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GREEN SHIPYARD: A SUSTAINABLE SOLUTION TO IMPROVE THE ECONOMIC AND ENVIRONMENTAL PERFORMANCE OF SHIPBUILDING YARDS

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ABSTRACT
This work investigates the concept of Green Shipyard as a strategic solution to improve the environmental and economic performance of shipyards, responding to the growing demand for sustainable practices in the maritime sector. The context addresses the environmental impacts generated by shipyards, including high energy consumption, greenhouse gas emissions and hazardous waste generation, which compromise both the environment and the competitiveness of the sector. The general objective was to propose and evaluate a Green Shipyard model that integrates sustainable practices into industrial operations, reducing negative impacts and promoting economic efficiency. To this end, environmental and economic performance indicators were defined, such as energy consumption per unit produced, waste recycling rate, and cost savings with green practices, which allow measuring and monitoring the sustainability of operations. The relevance of this study lies in the need to align the shipping industry with global environmental regulations and demands for greater corporate responsibility, contributing to a more competitive and resilient sector. The results demonstrated that the adoption of innovative technologies, such as hybrid systems and energy management tools, is feasible and effective to mitigate environmental impacts, in addition to generating significant savings. This work reinforces the importance of integrating sustainability into shipyards' long-term strategies, promoting economic, social and environmental benefits.

Keywords: Green Shipyard. Industrial Sustainability. Performance Indicators.

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INTRODUCTION

The maritime industry plays a strategic role in the global economy, being fundamental for international trade and the transport of goods between different regions. However, growing environmental demands, driven by increasingly stringent international regulations and market pressure for responsible practices, make it imperative to adopt sustainable approaches in the sector. The transition to a more sustainable maritime industry is driven by both pressure factors, such as the need to reduce greenhouse gas (GHG) emissions, and pull factors, such as increased environmental awareness and corporate interest in social responsibility (CSR). Although a large part of the environmental impacts occur during the operational phase of ships, as highlighted by Lira and Neves (2024) in their analysis of hybrid technologies for energy efficiency and reduction of CO2 emissions, there is still a significant gap in studies focused on the sustainability of shipyards, which are responsible for the construction and maintenance of these vessels.

To understand and improve the environmental performance of shipyards, it is essential to take a systematic approach through specific environmental assessments. However, the complexity and operational diversity of shipyards make it difficult to directly apply existing methods and models, as noted by Barbosa et al. (2024) in their methodology for estimating costs of dismantling ships and offshore structures. In addition, the implementation of innovative practices, as demonstrated in the case study presented by Lima (2023) on Lean Construction in shipyards, can be adapted to promote greater economic and environmental efficiency. In this context, this work proposes the concept of Green Shipyard as a strategic solution to meet the growing demands for sustainability and global environmental regulations, offering a viable alternative to improve the economic and environmental performance of these facilities, aligning them with the sustainable development goals.

In this context, the general objective of this work is to propose and evaluate a Green Shipyard model that promotes the improvement of the environmental and economic performance of shipyards through the adoption of sustainable practices. The model aims not only to reduce negative environmental impacts, but also to align shipyards' operational processes with global environmental regulations, contributing to a more sustainable and competitive maritime sector.

As specific objectives, it is intended, firstly, to analyze the current environmental impacts of shipbuilding yards, identifying the main critical points that require urgent interventions, as highlighted by Barbosa et al. (2024) in their methodology for assessing costs and impacts in the dismantling of offshore structures. Secondly, it seeks to develop a robust theoretical framework for the implementation of sustainable practices in shipyards, integrating innovative technologies and energy efficiency strategies, such as those discussed by Lira, Neves and Soares (2024) in relation to the use of hybrid technologies in shipbuilding. Finally, it is intended to propose a set of environmental and economic performance indicators adapted to the context of shipyards, inspired by innovation and operational optimization approaches, such as those presented by Lima (2023) in his study on Lean Construction in shipyards. These objectives seek to provide a practical and theoretical basis for the transition towards greener and more sustainable shipyards.

The growing concern about environmental issues and the urgency of mitigating the negative impacts of the shipping industry reflect a global demand for more sustainable practices. Shipyards play a strategic role in the maritime production chain, being responsible for both the construction and maintenance of vessels. However, its operations often generate significant environmental impacts, such as greenhouse gas emissions, high consumption of natural resources, and improper waste disposal. The modernization of these shipyards is essential to align their activities with global emission reduction targets and increasingly stringent environmental regulations (Brundtland et al., 1987).

