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VERIFICATION OF THE SYMBIOSIS OF ARTIFICIAL INTELLIGENCE AND NATURE-BASED SOLUTIONS AS A DEVELOPMENT PREMISE IN THE SHIPBUILDING INDUSTRY

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Abstract

The shipbuilding industry in Poland, Europe and the United States has been struggling in the 21st century with asymmetric competition from Asia. For several renowned shipyards – including those in Gdansk – identifying pathways for development and creating innovative solutions has become essential for survival. This article presents the dilemmas and research outcome that form part of the preparation for a project aimed at developing an innovative solution grounded in nature-based technologies supported by artificial intelligence. The project on efficient water management for planned production processes in the shipyard constitutes one component of the broader EcoTech initiative, which addresses a wider set of developmental needs of the shipbuilding sector, particularly in Gdansk. This article tackles the challenge of holistically identifying the wide spectrum of developmental conditions as well as the methodological responsibility guiding research and development activities intended to generate breakthrough solutions with business significance.

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Introduction

The shipbuilding industry has a rich and romantic history – both in ancient and modern times, including Poland. For centuries, it has been oriented toward long maritime journeys, whether for exploration or discovery. It has always constituted an important area of political and practical activity, forming a significant part of the economy at local, national, regional and global scales. The maritime economy has always played a crucial role, although its directions and goals have varied depending on the stage of civilization and the region of the world.

The maritime economy can be simplified – as a relationship between the supply and demand for floating units (mainly ships, vessels and boats). The supply of floating units can be understood as the core potential of the shipbuilding industry. Revolutionary geopolitical changes in the supply of such vessels over the last three decades of the twentieth century led to a significant decline in production in prestigious European and American shipyards in favor of the rapidly developing Asian ones, mainly Chinese[1] and South Korean. The essence of these changes lay in extensive government subsidies for shipbuilding, aimed at absorbing the knowledge and experience of former leaders and harnessing new technological capabilities.

The lack of "vigilance" among European and American politicians has led to an approximately fifty-year decline characterized by "asymmetric competition" – that is, on one hand, a significant reduction in the prices of floating units accompanied by a substantial decrease in their quality, and on the other, the liquidation or stagnation of the pioneers and mature leaders of the shipbuilding industry. The rules of the market are harsh, and demand as well as the location of production orders are determined primarily by price, while the low quality of vessels becomes apparent only over a longer period of operation. Understanding the specifics of the shipbuilding industry is extremely difficult not only for politicians but also for shipyard managers, who should undoubtedly combine knowledge of the global reality with macro- and microeconomic phenomena, engineering, and new – including digital – technologies.

In light of the above synthesis of the maritime economy's condition, the aim of this article is to gain insight into a holistic synthesis of the essence of the global shipbuilding industry at the turn of the 20th and 21st centuries, as well as its future prospects in the context of opportunities to overcome global, regional, national and local challenges – illustrated by the example of one of the Polish shipyards. The article attempts to verify the rationality of selected assumptions of the R&D project EcoTech by posing the following main research questions:

[1] China is the world's largest producer of ships, which, for example, in 2024 were responsible for approximately 51 percent of all new deliveries by tonnage (Landowski 2025b).

1. Is it possible to foresee and create another "revolution" in the shipbuilding industry?
2. Will the symbiosis of artificial intelligence and nature be sufficient to achieve a breakthrough in the shipbuilding industry?

The detailed research questions formulated by the authors will be presented along with the methodological and instrumental aspects.

Material, methods and tools

Methodology and definitions

The authors assume that the broadly understood maritime economy comprises three main sectors: maritime industries, maritime services and supporting infrastructure. The maritime industries include: sea, inland and coastal shipping; ship production and repair yards; sea and inland ports; dredging and regulatory works; suppliers and subcontractors to the maritime industries; the navy; sports, tourism and sailing; fisheries and fish processing; extractive industries (ANTONOWICZ et al. 2007). Accordingly, enterprises such as shipyards and the shipbuilding industry constitute an essential part of the maritime economy – one that has been, both historically and today, a key driver of global, regional and local development, particularly within the European Union, the Baltic Sea region and Poland (SALA , TAŃSKA 2018; *The Integrated Maritime Policy of the European Union* 2007; *Maritime Policy of the Republic of Poland* 2015), as well as the synthetic assessments of the European shipbuilding industry's condition (KARAŚKIEWICZ 2025; *SHIP FORUM* 2025a, 2025b).

Both this article and the verified main assumptions of the EcoTech project were developed using an interdisciplinary proprietary methodology dedicated specifically to them (TAŃSKA 2018, SALA, TAŃSKA 2019, 2023). Increasingly, renowned academic authorities advocate for interdisciplinary approaches. One particularly inspiring and compelling proponent of such an approach is the distinguished economist Professor Grzegorz W. Kołodko, well known in Poland and internationally, who uses the metaphor of the "wandering world" (KOŁODKO 2008). Consequently, an economist of such high standing de-emphasizes the significance of economics as the sole of primary foundation for decisions concerning socio-economic development. The rationale for the interdisciplinary proprietary methodology dedicated to the developmental enhancement of the Gdansk Shipyard can be found, among other sources, in more than 400 pages of the aforementioned publication. A particularly inspiring section is Chapter IX, titled "*The Coincidence Theory of Development and the New Pragmatism*", which supports resolving doubts such as: "What determines production growth and economic development, and what should be done to make things better?".

It is precisely pragmatism and the coincidence theory of development that provide a positive verification of the usefulness of continuously comparing achieved results at several stages and according to multiple comparative criteria (in steps 3, 5, 7, 8 and 9 of the methodology illustrated in Fig. 1).

Due to the limited length of this article, the authors cannot provide a detailed justification of their proprietary methodology. However, they wish to emphasize that it is by no means a heretical approach, as it incorporates not only the achievements of economic sciences but also those of other suggested and essential disciplines such as project management, ship design and construction technology, welding, production automation and robotics, environmental engineering, non-destructive testing, statistics, econometrics and computer science. Nevertheless, the authors refer to the aforementioned publication, as – in line with the intention of its distinguished author – well-formulated questions are often more valuable than lengthy answers or discussions. A synthetic diagram of the methodology is presented in Figure 1.

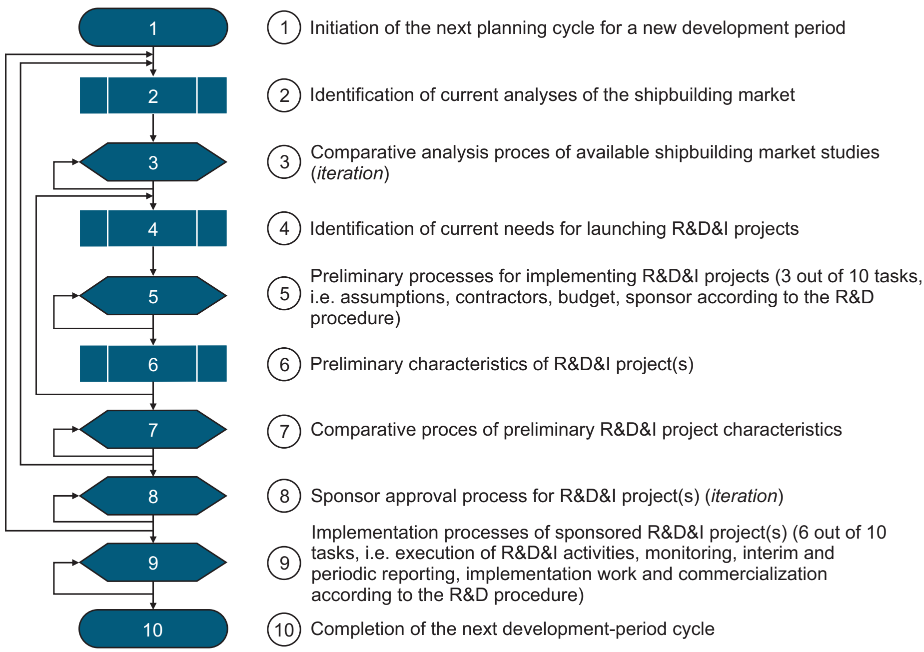

Fig. 1. Diagram of the interdisciplinary methodology dedicated to the developmental enhancement of the shipyard
Source: own elaboration.

