Figure 1 must be guaranteed by the ship digital platform services.

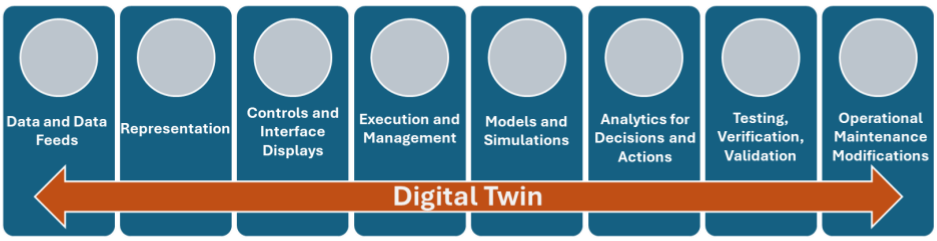

Figure 1. Important building blocks for enabling the ship digital twin.

The digital twin can be considered a service provided at the Application Service layer, able to provide support in decision making along the ship life cycle when requested e.g. at the possible User Application layer, in relation to a single ship onboard systems or spanning over some of them in an integrated performance prediction. The discussion of the several platform services able to implement a digital twin- based support tool, for crew assistance, should be carried out in parallel with the specific performance modelling issues. This can enable a robust process for data management (e.g. from sensors to machine learning, data availability,...) or an effective modular approach in digital twin development and deployment.

5. Digital Platform and Physical Platform

By embracing enterprise digital transformation, naval industry may improve in providing modern warships at technological edge, enhancing operational effectiveness, and better responding to the complex challenges of contemporary naval warfare. The topic of integration implies a consideration about the *convergence of Operational Technology (OT) and Information Technology (IT) due to deliver enhanced capabilities via* Industry 4.0 digital technologies (IoT, IIoT, Cloud computing, AI & ML, edge computing, cybersecurity, digital twin etc.), directly impacting operational security, efficiency, and resource optimization. The integration into the ship digital platform of data generated by various devices, sensors, and actuators, relevant to the several onboard systems (among which OT systems play a significant role), shall be approached differently based on the digital maturity (i.e., legacy-analog, mid-digital, or digital-native).

A systematical identification and integration analysis of the ship digital platform services, that could be requested and used by the ship systems, is advisable for a robust and efficient approach. The purpose of this paper is not to exhaustively catalog warship's onboard systems, nor comprehensively enumerate ship digital platform services. Nevertheless, as an example, in Figure 2 possible systems aboard naval vessels are recalled and represented as all potentially able to derive advantage from the ship digital platform.

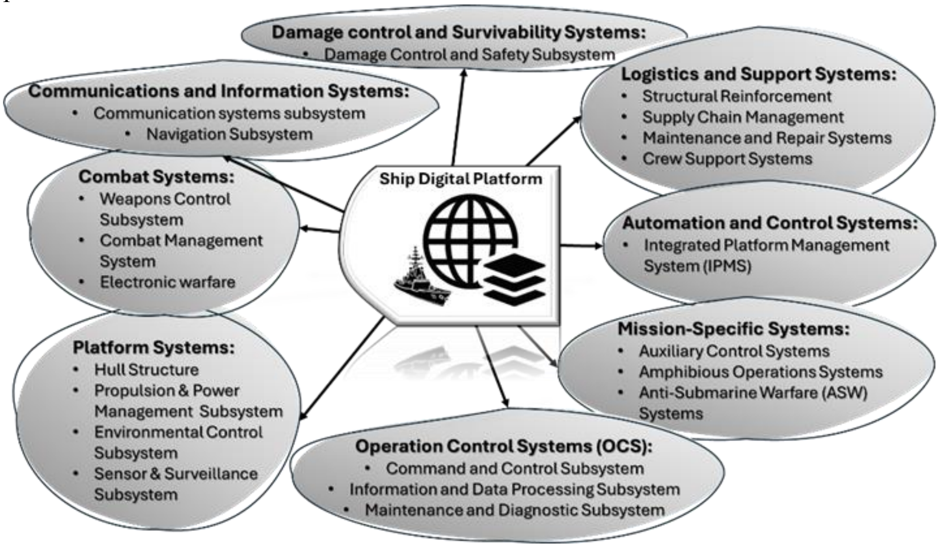

Figure 2. Systems aboard naval vessels possibly supported by ship digital platform.

