"Unlocking the sustainable value with digitalization: Views of maritime stakeholders on business opportunities"

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UNLOCKING THE SUSTAINABLE VALUE WITH DIGITALIZATION: VIEWS OF MARITIME STAKEHOLDERS ON BUSINESS OPPORTUNITIES

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Abstract

Digitalization in the maritime sector encompasses interconnected technologies that enhance efficiency, risk mitigation, and safety in marine operations and offshore assets management. Digital twin, or virtual assets, plays a pivotal role within this digital ecosystem. This study aims to explore the transformative potential of digital twins in the maritime industry, focusing on their capacity to improve sustainability, optimize productivity, and drive innovative business models. A quantitative methodology was employed to investigate this potential in the maritime sector, utilizing questionnaires to gather insights and perspectives from key stakeholders in the Northwestern part of Norway's maritime industry, including ship designers, shipyards, equipment suppliers, and ship owners. Among the 23 respondents, there were individuals holding senior, leadership, management, and specialized digitalization roles. Notably, 65% of these respondents possessed over 20 years of experience in the maritime industry. The survey reveals a strong interest in adopting digital twins within the maritime sector (70% of respondents). The findings underscore the potential advantages of digital twin solutions, including predictive maintenance (16%), real-time operational efficiency enhancements (17%), and design optimization (18%). Nevertheless, implementation complexity (73.9%) and data integration (73.9%) loom significant obstacles. Respondents also recognize the potential for new product opportunities and innovative business models arising from digital twin implementation. Sustainability initiatives are emphasized, particularly in real-time monitoring (83%), retrofitting (74%), and predictive maintenance (65%). Cybersecurity (65%) and data protection (62%) are critical concerns. Furthermore, implementing digital twins is anticipated to promote collaboration and information sharing among maritime industry stakeholders, underscoring their potential for transformative impact.

Keywords digitalization, digital twins, product-service-system, servitization, sustainable business model innovation

JEL Classification M10, O14, Q55

INTRODUCTION

The field of digital servitization in maritime shipping is expanding, though research on its sustainability impact is nascent. Current research includes exploring essential digital skills for a servitized maritime sector and examining supportive digital technologies like blockchain, autonomous systems, and the design of intelligent product-service systems. The maritime industry is experiencing a significant transformation driven by digital technology, enhancing sustainability and efficiency. Technologies such as cloud computing, the Internet of Things (IoT), Big Data, Virtual and Augmented Reality, and various forms of artificial intelligence are revolutionizing the sector. These advancements have led to developing cyber-physical systems, considered a pinnacle in the manufacturing and consumer service sectors. Moreover, advancements like 5G and Tactile Internet have vastly improved communication capabilities.

The digital twin concept has rapidly evolved from theory to application, significantly impacting operational efficiency, emission reduction, and innovation in business models. A recent report from the World Bank (2021) and the International Association of Ports and Harbors emphasizes the vast potential benefits of digital collaboration in the maritime supply chain.

This is extremely important to facilitate reaching the goal of zero emissions by IMO in 2050. ZEWT (2021) initiative outlined a two-pronged strategy for transitioning the maritime fleet to green energy. Firstly, part of the current fleet will undergo accelerated transformation through retrofitting. Secondly, new vessels are being designed with the flexibility to promptly adopt zero-emission technologies. Currently, the industry is working on converting around 55,000 merchant ships and 12,000 inland vessels to zero-emission standards through both retrofitting and replacement. Additionally, new ships are being constructed to be adaptable to various sustainable fuels, designed for maximum efficiency, including digital twins, and incorporating electric or battery drives along with renewable energy sources (ZEWT, 2021).

While digital technologies promise enhanced efficiency at both the firm and industry levels, realizing these benefits requires substantial organizational capital and management acumen. This includes investments in modernizing business practices and integrating routine tasks systematically. Achieving these efficiency gains may be a gradual process. The digital revolution in transportation also brings challenges, including cybersecurity threats, data quality concerns, regulatory hurdles, and skill shortages. Thus, developing specific strategies to promote industrial digitalization is essential, focusing on leadership, legal and regulatory frameworks, technology and data governance, and human capital (Sorbe et al., 2019).

The maritime industry is expected to develop advanced assessment methods and fully integrate digital twins in ship design and manufacturing to better understand and improve environmental performance. However, as digitalization progresses, it is imperative to incorporate stringent cybersecurity measures and physical safeguards in the design and retrofitting processes (ZEWT, 2021). The industry faces challenges in achieving the full potential of integrated digital twins, including data integration and interoperability. Collaboration among all stakeholders in the ship value chain is essential for realizing the collective benefits of this technology. Digital twins offer a pathway toward decarbonization, performance optimization, and innovative financing models for the maritime industry. Embracing a cooperative approach to data management and digitalization strategies is crucial for unlocking these opportunities and propelling the industry toward a sustainable and efficient future (Fonseca & Gaspar, 2021).

Maritime shipping, recognized as a complex and multi-stakeholder industrial sector, can benefit from adopting digital servitization to enhance value delivery, establish competitive advantage, and foster sustainable practices (Chávez et al., 2024). Nonetheless, there remains an unclear understanding of the factors that either facilitate or hinder the implementation of these business models within this particular sector. Moreover, there is a noticeable lack of comprehensive research on how the business model changes as digitalization unfolds, and how to comprehend the complexities and interdependencies that arise along the trajectory of digitalization.

1. LITERATURE REVIEW

1.1. Concept of digital twin and its implication

According to DNV (n.d.), digital twin technology offers a dynamic virtual representation of physical entities, systems, or processes, allowing continuous surveillance, assessment, and enhancement. This technology harnesses data from various sources, including IoT devices and sensors, to imitate various conditions, promote predictive maintenance, improve resource utilization, and support decisions rooted in data. The genesis of the twin concept can be traced back to NASA's Apollo missions, which utilized twin satellites – one for space

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travel and the other as a controlled lab replica – to monitor and analyze mission data. Piascik et al. (2010) describe how NASA incorporated the twin concept into their technological strategies, focusing on the symbiotic relationship between the physical entity, its digital counterpart, and their interconnections, facilitating a two-way data flow and continuous updates. The term "digital twin" was first mentioned in a Radiology Journal article by Renaudin et al. (1994), referencing a detailed arterial model created through stereolithography.