The selected assumptions of the EcoTech project that are currently being verified are situated at the eighth step of this methodological cycle[2] (steps 1 through 7, as shown in Fig. 1 have already been completed). This article represents an attempt to provide a comprehensive report on the research and preparatory process conducted thus far, as well as to outline the groundwork for its continuation (within steps 8 to 10 of the methodology illustrated in Fig. 1). In the case of the EcoTech project, the preparations for obtaining sponsors (step 8 of the methodology in Fig. 1) are primarily directed toward the National Centre of Research and Development (NCBR), but also toward the Ministry of Science (MNiSW), the Industrial Development Agency (ARP) and the Management Board of Baltic Operator (BO), representing the Gdańsk Shipyard.

The methodological foundation of this article (covering steps 1, 2 and 3 of the methodology shown in Fig. 1) is based on an analysis of both the authors' own research and publication results, as well as those produced by recognized centers of expertise on the global, regional and Polish shipbuilding markets. These include international teams such as Market Research Future (MRFR), as well as Polish academic and business communities integrated around the Ship Forum and the Institute for Market Economics Research (IBnGR) in Gdansk. The comparative process was carried out in eight iterations – comprising five international reports, two national reports and a final summary iteration (step 3 of the methodology shown in Fig. 1).

The interdisciplinary nature of the methodology for the developmental enhancement of the shipbuilding industry requires extensive specialized knowledge and the collection of numerous studies and publications. In this article, only those most relevant to its content are highlighted (not all of the sources used in formulating the assumptions of the EcoTech project during steps 4, 5 and 6 of the methodology shown in Fig. 1). Among the international sources of knowledge, particularly valuable were the publications of TWI[3] – one of the world's leading research and technology organizations – as well as contributions from Polish academic institutions, including Gdańsk University of Technology and the maritime universities in Gdynia and Szczecin. TWI (The Welding Institute) is globally recognized research and technology organization established in 1946 in Cambridge, United Kingdom[4].

[2] Arrangements with the EcoTech project sponsors are planned for March, April and May 2026 as part of step 8 of the methodology in Figure 1, and the start of step 9 is planned from September 2026.

[3] TWI's technical knowledge is available in the digital library in various forms, including papers from welding symposia, reports on industrial members, e-books, professional materials on welding processes, corrosion and testing, articles from journals and conferences, newsletters, cf. Technical knowledge – Engineering and Materials Joining Library – TWI, https://twi-global.com/technical-knowledge

[4] Source: Portal TWI, https://www.twi-global.com, the Welding Institute was formed in London on 5 February 1923, Evolution of The Institute, https://theweldinginstitute.com/about-us/history

Of significant operational importance is the fact that steps 4–9 of the methodology shown in Figure 1 are partially regulated through a formal procedure. The purpose of this procedure is to define the principles of BO developmental improvement through innovative activities and the conduct of research and development (R&D) work aimed at ensuring BO's competitiveness in the market. Its scope covers all employees and organizational units of BO, as well as consortium partners, subcontractors, suppliers and clients. The procedure concerns the implementation of innovations that optimize production processes – requiring effective, long-term action and substantial dedicated financial investment. It identifies task-oriented processes corresponding to the methodology and serves to inspire shipyard employees to undertake innovation initiatives. The procedure plays an undeniable motivational role for employees and provides strong support to the small R&D team, significantly enhancing the company's improvement potential and fostering a sense of shared responsibility among employees for increasing market competitiveness.

It appears that the main methodological aspects of a single planning cycle for a new developmental period of the exemplary Gdańsk Shipyard, starting from either 2010 or 2018, have been sufficiently indicated. The duration of a single cycle varies situationally, ranging from 2 to 8 years. To date, the methodology has been verified across 10 cycles. In 2025, four cycles are running concurrently, each at a different stage of implementation, while the remaining cycles have either been completed or put on hold. The temporal, substantive and budgetary relationships between the development cycles 1, 2, 3 and 4 ongoing in 2025 are shown in Figure 2, where the size of the shape represents the budget magnitude. The methodological cycle directly related to the EcoTech project is cycle 4, which, in a small part, continues the cycle no. 1 sponsored by NCBR (2020–2023) concerning the processing of ultrasonic images (Janiszewski et al. 2024).

Further clarification is also required for development cycle no. 2, which is sponsored by the Ministry of Science and Higher Education (MNiSW) under the "Implementation Doctorate" program. The tasks and results of this cycle will entirely enrich the outcomes of development cycle no. 4, particularly in the area of efficient water resource management in shipment production processes.

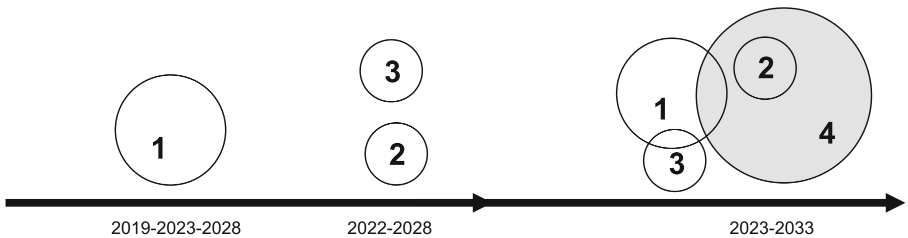

Fig. 2. Temporal and situational characteristics of planned and ongoing methodological development cycles at BO
Source: own elaboration.

As a result of identifying the needs of the exemplary Gdańsk Shipyard (step 4 of the methodology shown in Fig. 1), the authors concluded that the key concepts and definitions for the article should include economic development, the maritime economy – previously highlighted – and sustainable development. Consequently, one cannot disregard the knowledge of economic theory, particularly the essence of the market and its mechanisms, since "it is a system of interdependent transactions of buying and selling goods" (WNOROWSKI 2007). It should be emphasized that the shipbuilding market mechanism is highly complex and developing a model and conducting an analysis of the shipbuilding market is a very labor-intensive undertaking requiring deep industry specialization (STIGLITZ 2004). This includes, above all, the proper identification of demand and supply (demand over time, quantity offered over time) and equilibrium prices (including maximum and minimum price), as well as knowledge of natural and artificial barriers to entry (the large capital required to initiate production). On the global shipbuilding market, the theoretical notion of "perfect competition" does not exist, as there are not many buyers and sellers, and the product is not homogeneous (there are many market segments). Simplifying, one can note the occurrence of multi-facility monopolies, although features of an oligopoly are also present – that is, only a few shipyards operate globally, making interdependence among competitors the main market characteristic. This is reflected in agreements such as cartels (legal and open) and collusions (illegal and secret). Against this backdrop of international competition, the article details the specificity of Polish historical, political, economic and developmental conditions (section "Polish development conditions"). To search for developmental premises in the maritime economy, particularly in the shipbuilding industry, it is essential to utilize reports analyzing and forecasting the global shipbuilding market (section "Workshop and tool aspects") and to maintain awareness of the significance of public sector economics, especially as interpreted by Nobel laureate STIGLITZ (2004).

The idea of a long-term socio-economic progress is grounded in sustainable development, which assumes meeting the needs of the present generation while simultaneously preserving resources and developmental opportunities for future generations. This concept entails the integration of three key areas – economic, social and environmental (*WCOED* 1987). In the legal and strategic frameworks of both the European Union and Poland, sustainable development constitutes one of the fundamental goals of development and social policy, supported by treaty regulations (*TUE* 2012) and constitutional provisions (*The Constitution of the Republic of Poland* 1997). This idea is reflected in detail in global Agenda 2030, which includes 17 Sustainable Development Goals (SDGs) serving as a universal framework for action for the United Nations member states (*ONZ* 2015), as well as in EU development strategies (*EC* 2001), which emphasize the necessity of integrating economic objectives, environmental protection and social development.