Then a matrix is presented in figure 3: in the rows, a ship systems list is reported, while the columns represent possible services of the ship digital platform. In particular, in the column the same layers of services are used as already discussed in section 5 of this paper. The Security and Compliance Services are a transverse feature interesting the comprehensive service framework at any layer, where appropriate.

For each system on board, a specific user application can be envisioned, and the necessary Application and Information Services need to be discussed, together with the relevant Infrastructure Services. The matrix helps to put in evidence which digital platform services (at any layer) may be necessary for nearly all the systems onboard and which, on the other hand, are specific for a unique system. In the perspective of structured and efficient integration, a systematic discussion is a robust starting point. Additionally, although services reported in the matrix are meant to be relevant to the Onboard Environment, they could be mirrored on the other two environments as well (i.e., Shipyard, Navy and MoD), suggesting that a thorough analysis in this sense is required.

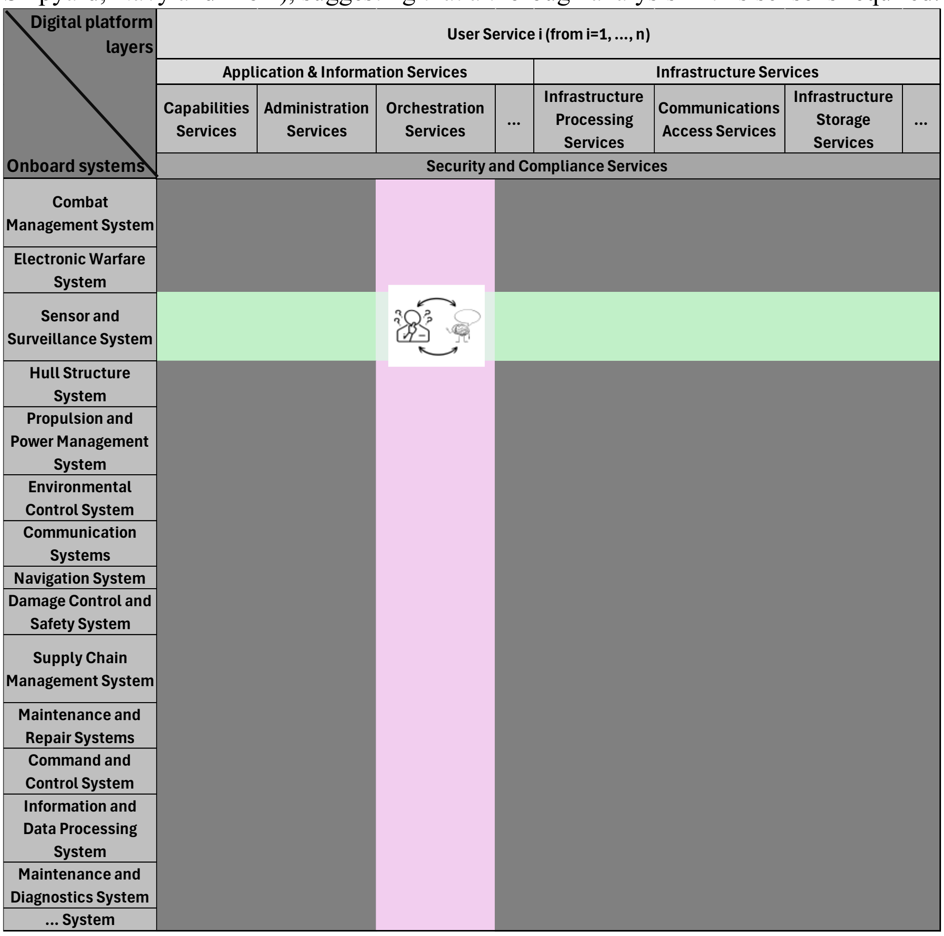

Figure 3. Systems onboard naval vessels, in connection to the ship digital platform services.