Grieves (2002) introduced the digital twin concept in 2002 at a manufacturing conference in Michigan. He envisioned a comprehensive digital profile for physical models that would persist throughout their lifecycle. Initially, digital twins were integrated into product lifecycle management, suggesting their application to not just products but manufacturing processes and broader value chains as well (Grieves, 2002). In his landmark book on product lifecycle management, Grieves (2006) termed this concept the information mirroring model, emphasizing the reflection of real-time data in the virtual model.

Digital twin technology has been a staple in the industry for several decades, finding utility in various sectors, including energy and transportation. Companies like General Electric have utilized digital twins for real-time monitoring of aircraft engines to identify maintenance needs preventively. These digital replicas collate extensive sensor data into comprehensive models for analysis, enabling predictive maintenance, optimization, and troubleshooting. Notably, this technology allows for data distribution across various platforms and formats, adapting to the user's capabilities and requirements. A well-executed digital twin is characterized by its ability to instantly reflect every aspect of its real-world counterpart (Skinner, 2023).

In manufacturing, digital twins create a detailed digital representation of machinery and processes to fine-tune production strategies, including layout, material flow, speed, and output. Factories leverage this technology to make informed adjustments and optimize operations through data-driven insights (Skinner, 2023). Despite a digitalization lag in the shipbuilding sector compared to other industries, the increasing volume of data generated throughout a ship's lifecycle presents significant opportunities for enhancing safety and efficiency during assembly, design, processing, and manufacturing stages (Seppälä, 2020; Lv et al., 2023).

Their initial application to maritime contexts has emerged as digital twins gain traction. Fonseca and Gaspar (2021) identified two primary categories of these applications: one that enhances decision-making in ship operations through condition monitoring and simulation model calibration using actual operational data and another that utilizes digital twins for system integration testing and personnel training.

Madusanka et al. (2023) detail the sequential steps for integrating digital twins in maritime operations, acknowledging the industry's shift from traditional, environmentally detrimental systems to those aligning with the International Maritime Organization's zero-emission mandates. The journey of digital twin technology in maritime affairs includes several stages (Madusanka, 2023):

1. Ship electrification (SE): Transitioning from conventional diesel engines to electric propulsion systems to address environmental mandates and improve operational efficiency.

2. Ship digitalization (SD): Employing digital tools for design, performance testing, and ensuring secure information flow, leading to more resilient maritime models.

3. Smart shipping (SS): Integrating advanced communication systems for data transfer, thereby improving safety, awareness, and decision-making in navigation.

4. Autonomous vehicles (AV): Developing self-navigating and autonomous vessels using digitalized and electrified frameworks.

5. Digital twin (DT): Implementing digital twins to create virtual counterparts of physical ships, facilitating continuous monitoring and optimization throughout their lifecycle.

Recent studies stress that continuous innovation and transformation within the marine industry evolves, new technologies should encompass the complete lifecycle of a ship, including its operation, maintenance, and dismantling phases (Gaspar et al., 2023). In this vein, Zhang et al. (2023) discuss the potential of data-driven prognostics and health management (PHM) systems, using the digital twin.

In sum, the development of such collaborative platforms and ecosystems as DT is crucial for fostering cooperation among maritime stakeholders, leading to more integrated and efficient operations.

1.2. Business model framework and sustainable value of digital twins

A lot of authors posit that a business model delineates the method through which a firm creates, delivers, and captures value (Teece, 2010; Kadyan et al., 2022; Gennari & Bocchi, 2023; Coutinho et al., 2023; Irfan et al., 2023; Bachtijeva et al., 2023; Timotius, 2023). This concept is broader than the confines of any single firm, involving a system of interconnected activities that extend beyond its boundaries (Zott & Amit, 2010, p. 216; Polinkevych et al., 2021; Straková et al., 2022; Kuznyetsova et al., 2022a, 2022b; Bencsik et al., 2022; Telenkov et al., 2022; Kolodiziev et al., 2022; Mazur et al., 2023).

The composition of business models has been the subject of various theories. Chesbrough and Rosenbloom (2002) identify key elements like the value proposition, targeted market segment, the arrangement of the value chain, cost structure, and profit potential, encompassing the product or service content, the network of activities (including R&D, production, sales, after-sales, etc.), and financial strategies (pricing, additional revenue streams, and government incentives). Zott and Amit (2010) view business models from an activity system perspective, focusing on three design elements: the selection of activities (content), the linkage and significance of these activities (structure), and the manner of their execution, whether internal or external (governance). Bohnsack et al. (2021) highlight the importance of identifying effective business models in fast-evolving markets, especially considering the growing need for sustainability in internationalization and performance metrics.

Shakeel et al. (2020) proposed a framework for sustainable business model innovation consisting of three components: innovation in sustainable value proposition, sustainable value creation and delivery, and sustainable value capture. Boons and Lüdeke-Freund (2023) further elaborated on this, identifying four key elements of sustainable business models: integrating value proposition, value creation and delivery, and value acquisition.

Synthesizing the perspectives of Osterwalder (2004) and Doganova and Eyquem-Renault (2009), a generic business model can be broken down into distinct elements:

1) the inherent value in the product/service offered (value proposition);

2) the structure and management of upstream supplier relationships (supply chain);

3) the structuring and management of downstream customer relationships (customer interface); and

4) the financial aspects encompassing costs, benefits, and their distribution among stakeholders (financial model).

Boons and Lüdeke-Freund (2023) observed that while designing and managing sustainable business models is critical, this field remains under-researched. They noted a gap in sustainable innovation research, particularly in how firms integrate a value proposition with the organization of the value chain (Koilo, 2021, 2022) and a financial model to market sustainable innovations effectively.

As previously discussed, the concept of the digital twin emerged in the early 2000s as part of the broader trend toward digitalization, which included emerging technologies such as cloud computing, machine learning, artificial intelligence, business intelligence, and the Internet of Things. Over time, as digital technologies advanced, there was a realization of the necessity to create innovative applications for business technology, while also finding ways to accelerate traditional processes through technology. This realization led to the concept of digital transformation (Figure 1).