Polish development conditions

Historical, political and economic conditions

This article focuses on the 20th and 21st centuries from a Polish perspective on the construction of water transport means. Nevertheless, is should be emphasized that since the times of the biblical Noah's Ark and Greek myths, this has always been hard, dirty and difficult work – capital-intensive and time-consuming – since the vessels being built were usually of large dimensions, and this remains true to this day. In the case of the period of the Second Polish Republic, which reappeared on the political map in 1918, it is worth nothing the romantic effort of Władysław Grabski and Eugeniusz Kwiatkowski (who served as prime minister, deputy prime minister, minister of the treasury and minister of industry and trade), as well as the Polish society, in the creation of a maritime economy through, among other things, the construction of Gdynia with its port and shipyard, complementing the potential of the port and shipyard in Gdansk, which had been operating since 1884.

In Poland, in the 20th century after the World War II, the potential of these shipyards was strengthened by the establishment of the shipyard in Szczecin and several smaller ones. As a result, Poland became a major power in the shipbuilding industry and this success was made possible by the enormous global demand for ships, many of which had been destroyed during the World War II. Unfortunately, the prosperity of the Polish shipbuilding industry was "crippled" first by the political isolation and centrally planned economy of the bloc of states under Soviet domination, and later by the systematic transformation of the 1980s and 1990s. In the 21st century, after Poland's accession to the European Union in 2005, the development of Polish shipyards was hindered for many reasons, including both fair and unfair[5] European and global competition. Simplifying the political and economic reality, it can be concluded that the shipyards in Szczecin, Gdynia and Gdansk were effectively "liquidated" in 2010, despite having full order books.

Confirmation of the pursuit to liquidate the shipbuilding industry serving maritime transport in Poland was the Strategy… until 2020 (with a perspective until 2030) (*The Maritime Transport in Poland was the Strategy…*, 2020) and its continuation from 2019, although the Plan for Responsible Development… (*Plan for Responsible Development…*, 2016) assumed otherwise. According to the document Report on the Implementation of Maritime Policy (*Report on the Implementation of Maritime Policy* 2024), the Gdańsk Shipyard and its representative company, Baltic Operator, no longer existed according to the

[5] a.o. the EU created a direction for controlling the internal competitiveness of the shipbuilding industry and Polish shipyards fell victim to the unfair protection of German and French shipyards.

condition of the shipbuilding industry in 2023. Synthetic conclusions regarding the past and future of the Polish shipbuilding industry are presented in the Polish Central Statistical Office (GUS) study Maritime Economy… (*Report on the Implementation of Maritime Policy* 2024), particularly in Figure 3, which depicts the Polish maritime transport fleet: “at the end of 2023, the maritime transport fleet comprised 88 ships (the same number as in the previous year) owned or co-owned by Polish shipowners and operators” (p. 3).

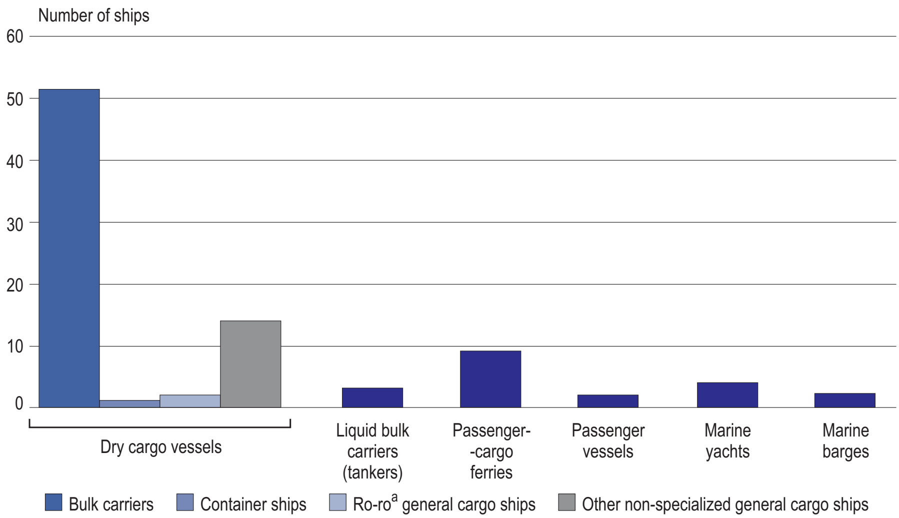

Fig. 3. Polish maritime transport fleet in 2023. As of December 31
Source: Maritime economy in Poland in 2023–2024.
Polish Central Statistical Office (*GUS* 2024), p. 3.

The Polish Central Statistical Office (GUS) commentary under Figure 3 reads as follows: “At the end of 2023, ships under the Polish flag accounted for 15,9% of the total number of vessels in the maritime transport fleet (…). The average age of a ship in the maritime transport fleet was 20.0 years (for ships sailing under the Polish flag – 42.9 years, while for ships sailing under a foreign flag – 15.6 years)” (p. 3). Furthermore, regarding the shipbuilding industry, GUS adds two sentences: “Over the year, the order book decreased. At the end of 2023, it included 5 ships (compared to 8 ships in the previous year). In 2023, 458 vessels were repaired in Polish shipyards… (in the previous year – 571 vessels)” (p. 5). The above date clearly indicate the very poor condition of this part of the maritime economy, resulting from past mistakes, and highlight the major challenge facing the future of the Polish shipbuilding industry and the Polish maritime transport fleet.

The balance of Polish R&D experience

The shock experienced by many thousands of unemployed shipyard workers resulted in a renewed determination, emerging in 2015, to reclaim the lost legacy of Poland's shipbuilding industry. Innovative development projects at the Gdańsk Shipyard had already been implemented during the difficult years of economic transformation – for example, the EUROSTER project (2004–2007). Between 2010 and 2015, the focus of these projects shifted toward innovative tools and qualifications in the shipbuilding industry (such as the project Path to Professional Excellence), including the introduction of flexible employment tools. In 2016, operational continuity was ensured through an initiative of product diversification into the field of wind energy. In 2018, a Research and Development (R&D) Department was established at the Gdańsk Shipyard, represented by the Baltic Operator (BO) company. Since then, numerous project concepts have been developed, encompassing product and/or process innovations, including: a floating crane with hybrid propulsion, a Ro-Ro vessel with and energy recovery system, an LNG bunkering unit, a digital ship designed according to the digital twin concept, the Shipyard 4.0 initiative and advanced ultrasonic testing of welded joints using the Phased Array method (solution design: 2019–2023, prototype implementation: 2023–2028). Among several initiatives, in 2022 the preparatory phase began for the EcoTech R&D project, which is the subject of this paper. The project integrates ecology, artificial intelligence and shipyard construction technologies for large-scale steel structures, marking a significant step toward the modernization and sustainable transformation of Poland's shipbuilding sector.

During this period, similar self-preserving and development-oriented activities were undertaken by teams associated with other Polish shipyards that had been subject to "liquidation". These groups, combining industry practitioners and academic communities, identified themselves with the legacy of the major former shipyards in Gdynia (the CRIST project) and Szczecin (the autonomous ship project). A particularly interesting and effective development strategy, modeled after the Chinese approach, was adopted by the repair shipyard, which expanded its capabilities beyond repair services to include the construction of new vessels. This represented a tremendous engineering and financial effort for a private enterprise, however, its successes were reinforced by its efficiency in securing production orders and by its broadly defined technical and managerial know-how.

A constant dilemma for the aforementioned R&D and innovation initiatives has been, and continues to be, the financing of their implementation – whether through co-financing or self-financing. This challenge necessitates a global business analysis, and in particular, a market analysis. Since 2020, market analyses have been highly optimistic, suggesting that it is worthwhile to focus on pro-development activities. Nevertheless, the expectations of potential sponsors are often irrational, and it is precisely in such terms that one can view pro-ecological directions in energy and material-intensive industries, such as large-scale steel structures in shipbuilding. It is very difficult to reconcile the costs of ecological solutions with their economic profitability, however, the strategic directions of the European Union require that these issues be seriously addressed. Hence, there has arisen a need to verify the rationality and usefulness of integrating pro-ecological technologies with other industrial technologies – in particular, with artificial intelligence technologies – a task undertaken in the present article.