A further conceptual support to discuss the integration framework could be provided by the Purdue Model (i.e., Purdue Enterprise Reference Architecture – PERA, [21]) enhanced with Zero Trust (e.g., never trust, always verify) principles. The combined model systematically and meticulously identifies the Industrial Control System (ICS) [22] as made of six distinct hierarchical levels. Each level is characterized by its specific function, unique communication requirements, and individual security needs while identifying a specific level of operational control. Level 0 includes sensors and actuators that act directly on physical processes. Level 1 includes intelligent devices such as Programmable Logic Controller (PLC), Intelligent Electronic Device (IED) and Remote Terminal Units (RTU) leveraging and facilitating immediate response in OT operations whereas Level 2 includes control systems such as Human Machine Interfaces (HMI) and supervisory control and data acquisition (SCADA) systems, alarms, and control room workstations. Level 3, which together with former levels, encompasses the so-called OT network, includes OT/core systems that support the main warship operations. Level 4 is represented by IT infrastructure that provides enterprise services (IAM, PLM, AI & ML, various data and analytics services, DevSecOps etc.). Level 5, which together with Level 4 completes the so-called IT network, represents the top-tier enterprise network for the end stakeholder, characterized by applications that use data elaborated by the IT services (cloud CSP, ERP, resource and route planning, mission and combat apps, etc.). In this configuration, the data generated by OT network can be transmitted to IT network, thereby enabling the generation of new digital services. By adhering to the Purdue Model's hierarchical segmentation, a structured framework to map ship digital platform IT services with the warship's OT systems is provided.

As a final general comment, it is considered worthwhile mentioning the ship digital platform, in principle, is an onboard system itself like many others! (although among the most important ones, due to the integrating functions it enables, and the services it provides).

In this perspective, beside the logic and functional aspects, the following physical aspects should be addressed for each element the ship digital platform is made of:

- volume, weight and relevant distribution, considering also the accessibility for operational reasons and or maintenance.
- energy supply with main emphasis on the need for conditioning and ventilation, due to the impact of high temperatures and humidity on the system's elements performance.

What above results of outstanding importance, while considering lifecycle perspective of ship digital platform and possible renewal programs because of IT systems fast obsolescence.

6. Conclusions

This paper discussed the importance of the ship digital platform as a comprehensive suite of services that span multiple technical domains and are provided through applications. The expected positive outcomes are put in evidence in terms of competitiveness for shipyards and of enhanced performance for warships fleet. It is put in evidence how DSA is a fundamental prerequisite to obtain an effective ship digital platform as an environment gathering new efficient digital services and possibly improving the IT and OT integration.

Also, high-level arguments were presented on how specific digital platform services could be beneficial for Digital Twin real exploitment. The positive outcomes are put in evidence in terms of competitiveness for shipyards and of enhanced performance for warships fleet. Nevertheless, digital transformation is a long and hard journey in which technology, culture, leadership and strategy need a wide and thorough discussion in the large and complex stakeholders' community.

References

[1] Chebudie AB, Minerva R, Rotondi D. Towards a definition of the Internet of Things (IoT). IEEE Internet of Things. 2015 May.

[2] Huang J, Seck M, Gheorghe A. Towards trustworthy smart cyber-physical-social systems in the era of Internet of Things. In: Proceedings of the 11th International Symposium on Service Oriented Software Engineering (SoSE); 2016 Jun; Kongsberg, Norway p.1-6, doi: 10.1109/SYSOSE.2016.7542961

[3] Schwab K. The Fourth Industrial Revolution. World Economic Forum. 2016; ISBN-10: 1944835016.