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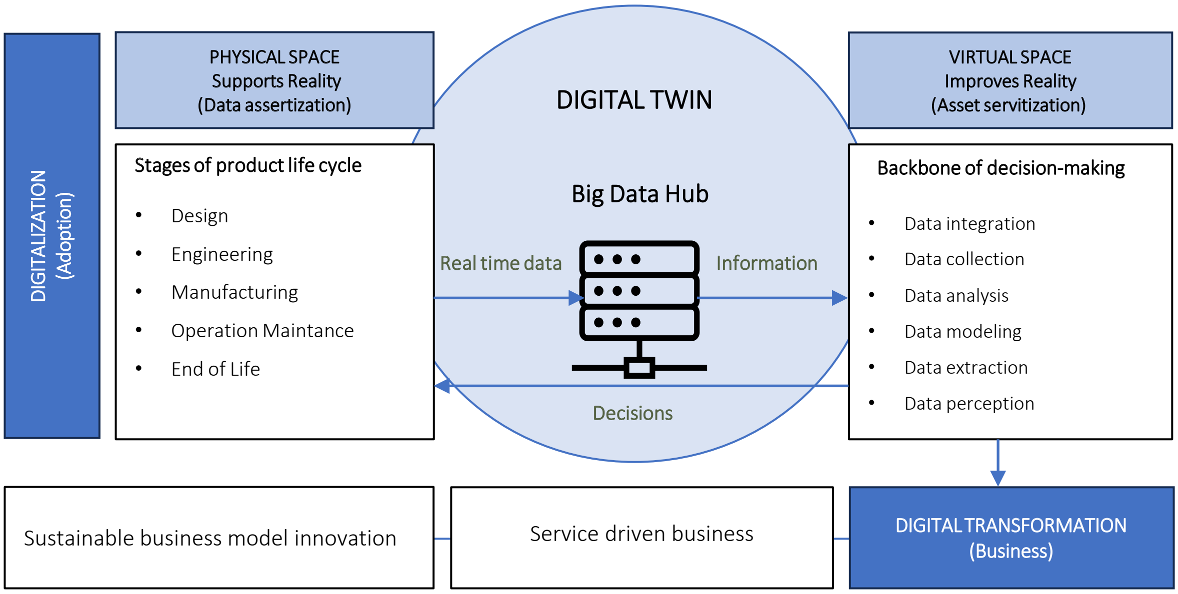

Figure 1. Interplay between digitalization, digital twin, and servitization, and business model

Hence, this transformation leads to the development of a digital business strategy. Moreover, digital transformation looks at all aspects of business: whether it's customer needs, innovative new products, market opportunities and challenges, hence a digital business model are needed.

To address the issue of the potential advantages of digital twins for established organizations and their role as catalysts for new business models, in 2022, the Centre for Digital Built Britain (University of Cambridge, n.d.) completed a five-year endeavor. The findings revealed significant hurdles in revenue generation from digital twins, primarily due to a need for more executive buy-in. The 4Vs framework was developed to assist leaders in understanding the business opportunities offered by digital twin services. 4Vs encompasses value proposition, value architecture, value network, and value finance.

In addition, CDBB (University of Cambridge, n.d.) highlighted key pathways for change and numerous catalysts for sustainable business model innovation:

1. From products to services: Digital twins play a pivotal role in servitization, offering added value across an asset's entire life cycle.

2. From efficiency to agility: Digital twins allow for greater customization to meet the diverse needs of users.

3. From separation to fusion: Digital twins can transform customer experiences and partnerships between stakeholders and increase collaboration within supply chains.

4. From sustainability to holistic: Digital twins lead not only to environmental benefits but also unlock new business opportunities and drive long-term growth.

According to Podmurnyi (2023), the vast potential of digital twins lies in their ability to predict future business scenarios through analyzed data from virtual counterparts. This predictive capability enhances informed decision-making and simplifies processes. However, realizing these benefits requires overcoming digital twin development challenges. Proper deployment ensures the system adapts quickly to changes in user and data volumes, with cloud services offering tools for automatic resource monitoring and management. Understanding the benefits of digital twins for business decisions is contingent upon a solid development approach, particularly in data management, to avoid outdated systems or process information. By addressing these challenges, businesses can ensure their digital twin development projects are successful and fully realize their potential benefits (Podmurnyi, 2023).

Barth et al. (2022) conducted a comprehensive study on applying digital twins across Swiss com-

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panies' product lifecycles, offering insights for practitioners and researchers. They investigated how companies aim to generate value at different lifecycle phases: Beginning-of-Life (BoL), Middle-of-Life (MoL), and End-of-Life (EoL). The study found that companies predominantly recognize the potential of digital twins in the BoL (79%) and MoL (60%) phases, with lesser emphasis on the EoL phase (15%).

Barth et al. (2023) explored an application-oriented framework for value creation using digital twins, employing design science research approaches. They highlighted the importance of integrating various data sources, from internal enterprise systems to external third-party data providers, to innovate services and processes.

From data to services to value. The approach "From data to services to value" elucidates how value is created from data via digital twins, transitioning from data categories to preparation, analysis, interpretation, and finally, the creation of value through services. This integration between digital twins and services is promising, enabling new and enhanced services through the data provided by digital twins.

For instance, in the recent study of Chen et al. (2021), authors aimed to explore the concept of digital servitization, which involves manufacturing companies transitioning from offering traditional products and services to providing intelligent solutions. Additionally, they emphasize the significance of changes in the value proposition, delivery methods, and the integration of digital technology in this context. They elucidate how these changes interact to influence shifts in the value capture mechanism, where digital servitization process unfolded over three distinct business model stages: 1) internal activity system; 2) supply and distribution chain; 3) ecosystem.

Everything-as-a-service paradigm. The overarching goal of DT is to support a realistic model of system behavior that can enhance established services like performance prediction and optimization while unlocking new potentialities in the everything-as-a-service paradigm. For example, pay-per-use (Müller, 2019), pay-per-product (Antikainen & Valkokari, 2016), thereby supporting all actors around the product-service-system (PSS) by integration with other technologies, and using a multi-stakeholder negotiation (Giourka et al., 2019). A more in-depth explanation is provided in Table 1.

Table 1. Sustainable value of digitalization (digital twin) from different industries' perspectives

Key elements	Innovation Business Model through Industry 4.0 (Müller, 2019)	Innovation Business Model for DT in the energy sector (Giourka et al., 2019)	Sustainable Circular Business Model Innovation (Antikainen & Valkokari, 2016)
1. Customer Segments	New markets – beyond the maritime industry	Citizens, municipalities, regional authorities	Recycling centers for used products both value the easiness and accessibility
2. Value Proposition	1. Better decisions by use of advanced analytics as a part of digital twins; 2. Better prediction of service needed 3. New product features, e.g., predictive maintenance, self-optimization or 5. Energy savings	Great support system for participatory planning and decision making; more efficient process for the administration, integration with other technologies (BIM); use in multi-stakeholder negotiations; short-term actions and longer-term policies	Updating the technology, fully scalable system; Radical increase in the re-usage of goods with the easy digitalization concept and platform; Resource efficiency, recycling; Local impact by employing people
3. Revenue Streams	1. New payment models, e.g., pay-per-use 2. Automation of revenue streams	Societal revenue, environmental benefits, stakeholders' new revenue opportunities through servitization and product development	Buyer: pay-per-product; future: monthly fee; sellers: commission-based fee for quality products
4. Channels	1. Digital channels for efficient communication; 2. Automation of communication through machine-to-machine communication	Apps to deliver information to citizens, use in negotiations for the development of digital twins	CH&L direct and reverse: web, social media
5. Customer Relationships	1. More long-term oriented partnerships; 2. From self-serve to assistant	Collaboration with the private sector is key; contracts with stakeholders, clearly define obligations; apps to deliver information to stakeholders	Facilitating B2B customers' business; platform for consumers