Workshop and tool aspects

Business condition analysis

In 2016, a strategy for rebuilding the shipbuilding industry potential was published in Poland[6], as was the case in Great Britain[7] and India in 2023 and in the USA in 2025. It is worth posing two key research questions that complement the two main questions introduced earlier in the article:

3. Do costly R&D activities make sense in shipyards that are continuously struggling with numerous challenges (regardless of whether they are located in the USA, Europe or Poland)?

4. What is the business (market) rationale behind the renewed efforts to rebuild and develop the shipbuilding industry?

The search for a rationale that addresses the fourth research question has been undertaken by several renowned analytical centers. Among them, it is worth highlighting the methodologically credible studies conducted by Market Research Future (MRFR). MRFR is a global research company that prides itself on providing comprehensive and reliable analyses of diverse markets and

[6] Among the 6 strategic projects was the project: "Modern products of the shipbuilding industry – providing the legal, organizational and financial framework necessary for the activation of the shipbuilding industry, the development of scientific research and development centers developing innovative types of ships", and among the flagship projects: "Batory project – stimulating the development of technology, design and construction of Polish vessels and marine structures, shifting the shipbuilding sector towards the production innovative products and specialized units with high added value" in: Plan for responsible development, *Plan for Responsible Development*, 2016, p. 77-78.

[7] The UK government announced the launch of a new Shipbuilding Credit Guarantee Scheme (SCGS) in July 2023. The scheme aims to provide customers with access to finance to modify their existing vessels or acquire UK-built boats, with the government acting as a guarantee for lenders. According to the UK Department for Business and Trade, the scheme will support the creation of hundreds of jobs in the country and inject several million pounds into the economy due to the need for commercial shipbuilding. The scheme also aligns with the government's £4 billion ambition to support British shipbuilding as part of the Refreshed National Shipbuilding Strategy announced in 2024, https://www.marketresearchfuture.com/reports/shipbuilding-market/toc.

consumers worldwide[8]. In 2023–2024, MRFR prepared a report (*The Global Shipbuilding Market. Market…*, 2024) on the global shipbuilding industry for the years 2024–2030. At the same time, other reports on the topic were published with more or less comparable findings, including those by Global Growth Insights (*Shipbuilding Market Size & Forecast…*, 2025), Business Research INSIGHTS (*Shipbuilding Market Size, Analysis, Trends…*, 2025), Statista (*Shipbuilding Industry Worldwide…*, 2025), Mordor Intelligence (*Shipbuilding Market Size & Share Analysis…*, 2025), Data Bridge (*The Global Shipbuilding Market Size, Share…*, 2025) and others. The full versions of these analytical and forecasting reports on the global shipbuilding market are commercial in nature, with prices starting at around 5,000 USD, which precludes detailed comparisons of methodologies, source data values and result credibility. Based on a review of partially published materials from the global shipbuilding market, it can be indicated that "the value of the shipbuilding market in 2023 was estimated at 155,91 billion USD. It is projected that the shipbuilding market will grow from 160,13 billion USD in 2024 to 197,94 billion USD by 2030, exhibiting a compound annual growth rate (CAGR) of 2,67% during the forecast period (2024–2030)." One example confirming the growing demand for the shipbuilding industry is the ongoing discussion in the United States[9] (LANDOWSKI 2025a). The results of the MRFR study are summarized in Figure 4.

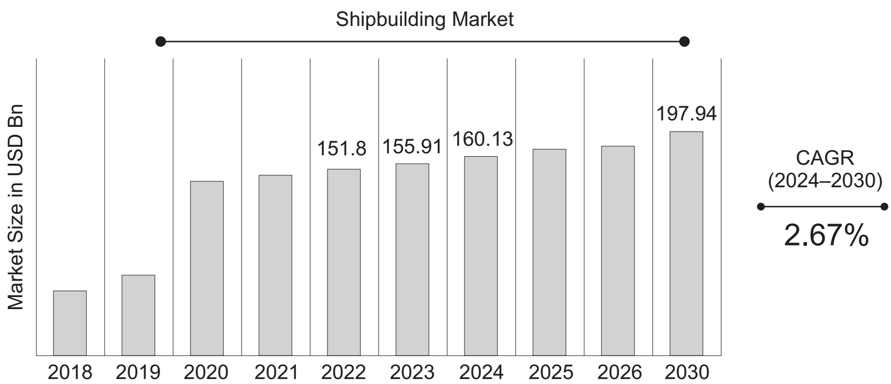

Fig. 4. Synthetic MRFR research results
Source: The Global Shipbuilding Market. Market Analysis (2019–2032) 2024.

[8] About the MRFR research company. Source: https://www.marketresearchfuture.com/about-us

[9] In the United States, plans are being discussed, a.o. to expand the US Navy's strike ship fleet. The fleet's potential is 295 such vessels in 2025 and by 2027, it will decline to 283 units due to planned decommissioning. The US Navy's plans to maintain a strength of 280 vessels by 2050 require annual expenditures of over $40 billion for 30 years, according to estimates from the US Congressional Budget Office. This example illustrates the civilizational challenge of balancing security needs with the capabilities of the shipbuilding industry for every country, regardless of wealth (LANDOWSKI 2025a).

In view of the above, there is a justified need to verify even the most questionable and controversial developmental, instrumental and methodological aspects of rebuilding the shipbuilding industry. The paradigm of interdisciplinarity requires directing research efforts toward the symbiosis of various fields of knowledge, experiences and skills. On the one hand, it is worth noting that symbiosis in an important phenomenon in nature, allowing organisms to better adapt to their environment and increase their chances of survival – a concept formulated in the second half of the 19th century. The Polish Language Dictionary (*The Polish Language…*, 2025) provides a concise definition of this phenomenon as "the coexistence of two different species, beneficial to one or both parties." The dictionary also notes two additional meanings of symbiosis, namely:

- "the coexistence of phenomena or individuals that mutually influence one another",
- "the coexistence within a given area of two or more cultures that functionally complement each other" (so called social symbiosis)[10].

In the context of the research, business and political questions posed, it is crucial to seek adaptive approaches to the global environment of the shipbuilding industry – approaches that enhance its chances of survival through a complementary symbiosis of shipyards, phenomena, cultures, tools, technologies and methods. Undoubtedly, it is important that all parties involved in the developed solutions benefit from the symbiosis, whether it is obligatory (necessary for survival) or facultative (not essential but advantageous). These premises have been incorporated into the EcoTech project, in which key issues of symbiosis include the interaction between nature-based technologies and artificial intelligence technologies.

Nature-based technologies

Nature-based solutions (NBS) are an approach that integrates natural ecological processes with special planning, climate change adaptation and environmental management. According to the definition of the International Union for Conservation of Nature (UCSN), NBS are actions involving the protection, sustainable management and restoration of ecosystems to address key environmental and social challenges (COHEN-SHACHAM et al. 2016). Examples of NBS technologies include green roofs, rain gardens, floodplains, bioretention swales, urban retention, air quality improvement, wastewater treatment and mitigation of the urban heat island effect (EGGERMONT et al. 2015).

In relation to heavy industry, particularly the shipbuilding sector, NBS can play a key role in two areas: the reclamation of post-industrial sites and supporting

[10] *The Polish Language Dictionary* 2025.

the ecological transformation of operational facilities. Industrial areas degraded by shipyard activities – such as former waterfronts, docks or production halls are often burdened with soil and groundwater contamination and a loss of ecological continuity (KEESSTRA et al. 2018). The application of nature-based solutions, for example through the creation of retention ecosystems, green recreational zones or natural flood barriers, enables effective revitalization and reiteration of these areas into the urban fabric (PINEDA-PINTO et al. 2022). In actively operating shipyards and ports, NBS can support climate change adaptation – for instance, by implementing green buffers that reduce flood risk, improve the microclimate around industrial facilities and limit the runoff of polluted rainwater into marine ecosystems (ZÖLCH et al. 2017). This approach is reflected in the practices of port cities such as Rotterdam and Turku, where NBS have become integral to sustainable industrial development strategies. In Rotterdam (Netherlands), the "Rotterdam Climate Proof" program implements nature-based solutions as part of the city's climate adaptation strategy – including green roofs, water storage spaces and green infrastructure in coastal areas (*Oppla* 2024). Similarly, in Turku, Finland, under the RESIST project, pilot initiatives are planned to modernize drainage systems using wetlands and stream restoration to enhance stormwater retention and resilience to extreme weather phenomena (*RESIST Project – Turku, Projekt Horizon Europe* 2023).