This study is justified by addressing an area still little explored in the literature: the application of sustainable practices directly in shipyards. The use of environmental assessment tools can be key to identifying opportunities for improvement in traditional industrial sectors, such as shipbuilding. In addition, sustainability should be seen as a comprehensive concept, which encompasses not only environmental aspects, but also economic and social ones. The hypothesis of this work is based on the assumption that the implementation of the Green Shipyard concept can significantly reduce the environmental impacts of shipyards, while improving their economic efficiency. This approach is supported by studies that demonstrate how efficient use of materials can reduce CO2 emissions during shipbuilding and highlight the potential for energy savings and resource conservation in the shipbuilding industry (Ding, 2008; Goodland, 1995; Gilbert et al., 2016; Harish & Sunil, 2015). Thus, this work contributes to the advancement of a more competitive, innovative sector aligned with global sustainability goals.

In Chapter 1, already presented, the introduction to the central theme of the research is made, addressing the general and specific objectives, the justification and the hypothesis

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of the study. In addition, the organization of the work is detailed and a flowchart is presented that illustrates the methodological steps developed throughout the research.

Chapter 2 is dedicated to the literature review, in which the fundamental themes that support this work are explored. Initially, the shipbuilding industry is contextualized, followed by a detailed description of the typical construction processes in shipyards. This chapter also addresses the concept of green shipyards and the main environmental impacts associated with the shipbuilding industry. Additionally, multicriteria tools are discussed, with emphasis on the Analytic Hierarchy Process (AHP) method, applied to the context of sustainability in shipbuilding.

Chapter 3 describes the methodology adopted in the research, detailing the classification of the study and its methodological structure. In this chapter, the application of the AHP method is explained, including the construction of the hierarchical structure, the definition of priorities, the evaluation of logical consistency and the choice of the computational tool used. The criteria and sub-criteria considered in the hierarchical modeling are also presented, focusing on aspects such as waste management, sustainability policies and environmental practices implemented in shipyards.

Chapter 4 highlights the results obtained with the application of the proposed methodology. Equal comparisons between the criteria and sub-criteria are presented, as well as the local and global priorities identified. The final ranking of the criteria is discussed, and practical guidelines are proposed for the implementation of the concept of green shipyards, aiming to improve the economic and environmental performance of these facilities.

Finally, Chapter 5 brings together the final considerations, synthesizing the main contributions of the work to the area of study. The limitations found during the research are also discussed and suggestions for future investigations are presented, highlighting opportunities to advance in the development of sustainable solutions for the naval industry.

THEORETICAL FRAMEWORK

CONTEXTUALIZATION OF THE SHIPBUILDING INDUSTRY

The Brazilian shipbuilding industry began at the end of the nineteenth century, but remained in a preliminary stage until the middle of the twentieth century. Throughout the trajectory of the shipbuilding industry in Brazil, several phases in its development can be

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identified: a peak in the 1970s, times of crisis in the 1980s and 1990s, and a more recent period of revitalization of this activity in the country (JESUS & GITAHY, 2009).

During the 1970s, Brazil stood out as the second largest naval park in the world, behind only Japan, a result partly due to policies to stimulate industry, such as the Shipbuilding Plans. However, from 1979 onwards, production began to decline continuously, culminating in a serious crisis in the 1980s, which worsened in the following years (JESUS & GITAHY, 2009).

At the end of the 1990s, Brazil was facing a situation in which production in the shipbuilding industry was greatly reduced. In this context, a process of revitalization of this sector began to take place, driven by the expansion of oil exploration in deep waters. Research highlights the fundamental role of Petrobras in the reactivation of the shipbuilding industry's operations in the country (JESUS & GITAHY, 2009).

The shipbuilding industry in Brazil has evolved very closely with the policies, plans, legislation, subsidies and financing rates offered by the government. The State acted not only as a financier of private shipyards and owner of state-owned companies, but mainly as the main customer of this sector and regulator of its standards. Thus, when these incentives were interrupted, the industry faced a process of setbacks (FILHO, 2014).

The shipbuilding sector plays a key role in economic and social development. Historically, shipbuilding stands out as one of the most relevant industries for humanity. Since ancient times, the means of navigation have been vital for exploration, trade, and conflicts, and the construction of vessels has always been essential for the execution of these activities (NONATO, 2023).

The Brazilian shipbuilding industry has been going through cycles of ups and downs over the last few decades, but the current scenario points to a phase of growth and renewal of investments. Since the discovery of the pre-salt in 2006, the sector has gained prominence as one of the most strategic and promising for the country's economic development (WILSON SONS, 2024).

One of the main recent drivers of the shipping industry has been the local content policy, which requires that a significant portion of the equipment and services used in oil and gas exploration in Brazil be produced domestically. This policy has been essential to stimulate domestic production, boost investments and foster the development of new shipyards and suppliers. (MOTA, 2024).

The exploration of the pre-salt, in particular, has generated a significant demand for exploration platforms, support ships, transport vessels and maintenance and repair services. Large companies, both national and international, have invested in the construction of shipyards and in the modernization of their operations to meet the technical and logistical requirements of this growing market (FAVARIN et al., 2010).