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Table 1 (cont.). Sustainable value of digitalization (digital twin) from different industries' perspectives

Key elements	Innovation Business Model through Industry 4.0 (Müller, 2019)	Innovation Business Model for DT in the energy sector (Giourka et al., 2019)	Sustainable Circular Business Model Innovation (Antikainen & Valkokari, 2016)
6. Key Activities	1. New activities that build upon data analysis; 2. Data analysis enables, e.g., optimization	Understand the process digital twin should support, joint public and private forces in a shared vision, ensure data quality, interoperability, understand data privacy, governance, data handling, long-term capacity	Technology and concept development; consulting
7. Key Resources	1. New or altered production equipment? 2. New competences; 3. Retraining of existing personnel	Time and data (from different sources) should come from all main actors involved	Business concept technologies, competences
8. Key Partners	1. New partners with IT or data expertise; 2. Competence from suppliers	Public: planning, politicians; private: entrepreneurs, business, citizens, academia, data providers	National recycling centers, logistics, technology, providers, municipality, waste companies
9. Cost structure	1. Large investments necessary; 2. Cost savings through increased productivity; 3. Reduced costs by automation of the process	Cost savings through automation in digital twins, smooth collaboration with stakeholders	The packing and the logistics; challenges with the workforce (motivation, skills)

Nevertheless, Malakuti et al. (2019) acknowledge that while various business models, such as guaranteed availability and pay-for-performance, have been discussed over the years, few have achieved commercial success. Typically, these models have devolved into leasing agreements, differing from traditional product sales primarily in asset ownership. A significant barrier has been the lack of continuous and dependable access to the device's properties and data. The proliferation of digital twins may alter this landscape.

Therefore, despite existing capabilities, the full potential of digital twins has not been fully realized. This is particularly true in the maritime domain, which remains relatively unexplored. Hence, the present study aims to fill in this research gap.

2. METHODOLOGY

The current body of literature has not sufficiently explained the progression of digitalization. At the same time, it found valuable insights that have shed light on business model elements (Table 2), specifically in the areas of value creation, proposition, delivery, and value capture. The study has embarked on empirical research with the goal of examining these alterations, paying special attention to their stakeholders' interactions, to gain a deeper understanding of the entire process.

Given the limited number of participants available for this study, a quantitative approach was feasible and was implemented through a structured questionnaire[1]. This qualitative research design was chosen to effectively explore and describe the structural changes in business models and the benefits of adopting digital practices in the form of digital twins. The methodology is particularly suited to investigating the intricate relationships among various stakeholders.

The survey targeted key stakeholders in the maritime industry of Northwestern Norway, a region noted for its innovation in advanced technologies. The respondents included professionals from four key maritime sectors: ship ownership, ship design, equipment provision, and shipyard management. This diverse group comprised individuals in senior, leadership, management, and specialized roles in digitalization.

The survey was conducted over two weeks, yielding 23 responses. Participants were prompted to offer detailed and thoughtful answers. To maintain respondent confidentiality, all collected data were anonymized. The survey questionnaire was meticulously crafted to gather both quantitative and qualitative insights. In research studies, two types of questions are typically employed:

1. Open-ended questions, which encourage participants to explore a topic freely, allowing

1 To access the questionnaire, please follow this link: https://nettskjema.no/a/digitaltwin

Table 2. Structure of business model framework

Value	Model	Key elements		Example
I. VALUE DELIVERY				
HOW do we deliver the value proposition?	**Operating Model:** Infrastructure	1. Key Stakeholders	Who are your key helpers?	Suppliers, co-financiers, and others to deliver a positive impact
		2. Key Activities	What do you do?	Process, development, and technology from a systemic point of view
		3. Key Resources	Who are you, and what kind of value do you possess?	Materials, human, financial, networks, infrastructure
II. VALUE CREATE				
WHO is at the center of each business model?	**Market Model:** Customer	4. Customer Segments	Who do you help?	Target groups who made use of the offering
		5. Channels	How do the customers know you, and how are the channels integrated with customer routines?	Touchpoints with customers, including a take-back system, for example
		6. Customer Relationships	How do you maintain contact with clients?	Relation between company and customer
III. VALUE PROPOSITION				
WHAT is offered to the client to meet their needs?	**Value Model:** Offer	7. Value Proposition	How do you help?	People: positive impact on the common interest of society. Planet: positive impact on the environment. Profit: Superior value for economic growth without negative impact.
IV. VALUE CAPTURE				
WHY do we use this business model?	**Revenue Model:** Finance	8. Cost structure	What kind of costs are existing in the business model?	For stakeholders in the system
		9. Revenue Streams	New income sources?	For stakeholders in the system

them to decide the level of detail and information they wish to provide. These questions prompt reasoned responses rather than one-word answers or brief phrases.

2. Closed questions, such as multiple-choice or rating-scale items, are favored in surveys due to their ease of response. They provide predetermined answer options, making it straightforward for respondents to choose from the provided selections. This format also facilitates the quantitative analysis of responses, common in survey-based research.

For this study, a combination of both approaches was chosen. While closed questions were used for their ease of statistical analysis, some of them allowed respondents to provide additional information through an open-text field. This approach aimed to enhance the respondent's experience while still enabling quantitative analysis.

To get an insight into how digital twins affect the business value and change the business model concept, the questionnaire consisted of several blocks:

- Section 1: Respondent information.
- Section 2: Adoption of digital twin.
- Section 3: Value creation opportunities.
- Section 4: Sustainable performance and optimization.
- Section 5: Data standards, interoperability, and security.
- Section 6: Future perspectives.