AI technologies

The development of artificial intelligence (AI) technologies is fundamentally rooted in information theory – both quantitative and qualitative – as discussed by, among others, BRILLOUIN (1956), MAZUR (1970), WĘDROWSKA (2010), as well as in cybernetics as explored by SALA and TAŃSKA (2022), not to mention its strong mathematical foundations. A review of AI definitions is a significant and continuously undertaken endeavor by various authors. However, from a pragmatic standpoint, a particularly influential work is that of RUSSELL and NORVIG (2010), who systematized definitions of AI – dating back to the 1970s – according to two dimensions: processes (thinking and acting) and contexts (performance and rationality). The interpretations of the terms and definitions used in this article are widely recognized and consistent with key reference documents, including *Artificial Intelligence for Europe* (2018), Scoping the OECD…, (*OECD* 2019) and resolution of the Council of Ministers of the Polish government (*Uchwała nr 196 Rady Ministrów…*, 2021).

Undoubtedly, the Polish economy, and particularly the maritime industry, continues to struggle with overcoming technological delays – including those related to artificial intelligence – as noted by SALA and TAŃSKA (2024). In this context, the establishment of a clear legislative framework through the "Policy for the development of artificial intelligence in Poland from 2020" (*Uchwała nr 196 Rady Ministrów…*, 2021) appears both justified and necessary. Among the six key areas for which goals and tools for AI development have been defined, one of particular relevance is "AI and Innovative Companies". This area focuses on actions aimed at supporting Polish AI enterprises and creating mechanisms for financing their growth. Among the short-term objectives (to be achieved by 2023), one notable goal (goal 3) is the "increase in the number of Polish state-owned companies implementing AI projects". The associated implementation tools would represent a significant support measure for the shipbuilding industry, especially for the Gdańsk Shipyard (*Uchwała nr 196 Rady Ministrów…*, 2021, p. 36). Similarly, the policy outlines medium-term goals (by 2027) and long-term objectives, which are equally noteworthy in the context of industrial modernization and innovation. It is also important to emphasize that this national development initiative adopted the internationally recognized OECD definition of an AI system, describing it as a system based on "the concept of a machine that influence the environment by formulating recommendations, predictions or decisions for a given set of objectives. It does so by using input data, whether machine-generated or human-provided, to:

- perceive real or virtual environments,
- abstract such perceptions into models, either manually or automatically,
- use model interpretations to formulate options for outcomes.

In the framework, an artificial intelligence system consists of three main components:

- sensors,
- operational logic (algorithmic models),
- actuators (executive mechanism)" (*Uchwała nr 196 Rady Ministrów…*, 2021).

In an AI system, the role of sensors is to collect raw data from the environment, while the role of actuators is to take actions that change the state of the environment. At the core of the AI system lies the operational logic – that is, the algorithmic models – which, for specified objectives, process input data received from sensors to generate recommendations, predictions or decisions that guide the actions of actuators interacting with the environment. A universal conceptual diagram of a business process implemented by an AI system is illustrated in Figure 5.

In the assumptions of the EcoTech project, a universal instrument ensuring the symbiosis of AI technologies with other disciplines, particularly with NBS technologies, is the Unified Modeling Language[11] (UML) – a graphical modeling language used for collaborative identification of the operational logic of an

[11] The UML language provides 13 types of diagrams, including: use case diagrams, class diagrams, activity diagrams, state machine diagrams, sequence diagrams, communication diagrams, interaction overview diagrams, package diagrams, component diagrams, deployment diagrams, object diagrams, composite structure diagrams and profile diagrams. Interdisciplinary teams

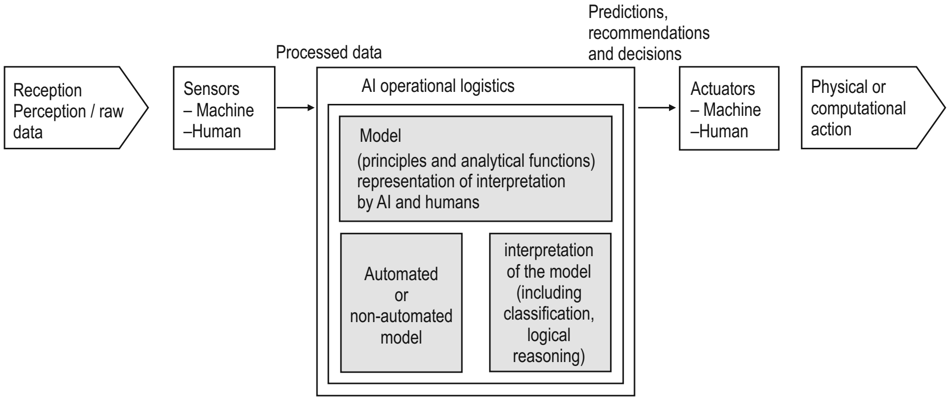

Fig. 5. Diagram of the artificial intelligence system in the context of data processing for effective water management in shipyard production processes
Source: own study based on OECD (2019), resolution…
(Uchwała nr 196 Rady Ministrów…, 2021).

AI system. The choice of this instrument builds upon the authors' previous experience, as presented in earlier publications – SALA and TAŃSKA (2014a, b, c).

In recent years, there has been a significant increase in the number of scientific publications devoted to nature-based solutions (ADARSH, HANEENA SULTHANA 2025). These works primarily focus on applications in urban environments and spatial planning. However, the implementation of such solutions remains fragmentary and limited to select pilot cases (CORGO et al. 2024). Only about fourteen percent of studies address issues related to coastal environments (LOUARN et al. 2025), and so far, no documented analyses have been found concerning the integration of nature-based solutions with artificial intelligence technologies. Given the lack of confirmed global experience in combining these two approaches within the shipbuilding industry, it is worth formulating two additional research questions to complement those previously posed in the article:

5. How can the integration of AI with NBS support the sustainable development of the shipbuilding industry, particularly in the area of water resource management?

6. What benefits arise from applying AI to the monitoring and management of water resources in shipbuilding production processes?

use selected diagrams to represent an AI system from different perspectives, focusing either on its structure or its behavior.

Results and discussion

Synthesis of the EcoTech project

Based on the activities carried out in accordance with the adopted methodology (steps 1–7 in Fig. 1), a comprehensive set of documentation has been completed in preparation for the implementation of the EcoTech project, titled: "EcoTech Marine Manufacturing: Advanced and innovative solutions in production preparation, welding and water management processes in the offshore and shipbuilding industry" (Project no. 4 in Fig. 2). This project specification spans nearly 200 pages and has been developed following the documentation template required by the main sponsor, namely the National Center for Research and Development (NCBR). A grant application for project funding – covering 56% of the total budget (see Table 1) – is planned for submission as part of the NCBR's competitive funding program (*Wniosek o dofinansowanie NCBR…*, 2025).

General and financial information

The EcoTech project is the result of work carried out by the Steering Committee for R&D and KPO projects (established by the Management Board's directive) between March and December 2023. During this period, the team developed initial project assumptions that meet the NCBR sponsorship criteria under the SMART competition, as part of the European Funds for a Modern Economy (FENG) program. The EcoTech project focuses on the digitalization of production preparation and manufacturing processes. Its concept and technical description were developed during 2023–2024 in cooperation with the Director of the Technological and Construction Department, the AGH University of Science and Technology in Kraków and the Gdańsk University of Technology (PG). In 2025, the project was further expanded to include digital production requirements, in collaboration with the Director of Shipbuilding Production and the Head of Prefabrication Department, representing the next iteration of methodological steps 4, 5, 6 and 7 (as shown in Fig. 1).

As a result, two primary modules of the EcoTech project have been defined (R&D module and Innovation implementation module). The preliminary consolidated budget for the project's direct costs assumes acceptance by three sponsors (as part of step 8 of the methodology shown in Fig. 1). The detailed financial structure is presented in Table 1.