[4] Xu LD, Xu EL, Li L. Industry 4.0: State of the art and future trends... . 2018 March; 56(8):2941-2962, doi: 10.1080/00207543.2018.1444806

[5] Diaz R, Smith K, Bertagna S, Bucci V. Digital Transformation, Applications, and Vulnerabilities in Maritime and Shipbuilding Ecosystems. Procedia Computer Science. 2023; 217:1396-1405, doi: 10.1016/j.procs.2022.12.338

[6] Vial G. Understanding digital transformation: A review and a research agenda. Journal of Strategic Information Systems. 2019 Jun; 28(2):118-144, doi: 10.1016/j.jsis.2019.01.003

[7] Omol E. Organizational digital transformation: from evolution to future trends. Digital Transformation and Society. 2023 Dec; 3(3):240-256, doi: 10.1108/DTS-08-2023-0061

[8] Industry IoT Consortium. The Industrial Internet Reference Architecture. Foundational Document Version 1.10, 2022 Nov.

[9] Vardalas JN. The Computer Revolution in Canada: Building National Technological Competence. The MIT Press. 2001; ISBN electronics: 9780262285469, doi: 10.7551/mitpress/2046.001.0001

[10] Boslaugh DL. When Computers Went to Sea: The Digitization of the United States Navy. IEEE Computer Society Press; 1999. 468 p, ISBN 0-7695-0024-2

[11] Evans J. H., BASIC DESIGN CONCEPTS, 1959

[12] David G.M. Watson, Practical Ship Design, 1998

[13] Stark R. Virtual product creation in industry: the difficult transformation from IT enabler technology to core engineering competence. Berlin: Springer, 2022. 67 p, doi: 10.1007/978-3-662-64301-3

[14] The digitalization of naval shipbuilding: Launching a new era in development efficiency and production versatility. 2019 [cited 2025 Mar 17] Available from: https://www.plm.automation.siemens.com/media/global/ko/The%20Digitalization%20of%20Naval%20Shipbuilding_tcm72-65038.pdf

[15] Brown G. Implementing an Integrated Product Data Environment—A Strategic Plan. [cited 2025 Mar 17]. Available from: https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Chronicles/brown1.pdf

[16] McIntyre M.H. An integrated product development framework. Annual Reliability and Maintainability Symposium. In: Proceedings of the International Symposium on Product Quality and Integrity; 1998 Jan 19-22; Anaheim, USA. p.23-25, doi: 10.1109/RAMS.1998.

[17] Oh DK, Jeong YH, Kim YG, Shin JG, Yeo YH, Ryu C. Development of Product Model Management System for Naval Shipbuilding. Journal of Ship Production. 2008 May; 24(2):82-91, doi: 10.5957/jsp.2008.24.2.82

[18] Shannon K, Housel TJ, Jansen E, Silkey T. Benchmarking Dutch and U.S. Naval Shipbuilding: Reducing U.S. Naval Shipbuilding Costs Using Collaborative PLM and 3D Imaging. Naval Postgraduate School. 2012 Nov; NPS-AM-12-211.

[19] Silvera Vez, JI, Regueiro IP, Lindberg FW, Eriksson MM, Kvamsdal T, Zini A, Gualeni P. EDINAF – THE FUTURE DIGITAL SHIP FROM THE NAVAL INDUSTRY PERSPECTIVE. ICCAS 2024: International Conference on Computer Applications in Shipbuilding. Applications in Shipbuilding 10-12 September 2024 Genoa, Italy

[20] Bonomi F, Drobot A. Infrastructure for Digital Twins: Data, Communications, Computing, and Storage. DOI: 10.1007/978-3-031-21343-4_15.

[21] Williams T.J. The Purdue Enterprise Reference Architecture. IFAC Proceedings Volumes. Volume 26, Issue 2, Part 4, July 1993, Pages 559-564.

[22] Conti M, Donadel D, Turrin F. A Survey on Industrial Control System Testbeds and Datasets for Security Research. February 2021. DOI: 10.48550/arXiv.2102.05631.