3. RESULTS

3.1. Respondent information

Based on the provided data for the respondents' roles in the maritime industry, one can observe the following distribution:

- Shipowners: 7 submissions, accounting for 30.4% of the total participants;

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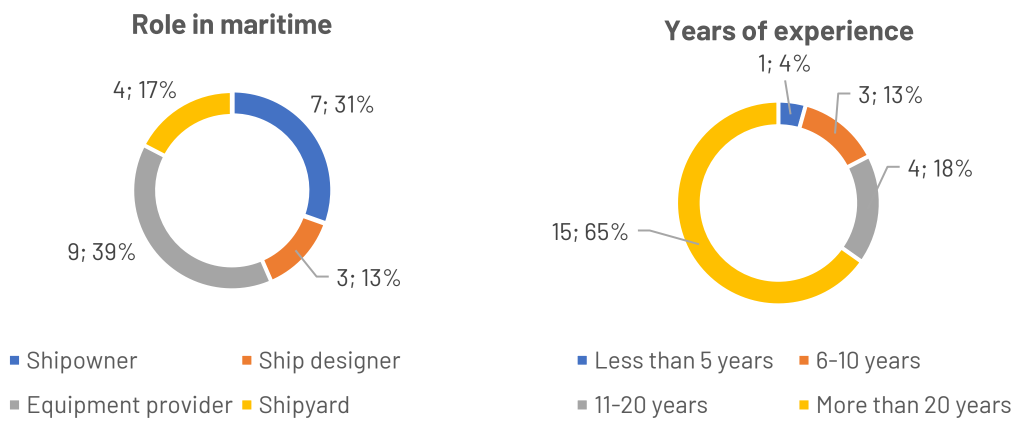

Figure 2. Respondent information

- Ship designers: 3 submissions, representing 13%;
- Equipment providers: 9 submissions, making up 39.1% of the total participants;
- Shipyards: 4 submissions, comprising 17.4% of the total participants.

The data show a significant representation of equipment providers, followed by shipowners and shipyards, with a smaller percentage. In addition, respondents were asked a question about their years of experience in the maritime industry; Figure 2 shows the breakdown of replies.

The data indicate that most respondents, 65.2%, have more than 20 years of experience, while smaller percentages of respondents have 11-20 years (17.4%) and 6-10 years (13%) of experience. A small percentage of respondents, 4.3%, have less than 5 years of experience.

3.2. Adoption of digital twin

The data indicate that most respondents, 39%, are very familiar with the concept of digital twins for maritime assets (Figure 3). Most respondents, 69.6%, consider implementing digital twins in their work. Next, Figure 4 shows the benefits or barriers anticipated when adopting digital twins.

The data suggest that predictive maintenance (16%), improved operational efficiency through real-time data analysis (17%), and design and engineering optimization (18%) will be the most beneficial for stakeholders due to the implementation of the digital twin platform. Regarding threats and barriers, it was indicated that a high implementation complexity (73.9%) and the integration

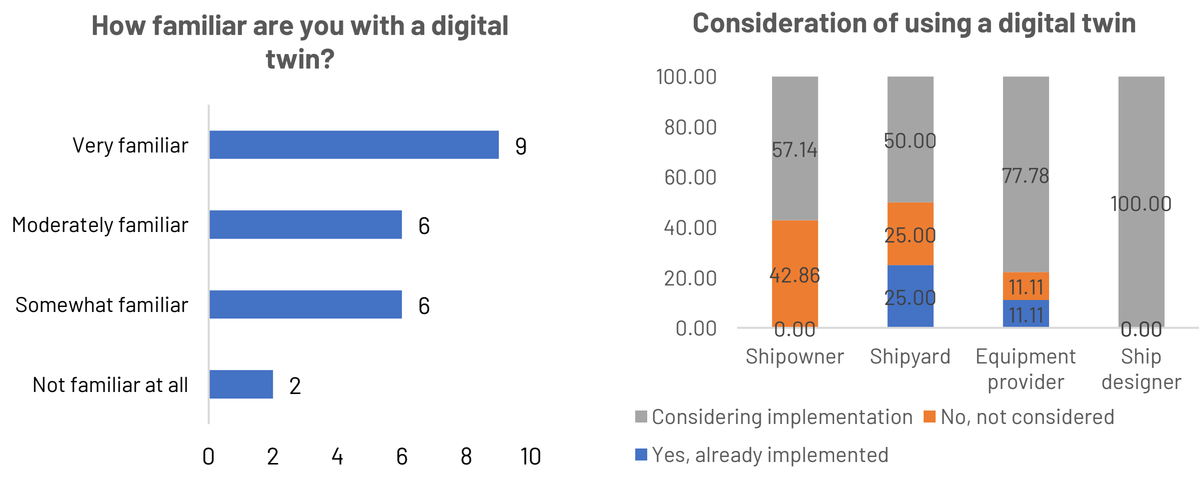

Figure 3. Adopting digital twins

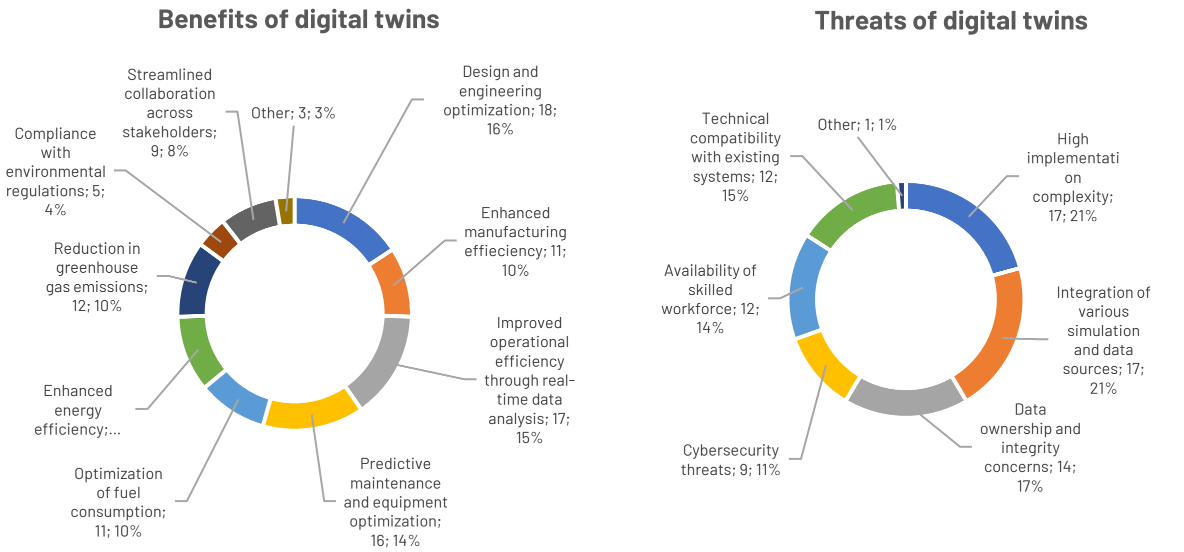

Figure 4. Anticipated key benefits and challenges of digital twins

of various simulation and data sources (73.9%) are considered the most significant challenges. Additionally, concerns about data ownership and integrity (60.9%), as well as the availability of a skilled workforce (52.2%) and technical compatibility with existing systems (52.2%), are also perceived as notable barriers.