Table 1 represents a simplified summary prepared for the purpose of negotiations with the project sponsors. The implementation period of the EcoTech project is planned to extend from September 2026 to the end of 2028, with a sustainability continuing until 2033.

Table 1

The preliminary consolidated budget for the EcoTech project (MLN PLN)

Main positions	Direct costs	NCBR funding	Sponsor 2	Sponsor 3
R&D module	15	10	0	5
Implementation module	15	6,8	6,6	1,7
Total	30	16,8	6,6	6,7

Source: own study based on *Wniosek o dofinansowanie NCBR…* (2025).

Detailed information

The main problem to be solved in the EcoTech project is the low level of digitalization of production processes (preparation, welding, painting) in the shipbuilding industry, not only in BO and Poland, but also in the global industry, and above all, in the European one. In BO, the following specific problems have been identified:

P. 1. Low efficiency of production preparation processes;

P. 2. Low efficiency of welding processes;

P. 3. Lack of pro-ecological actions in the planned process of painting structures;

P. 4–5–6. Lack of a communication system for the tactical and strategic integration of production preparation and production processes in cooperation with business partners.

In response to the above problems, the main objective of the EcoTech project is to increase the competitiveness of BO on the market through the integration of key production preparation and production processes, while the specific objectives are as follows:

Objective 1. Improve the efficiency of production preparation processes by at least 40%;

Objective 2. Develop a modular, adaptive decision-making and control system to support the new welding technology;

Objective 3. Develop pro-ecological solutions for the process of painting structures;

Objective 4–5–6. Develop a model of workshop dynamics and their integration between production preparation and production processes.

Each of the objectives is assigned to specific tasks dedicated to teams according to their competencies, with the first objective being implemented by the R&D team and approximately 100 specialists, mainly from BO, AGH and PG. In the first R&D module, the following main tasks are planned:

1. Development of an AI model reflecting the operational logic of production preparation processes;

2. Development of a WBS standard for BO and its synchronization with the standards of business partners;

3. Development of AI solutions enabling bidirectional conversion of the model of the structure/ship/block/section in relation to the client and subcontractor;

4. Development of procedures for the absorption of parametric 3D solid design and product lifecycle management;

5. Development of a model for the innovative K1 hall development;

6. Development of water recycling technologies for industrial processes – primarily focusing on water recovery during the structure washing processes;

7. Development of technologies for water recovery based on NBS.

Tasks 1–5 will be carried out using selected AI technologies, while tasks 6–7 will utilize selected nature-based solutions.

The objective of the second module, Innovation implementation, is to implement selected prototype process innovations developed and verified within the first R&D module, focusing on two production areas, as follows:

Area A: Increasing the efficiency of the technical production preparation process through:

• Digitalization of 3D documentation/information flow from the client to the technological and production departments (CAD/CAM/CAE/PLM integration);

• Automation of material logistics, covering the flow of materials from the steel product warehouse to the production workstations.

Area B: Increasing the efficiency of shipbuilding structure welding processes through the robotization of component prefabrication.

The foundation of the second module, Innovation implementation, will be models 1–5, with model 5 serving as the main framework. Model 5 encompasses seven areas of material flow automation within the prefabrication process (preliminary prefabrication, plate bending, reusable plate material storage, frame production, LSP, CSP and roller conveyors), as well as 14 production stations (including 5 new ones). Implementation of this model requires the completion of 22 tasks aimed at creating, modernizing and integrating all automated and robotized components. The developed assumptions and detailed documentation of the EcoTech project, prepared for negotiations with sponsors, represent the vital developmental needs of BO, confirmed by numerous BO employees, including the Directors of the Technological and Construction Department and the Production Division.

The essence and benefits of the symbiosis between NBS and AI technologies

The research site – and at the same time, the planned location for the development and implementation of innovations – is situated on Ostrów Island in Gdansk, between the Martwa Wisła River and the Kashubian Canal, within the Młyniska district. This area, covering approximately 2.2 km^2, forms an essential part of the industrial infrastructure of Gdansk's maritime economy, concentrating facilities associated with the shipbuilding and shipbuilding-related industries. The location is characterized by a well-developed transport infrastructure, including direct access to cargo-handling quays and a connection to the railway network, which supports the integration of production and logistics processes. Within the island's area are facilities linked to the shipbuilding sector, including Baltic Operator, located at 15/20 Na Ostrowiu Street. Figure 6 presents Ostrów Island[12], with the main components marked – namely, the K1 production hall (with a roof area of 120.000 m^2) and the LKM structural maintenance center, which features two large-scale conservation and painting lines with an area of 8927 m^2, making it one of the largest facilities of this kind in Poland.

Fig. 6. Ostrów Island – location of the K1 production hall and the LKM center
Source: own study.

The LKM Center is designed to handle large-scale steel structures, and processes include, among others, abrasive blasting, high-pressure washing using industrial detergents and application of protective coatings by hydrodynamic spraying. The essence of the planned solution, based on Nature-Based Solutions (NBS) in symbiosis with AI technologies, is illustrated in Figure 7, which symbolically presents the main conceptual components and their two

[12] The industrial development of Ostrów Island is undergoing dynamic changes, which are not reflected in the photograph shown in Figure 6.

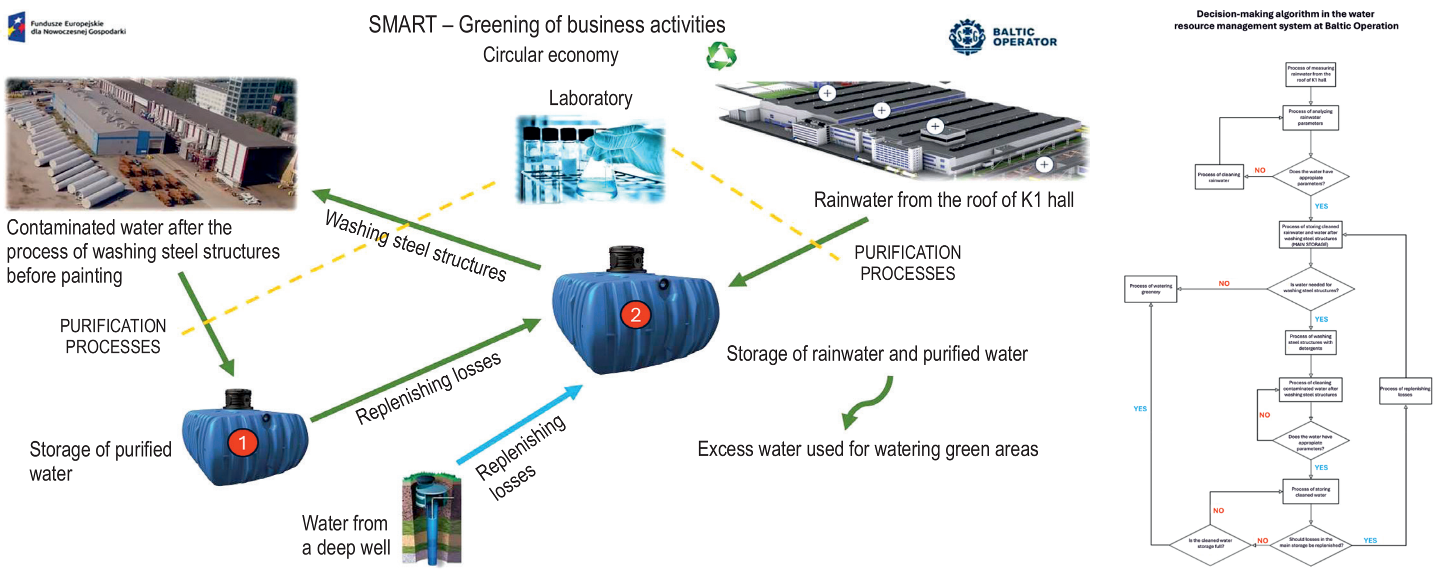

Fig. 7. A circular economy concept dedicated to the process of pre-painting structure maintenance, along with a decision diagram
Source: own elaboration.

locations – the K1 production hall (in the upper right corner) and the LKM structural maintenance center (in the upper left corner). The concept requires the development of two technological solutions, formulated as prototypes/tasks no. 6 and no. 7, as previously outlined in the detailed project information (section "Synthesis of the EcoTech project"). In Figure 7, the conceptual solution in accompanied by a decision diagram consisting of five decision nodes, each of key importance at the highest level of abstraction.