3.3. Value creation opportunities

The majority of respondents stated that a developed platform can enable the generation of a revenue stream in the operational phase, demonstrating the value-added benefits for customers and enabling a more efficient value stream. Nevertheless, currently, companies see only increased costs and resource usage. A positive aspect could be strengthening relationships throughout the value chain by enhancing communication and collaboration between stakeholders. Additional information regarding business opportunities arising from digital twins is provided in Table 3.

Figure 5 shows that according to respondents' estimation, the majority of elements will have a moderate impact, including cost structure,

Table 3. Perspective of respondents' sustainable business models' innovation facilitated by digital twins

Key elements	Sustainable business model innovation for digital twins in the maritime sector
1. Customer Segments	New market opportunities beyond the maritime industry, e.g., marine, renewables
2. Value Proposition	New product – developed a platform, and as a result – servitization: energy efficiency, predicted maintenance, retrofitting, etc.
3. Revenue Streams	Generation of a revenue stream in the operational phase; The sharing and owning of data into the digital twin will be essential to enable a more efficient value stream
4. Channels	Enhanced communication and collaboration through open dialog and digital channels
5. Customer Relationships	Transparency and trust, sharing and ownership of data will lead to strengthened relationships throughout the value chain
6. Key Activities	Facilitate concurrent and updated communication, providing learning, experience harvesting, design optimization, and sharing to attract a broader customer base; Implement testing of new equipment or technical solutions in a virtual environment to improve the efficiency and effectiveness of critical activities
7. Key Resources	Efficient allocation of resources by the implementation of integrated digital twin technologies will enable it to stay competitive and responsive to industry demands
8. Key Partners	Flag state, port state, IMO – establishing partnerships that enhance compliance and meet industry standards
9. Cost Structure	Increase costs in the introduction state and big resource usage; Reduced costs by automation, integration, and decreased energy consumption

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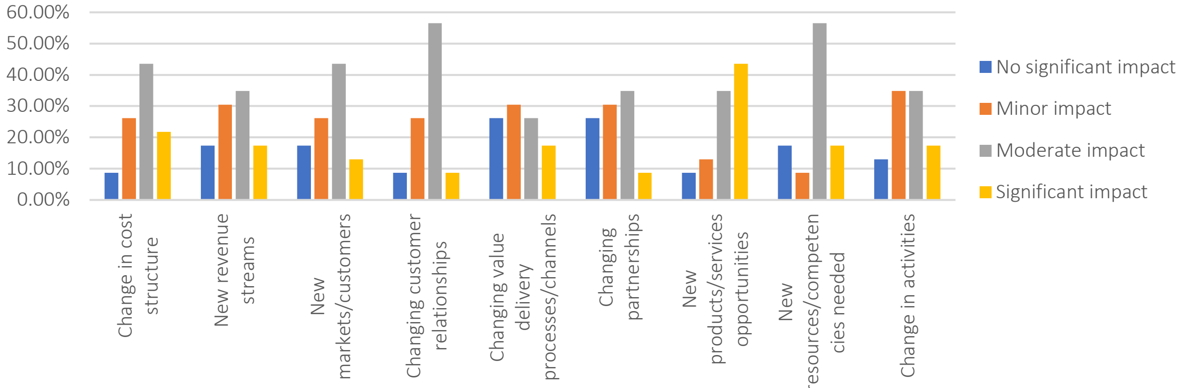

Figure 5. Potential business model structural changes due to the adoption of digital twin

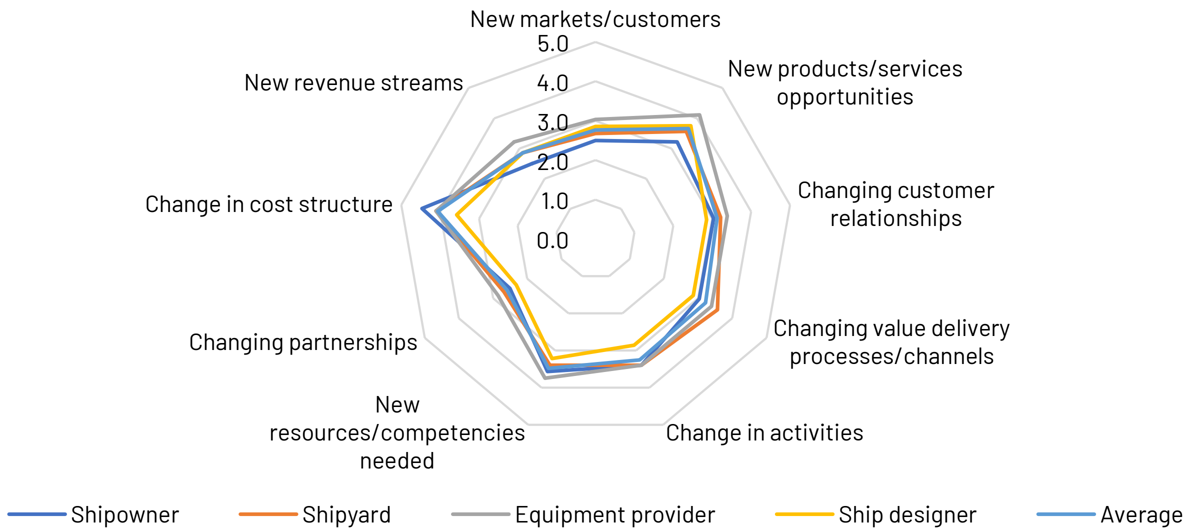

Figure 6. Potential business model structural changes (within the groups)

revenue streams, customer relationships, value delivery processes, partnerships, and the need for new resources and competencies. They highlight that new product opportunities will have a significant impact due to digital twins. Hence, new technology will give new ways to offer value. When it comes to the value delivery process, it will have a minor impact. Thus, according to respondents' beliefs, the infrastructure will have less transformation.

The same answers are presented within the groups of participants in Figure 6.

Furthermore, based on the data provided, the average rating of 5.78 and the median of 6 suggest that, on average, the respondents perceive that the integrated digital twin platform can moderately contribute to value creation at their companies.

3.4. Sustained performance and optimization

The data suggest that real-time performance monitoring and analysis (82.6%), as well as retrofitting opportunities (73.9%), are considered to have the most significant impact, followed by the optimization of the vessel's equipment through predictive maintenance (65.2%). Other aspects, such as enhanced fuel efficiency (52.2%), improved voyage planning (52.2%), and ensuring data integrity and security (26.1%), are also recognized as significant contributions to the digital twin platform (Figure 7).

According to the analysis, the average rating of 5.61 and the median of 6 suggest that, on average, the respondents perceive that the use of digital twins has the potential to moderately prolong the life cycle of existing vessels through retrofitting.

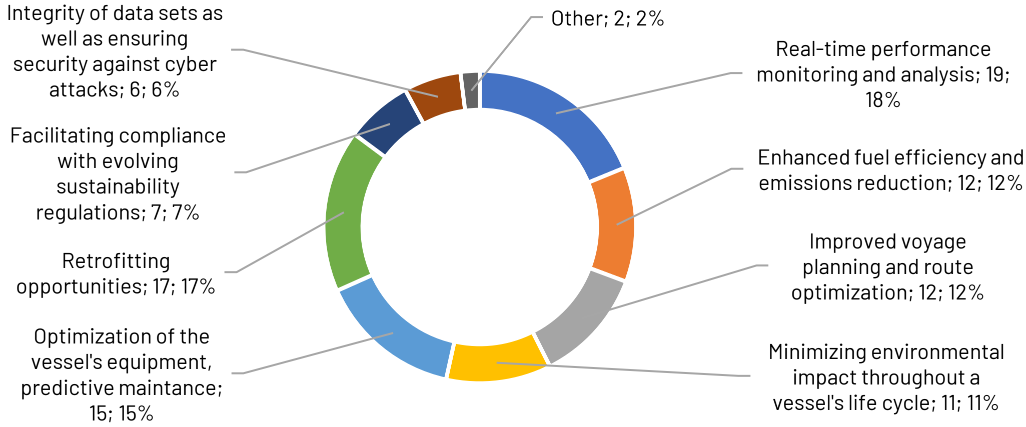

Figure 7. Contribution to sustained performance and optimization

3.5. Data standards, interoperability, and security

Figure 8 highlights the significance of protecting sensitive vessel data from unauthorized access (60.9%) and cybersecurity threats (65.2%), as well as protecting intellectual property associated with data (56.5%) and the importance of resolving data ownership disputes (52.2%). Additionally, maintaining data accuracy and consistency throughout the vessel's life cycle (47.8%) and ensuring compliance with data privacy regulations (30.4%) are significant concerns among the respondents.

Furthermore, the average rating of 7.65 and the median of 9 suggest that the respondents consider it critical to address data ownership, integrity, and security against cyber and physical threats in implementing digital twins.

3.6. Future perspectives

Figure 9 shows that the respondents believe the adoption of digital twins is likely to significantly strengthen collaboration and information sharing (69.6%) among stakeholders in the maritime industry's supply chain. Additionally, the data indicate that there is an expectation of increased transparency, traceability (47.8%), and real-time communication and data exchange (56.5%), fostering more integrated and sustainable supply chain practices (43.5%). However, fewer respondents anticipate streamlining procurement and logistics operations (26.1%) due to the adoption of digital twins.

4. DISCUSSION

The purpose of the study was to uncover how the business model changes as digitalization unfolds, and how to comprehend the complexities and in-

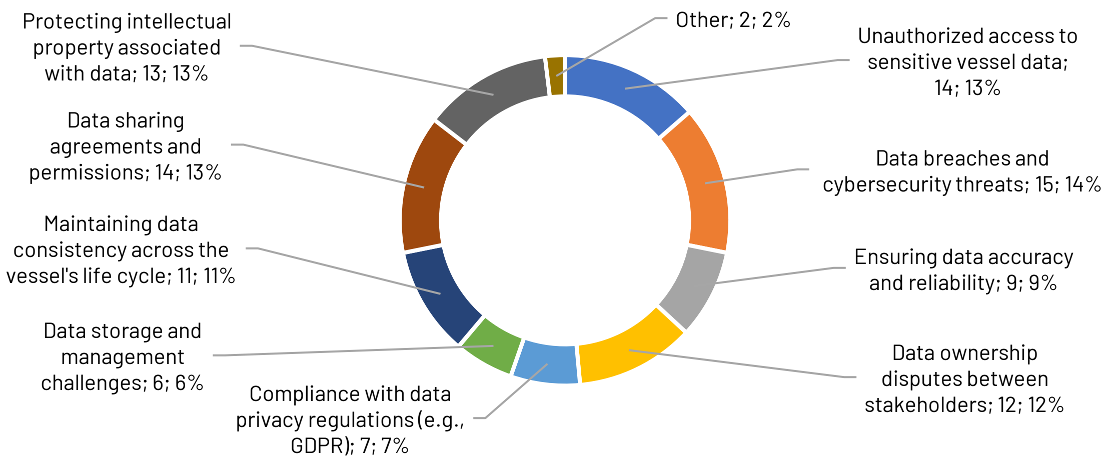

Figure 8. Data ownership and integrity concerns due to digital technology use

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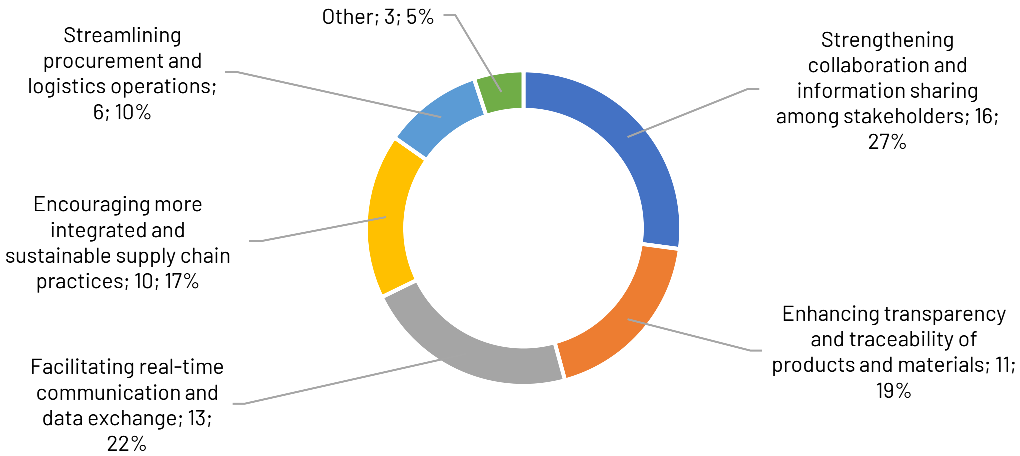

Figure 9. Supply chain impact and relationship changes due to the adoption of digital twins

terdependencies that arise along the trajectory of digitalization.