In response to the growing industrial demand for sustainable water resource management (*UNEP* 2021), a concept for a closed-loop rainwater recovery and recirculation system has been developed, dedicated to the preparation of large-scale steel structures for painting. The proposed solution will be based on the gravitational collection of rainwater from the roof surface of the production hall, followed by preliminary mechanical treatment (sedimentation and filtration) and subsequent storage in a main reservoir. The recovered water will be used in the washing processes of steel structures, where industrial detergents are applied. After use, the technological wastewater will be directed to a physicochemical treatment module that includes suspension separation, detergent neutralization, filtration, and – if necessary – disinfection. Once treated, the water stream – after meeting the required quality conditions – will be directed to a secondary reservoir, from which it will be recirculated back to the main reservoir, thus ensuring a closed water cycle. The system design includes automatic replenishment of volume losses by switching to deep-well supply during periods of increased production or low rainfall, as well as the use of excess stored water for auxiliary purposes, such as irrigation of nearby green areas during periods of reduced production demand or heavy rainfall. The entire system will be supported by an integrated automation and monitoring platform, enabling real-time control of water quality parameters, flow optimization based on production schedules and operational compliance with circular economy principles and regulatory standards.

At the preparatory stage of submitting the EcoTech and MNiSW project funding applications, it is recommended do develop a context diagram of concept and a diagram of the key process, which are illustrated in Figures 8 and 9 in UML notation.

To evaluate the effectiveness of the solution illustrated in Figure 8, the application of the following performance indicators is planned:

- Efficiency of rainwater recovery [%];
- Water recirculation coefficient [%];
- Reduction of primary water consumption [m^3/year];
- Reduction of pollutant load discharged into the sewage system/receiver [mg/l / kg/year];
- Unit cost of recovered water [PLN/m^3] (to be compared with the purchase price of water supplied from the municipal network).

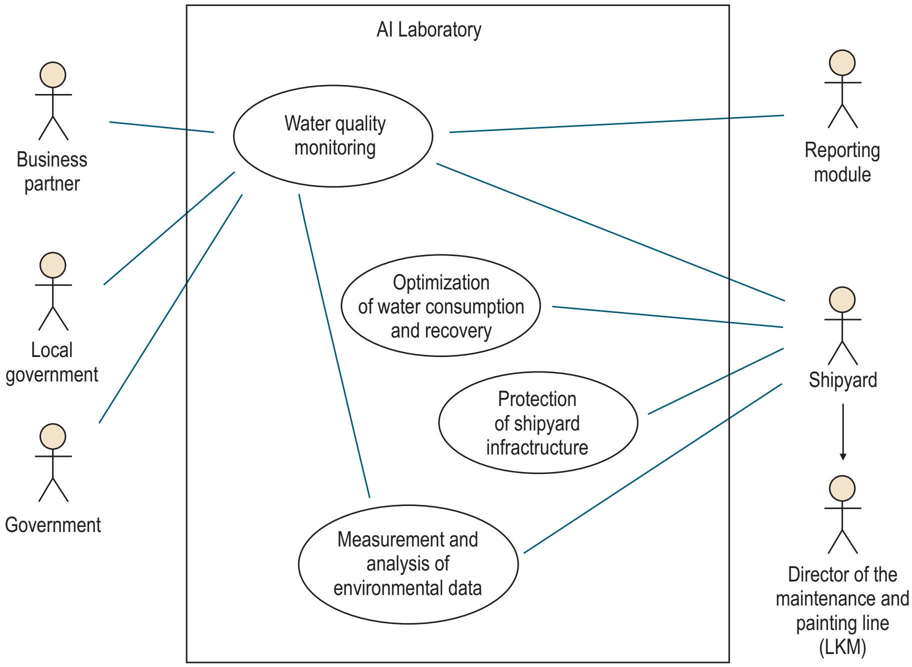

Fig. 8. Context diagram of the circular water economy concept in UML notation
Source: own elaboration.

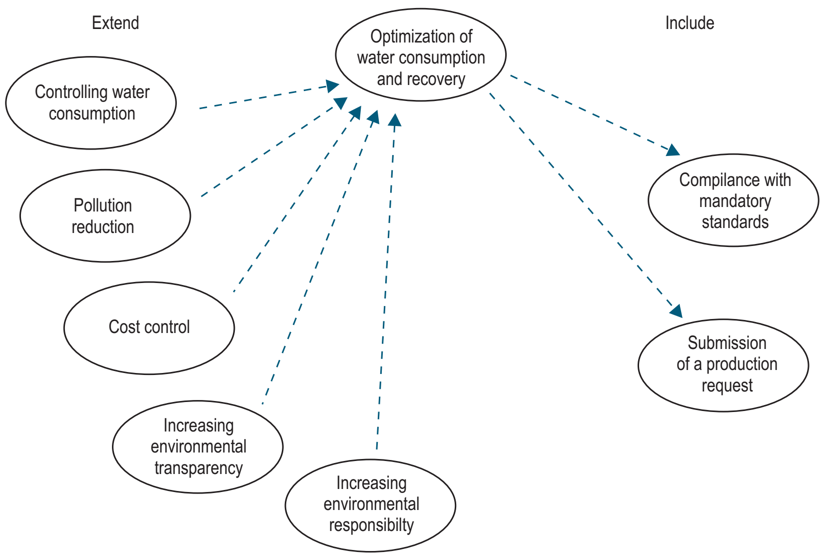

Fig. 9. "Optimization of water consumption and recovery" process diagram in UML notation
Source: own elaboration.

The above performance indicators have been linked to six actors identified in the context diagram of the system concept shown in Figure 8: the business partner, local government, national government, reporting module, shipyard and the LKM director. For each actor, these indicators serve a distinct informational and decision-making function. For instance, the reporting module acts as the central node for data collection and processing, the shipyard provides the primary operational data on water consumption and recovery, the business partner can access the commercial potential of the solution based on the unit cost of recovered water, the governmental and local authorities can use information on reduction in water use and pollutant discharge to monitor compliance with environmental policies and regulations and the LKM director, as the key operational decision-maker, can use the aggregated indicator values to plan and optimize processes within the shipyard. The relationships presented in the context diagram (Fig. 8) are further developed in a set of process diagrams, one of which is the "Optimization of water use and recovery" process diagram shown in Figure 9. This model identifies the main process of water management in the shipyard, complemented by five "Extend-type" processes: water consumption control, pollution reduction, cost monitoring, environmental transparency enhancement and environmental responsibility improvement. These extensions enable the adaptation and deepening of the core operational scenario, ensuring a more flexible and comprehensive approach to sustainable water management within the shipyard environment.

Additionally, the model shown in Figure 9 includes two "Include-type" processes: consideration of mandatory standards and submission of production demand, which represent obligatory elements of every process workflow. This approach allows for the integration of operational and regulatory activities with the strategic objectives of the system, while simultaneously reflecting the close interconnections between formal requirements, production needs and initiatives for sustainable water resource management.

The symbiosis of artificial intelligence and nature-based solutions will enable significant improvements in resource efficiency, operational flexibility and environmental resilience of technological processes. In the closed-loop rainwater recovery system, AI will support dynamic control of water flow, optimization of treatment time and methods and predictive management of detergent demand based on production schedules and historical consumption data. At the same time, the application of NBS will integrate the system into the local hydrological cycle, reducing pressure on drinking water resources and the sewage infrastructure. AI will also enhance the operational efficiency of the NBS system through water quality analysis and the automation of switching between primary and recirculated water supplies, based on meteorological data (using supervised learning models) and dynamic water usage patterns. The synergy between these technologies will ultimately lead to sustainable water resource management, a reduction in environmental footprint, minimization of systemic losses and the creation of resilient, circular operational models aligned with the principles of Industry 5.0 and the decarbonization strategy of the maritime industry.