To accomplish this, it was decided to rely on insights from business model and servitization, digitalization literature. The study also revels the views of maritime stakeholders on ways the concept of digital twin can evolve and impact sustainable practices and value chains in the maritime industry over the next 5-10 years. Hence, the findings offer several contributions to the current literature and provide several observations.

Observation 1: Sustainability as a potential benefit of digital twins. All respondents agreed on the environmental benefits of digital twins: "It will be very important to reduce emissions from the maritime industry in the next 5-10 years, and digital twins can contribute here" (Designers); "The concept of digital twin will be very important to reduce emissions from the maritime industry of the next 5-10 years" (Shipowners); "Energy efficiency is important here" (Equipment suppliers). Nevertheless, it was found that there's a scarcity of initiatives promoting actions like retrofitting and strategic technology investments for a greener maritime industry, which digital twins could contribute here (Chávez et al., 2024).

Observation 2: Importance of the stakeholders' engagement. The stakeholder's engagement will be essential to enable increased value creation. For example, "When the shipowners see the various benefits with regards to saving money – the implementation will increase" (Equipment suppliers); "Digital twin will need to be completed by the shipyard as the designer are not able to complete it above a design and engineering level. The yard buys equipment and install it, they are the only one that can complete the model and assure that it is correct" (Ship designer); "Digital twin can be of big impact if it's done right in collaboration" (Shipyard). This is strongly in line with Giourka et al. (2019), where they highlight the value of negotiations between stakeholders. In addition, Chávez et al. (2024) argue that the lack of awareness and proactive engagement is a significant barrier to more collaborative efforts, alongside the need for clarity in roles, especially critical due to the numerous stakeholders in the maritime sector.

Observation 3: Complexity of supply chain and data privacy. The respondents indicated the same concerns regarding the ownership of data and cyber security, and data protection: "IP conflicts; leakage of company confidential information; competition conflicts – should be addressed" (Designer); "Implementation of digital twins needs huge investments, and there are concerns around "who will do, who will be responsible, who will be the end user, who will be willing to pay extra for it." The sharing between stakeholders and ownership of data into the digital twin will be essential to enable a more efficient value stream" (Designer); "Digital twins will realize the true potential of the ever-increasing complexity of the components we are manufacturing for the systems that are so vital to the wellbeing of man. Still, the maritime industry is very conservative and is not really data-driven in its design approach" (Equipment supplier). Thus, digital twins can bring benefits along the value chain. However, ambiguities in defining roles and responsibilities may impede the adoption of sustainability-focused changes. This complexity of the supply chains necessitates robust agreements on data privacy and security (Chávez et al., 2024).

Observation 4: New value opportunities – digital platforms. "New product – developed a platform, and as a result – servitization: energy efficiency, predicted maintenance, retrofitting, etc." For instance, firms are leveraging digital technologies to engage with clients, various partners, and ecosystem contributors via a digital platform framework. This approach enables the creation of tailored solutions through modular design, joint creation of digital service innovations, and the incorporation of digital modules and intelligent solutions (Chen, 2021).

Observation 5: Business models are needed. In general, ship owners are very uncertain how big the impact digital twin will have on the maritime industry: "It is still hard to say – it will be very fragmented." It has great potential, but respondents are unsure if models will be developed for existing vessels: "In new building projects, this is a must-have" (Shipowner); "If the stakeholders in the value chain will not find good enough business models to convince the customer, the implementation will take some time" (Equipment provider). Moreover, a value proposition is expected to be among the most affected elements of the business model, whereas channels are the least affected (Müller, 2019; Antikainen & Valkokari, 2016).

All above mentioned proves that new business models are needed, requiring thoughtfully crafted contracts and a willingness to explore new avenues of value capture amidst ongoing challenges.

CONCLUSION

Digital twins' opportunities and the potential for value creation in the maritime domain remain underexplored. Given the maritime industry's continued role in the global economy, there is an urgent call for more research and industrial evolution that embeds sustainability into the early phases of business model development. Therefore, this study aimed to bridge this gap and has been done with specific tools employed to map the potential value of digital twins in the maritime industry.

The methodology was presented as a survey questionnaire designed to collect quantitative and qualitative data. The target audience comprised professionals and organizations involved in ship owning, ship design, equipment provision, and shipyard operations.

The study highlights the anticipated advantages of digital twin solutions for the maritime industry, including predictive maintenance, operational efficiency enhancements, and design optimization. However, challenges such as implementation complexity and data integration exist. Survey participants foresee new product opportunities and value creation through digital twins, particularly in real-time monitoring and retrofitting for sustainability. The implementation of digital twins is expected to foster collaboration and information sharing among industry stakeholders, emphasizing its potential impact on the maritime sector's future. However, it was recognized that such collaborations can introduce complexity and create confusion, which can be addressed by robust agreements on data privacy and security.

The outlook on digital twins in the maritime industry over the next 5-10 years acknowledges the conservative nature of the sector as a potential impediment to widespread adoption. Nonetheless, there is a recognition of the substantial opportunities digital twins present in reducing emissions, boosting energy efficiency, and leveraging the intricacies of maritime systems to their full potential.

Hence, fusion between digital twins and services is promising, enabling new and enhanced services through the data provided by digital twins. The overarching goal is to support a realistic model of system behavior that can enhance established services like performance prediction and optimization while unlocking new potentialities in the everything-as-a-service paradigm. This synergy is a key area for further research and development, as it promises to push the boundaries of how services are offered and consumed.

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Formal analysis: Viktoriia Koilo.
Funding acquisition: Viktoriia Koilo.
Investigation: Viktoriia Koilo.
Methodology: Viktoriia Koilo.
Project administration: Viktoriia Koilo.
Resources: Viktoriia Koilo.
Software: Viktoriia Koilo.
Supervision: Viktoriia Koilo.
Validation: Viktoriia Koilo.
Visualization: Viktoriia Koilo.
Writing – original draft: Viktoriia Koilo.
Writing – review & editing: Viktoriia Koilo.

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