Conclusions and development plans

In the presented case of a shipyard as a key component of the maritime economy, it is crucial to ensure a reliable analytical and decision-making potential that provides a holistic developmental perspective. Therefore, the authors concluded that attention should be focused on the aspects of proper relationships between theory and practice in the context of technical and economic sciences. Due to the extensive substantive scope of the article, it was necessary to abstract from many important details. It was possible to present mainly a synthesis of the conducted research, collected data and obtained results. Hence, among other things, not all methods applied and positively verified so far, as well as new methods planned for use (e.g. JANISZEWSKI et al. 2024) were cited, since the list is long. Instead, the significance of an interdisciplinary methodology was emphasized, as it provides integrative support when applying diverse methods to solve numerous thematic problems over a long-term time horizon.

In the projects developed during the methodical development cycles no. 2 (project sponsored by MNiSW) and no. 4 EcoTech (with NCBR as the planned main sponsor), as shown in Figures 1 and 2, it was assumed that a standard graphical modelling language – UML – would be applied. This language in widely and successfully used for business process modeling, software design and system architecture development. At the R&D stage within the shipyard, the interdisciplinary nature of knowledge and the need for its modeling in form of the business processes are and will remain of fundamental importance. All teams of specialists invited to collaborate within the multi-year process of developing the AI system for the shipbuilding industry (3+5 years) will require a common UML-based language to communicate and consolidate the results of their partial work. This will constitute a unified analytical and decision-making framework, supporting not only the identification of operational logic of individual AI system objectives for the shipbuilding industry, but above all, a holistic representation of the entire AI system, including its sensor and actuator models. UML will enable visualization, specification, forward and reverse engineering and documentation of artifacts created during system development. Thus, it will serve as a language useful both for humans and machines, applicable not only during industrial research and development work but also during implementation stages. UML graphical modeling is a method that was positively verified in development cycle no. 1 (Fig. 2). This is an R&D project carried out in cooperation with AGH University of Krakow, for which funding and settlement by the NCBR have already been completed. The implementation work and commercialization phase are now nearing completion (i.e., steps 9 and 10 of the methodology shown in Fig. 1). Similarly, in the example shipyard, such methods as participant observation, individual interviews, group interviews (focus group research), surveys, questionnaire-based studies and SWOT analysis were also positively verified. Undoubtedly, in order to integrate the results of multiple projects, it will be necessary to develop and implement a highly complex system requiring the creation of many interrelated models constituting a kind of "digital shipyard". Naturally, this will also require extensive tool support from other solutions, including CAD/CAM/CAE/PLM systems, ensuring full integration between engineering design, digital simulation and AI-driven process optimization.

In the authors' view, when considering any developmental premises within the shipbuilding industry, the following conclusions and assumptions should be taken into account as key elements of the analytical and decision-making potential derived from this article:

1. The development of enterprises, including shipyards, is unimaginable without AI, yet it is essential to maintain a measured approach to its instrumentalization within projects. This moderation ensures pragmatic alignment with real business processes of production preparation and shipbuilding manufacturing (a significant problem in this area is the multitude of superficial market offers that do not take into account the specificity of the shipbuilding industry);

2. The development of enterprises, including shipyards, is equally unimaginable without NBS, however a balanced approach is necessary to avoid the instrumentalization of ecological aspects, ensuring that sustainability efforts remain aligned with shipyards production needs;

3. It is essential to establish an "AI application strategy" that reflects the production order portfolio, the industry's specific characteristics and the current state of the enterprise;

4. The creative and interdisciplinary potential of experienced engineers and specialists employed long-term in the shipyard must be actively integrated into project execution. Neither an internal project team nor an external consulting group can independently deliver the required developmental capacity. The appropriate composition of a mixed team and effective coordination of collaboration are therefore critical success factors;

5. It is necessary to continuously monitor global socio-economic policy directions, particularly international and national maritime/shipbuilding development polices, throughout the execution of such a multi-year project, as these external factors may pose risks to the project's success or diminish the practical applicability of the developed solutions.

The conclusions formulated in points 1–5 may not be entirely convincing, however, it should be highlighted that in the case of enterprises engaged in unit production, such as the example shipyard, the strategy for AI applications and the symbiosis between AI and NBS should be strictly dedicated rather than universal. In view of the above and in the context of the research questions posed in this article, it is worth emphasizing the conclusions regarding developmental opportunities and the potential to overcome long-standing global, regional, national and local challenges. It is certain that a new "revolution" in the shipbuilding industry cannot be predicted – nor, it seems, can it be artificially created. The United States is attempting to do so, supported by presidential initiatives and Poland is also making efforts (*SHIP FORUM* 2025a, c), albeit without the backing of political decision-makers (research question no. 1).

Moreover, as a result of the preparatory process conducted between 2022 and 2024, it has been determined that the symbiosis of AI and NBS technologies is not only feasible, but indeed necessary. When properly designed and implemented, this integration can become a self-sufficient factor capable of driving a breakthrough in the shipbuilding industry. In response to the strong regulatory pressure from EU directives, such as Fir fot 55 (*European Parliament* 2023) and FuelEU Maritime (*FuelEU Maritime* 2025), the AI-NBS symbiosis can simultaneously enable reductions in CO_2 emissions, decreases in water pollution and improvements in energy efficiency. These outcomes may yield a regulatory and cost advantage, which, in an industry characterized by low profit margins (GOURDON et al. 2023), would represent an authentic market breakthrough (research question no. 2).

In the context of research question no. 3, the experience gained by the R&D team in the example shipyard clearly indicates that effective management of development processes, tailored to the needs and capabilities of the enterprise, is essential (a preliminary example of such an approach is illustrated by the methodology shown in Figure 1). Undoubtedly, R&D activities in shipyards are meaningful and justified, at least when adequate founding or co-founding opportunities are available. Projects sponsored with public funds should incorporate a proven project management methodology, such as PRINCE, while at the same time retaining the flexibility and iterative advantages of the Agile approach (which was verified in development cycle no 1 (Fig. 2)). Naturally, the success of R&D outcomes depends on the active involvement of top shipyard management as well as the ownership bodies, which simultaneously provides the basis for addressing research question no. 4. There is indeed a real opportunity for the shipbuilding industry – including Polish, European and American shipyards – to regain strong market positions. However, without effective and coherent industrial policy dedicated to this sector, achieving such a recovery will be extremely difficult, if not impossible.

An attempt to address the detailed research question no. 5 and no. 6 is presented in section 3 of this study. However, the validation of these answers can only be expected after the completion of the project no. 2, titled "Efficient use of water resources in production processes using nature-based solutions supported by artificial intelligence". This project has already received symbolic sponsorship from the Ministry of Science, in cooperation with the Department of Environmental Engineering Technologies at the Gdańsk University of Technology, and is scheduled to be carried out during the years 2024–2028. Alongside the selected issues of AI and NBS symbiosis addressed in this article, the authors are convinced that incorporating into the EcoTech project the key principles of the Industry 4.0, Industry 5.0, Digital Twin and Digital Factory concepts will enable the creation of cyber-physical solutions that will serve as the model foundation for Shipyard 4.0, specifically in the domains of production preparation and shipbuilding manufacturing. Following the completion of negotiations with potential EcoTech project sponsors – as part of step 8 of the methodology shown in Figure 1 (by the end of May 2026) – which will conclude the preparatory phase, it is planned to commence step 9 in September 2026, representing the main implementation phase of development improvement methodology applied by the R&D team at BO. In the future – after 2028 and 2033 – a systematic integration is planned between the areas of production preparation and manufacturing (covered by EcoTech and MNiSW projects) and the other key operational domains essential for the functioning of any shipyard at the global, regional, national and local levels. Of course, this represents a long-term development perspective for the Gdansk Shipyard, primarily due to the high financial outlays distributed over time. Nevertheless, the detailed implementation schedule includes phased tasks for introducing the developed innovative solutions, which will begin to generate measurable savings and benefits – enhancing the competitiveness of the shipyard on the global shipbuilding market well before the full project completion. However, the key determinant is the development of proper relationships between theory and practice in the context of engineering and economic sciences, including the continuous analysis of the global market.

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