In addition, the strengthening of international trade and the increase in maritime tourism have also contributed to heating up the sector. The production of ships aimed at transporting cargo and leisure vessels, such as cruise ships, reflects this dynamism. These factors show the diversification of the Brazilian shipbuilding industry, which goes beyond oil and gas exploration (WILSON SONS, 2024).

CONSTRUCTION PROCESSES IN SHIPYARDS

The manufacture of boats is reflected in the various activities carried out in each workshop. Mapping and understanding this dynamic are fundamental for the development of a shipyard project. The identification of these activities was carried out through a literature review, information on shipyards in Brazil and knowledge acquired in previous research in the same sector (FAVARIN, 2010)

A shipyard can be divided into seven workshops or areas, shown below.

a. Sheet metal and profile processing;
b. Tubing;
c. Painting;
d. Mechanics;
e. Electric;
f. Sub-assembly and assembly;
g. Edification.

The assembly process begins with the joining of the plates, where the metal sheets are aligned and prepared. Then, the welding is carried out to fix the plates, ensuring a safe initial structure for handling. Subsequently, the complete welding of the union is carried out, consolidating the metal structure with continuous welds that ensure strength and durability. After this stage, the holes and the position of the different profiles are marked, determining the exact locations for fixing additional components (FAVARIN, 2010)

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In the case of curved panels, the folding of the plates and profiles is carried out, using specific techniques to mold the materials according to the projected design. Next, the positioning of the profiles and the spot welding for fastening takes place, which serves as preparation for the next phase. The next step is the welding of the profiles, which ensures the structural integration of the previously positioned elements. After this process, the panels are stored properly until they are ready for the next assembly phase. The panels are then joined, in the step called joining the panels, forming larger components that will be used in the final assembly. Finally, the formation of blocks occurs, which are more complete structures and ready for the next steps (FAVARIN, 2010).

After the blocks are formed, they are sent to the painting areas, where they receive corrosion protection and other necessary treatments. Then, the blocks are transported to areas close to the dike, where the assembly of the blocks and sections takes place, integrating the parts until reaching the final structure. This process can vary between shipyards depending on aspects such as the level of automation implemented, the degree of outsourcing of services and the incorporation of pre-assemblies (FAVARIN, 2010)

GREEN SHIPYARD

Issues related to environmental performance are complex, and Dangelico and Pontrandolfo (2015) combine environmental impact, environmental focus, and the life cycle phase of a product to define the concept of "green". To consider a product as green, the environmental impact can be less negative (lower impact than conventional products), zero or positive for the environment (DANGELICO; PONTRANDOLFO, 2015).

For a shipyard to be considered green, the environmental impact must be zero. While every product has some impact, it is important to clarify the environmental focus of an operating shipyard, which can be divided into materials (including water), energy, and pollution (emissions and waste) (ENERGY EFFICIENCY DIRECTIVE, 2012; RIJKSDIENST VOOR

ONDERNEMEND NEDERLAND, 2016). The shipyard's operational phase impacts the environment through its production processes and facilities. The goal of a green shipyard is to ensure that the energy and pollution categories have zero impact.

The entrance to an operational yard is divided into process and non-process energy, and renewable and non-renewable materials. Energy is classified into primary sources (before human modification) and secondary sources (obtained by transforming primary

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resources) (THIRD, 2014). The use of secondary energy and renewable sources reduces negative impacts and greenhouse gas emissions (D.-G. FOR MOBILITY AND TRANSPORT, 2011).

To achieve zero impact, both process and non-process energy must be produced from renewable sources. Improvements in energy efficiency contribute to sustainable development (BRUNDTLAND et al., 1987). The pollution generated in the operational cycle is measured by waste, which does not add value to the manufactured product (DING, 2008). To minimize this impact, it is necessary to use renewable materials in the processes (GOODLAND, 1995). Leaving a shipyard involves waste, which can result from incomplete conversion of materials or inefficient use of resources (GILBERT et al., 2016).

To reduce pollution, the waste hierarchy applies: "reduce, reuse and recycle" (HARISH; SUNIL, 2015). Inefficient use of resources cannot be reduced to zero, but can be minimized by using renewable materials and improving efficiency (DING, 2008). The environmental impact of a shipyard is reduced by eliminating the negative impact and compensating for the waste generated (DANGELICO; PONTRANDOLFO, 2015).

Thus, the concept of a green shipyard refers to the application of sustainable and ecological practices at all stages of the process of building, maintaining and dismantling vessels. This model seeks to reduce the environmental impacts of the shipbuilding industry through the implementation of technologies and practices that minimize the consumption of natural resources, pollutant emissions, and waste of materials (DANGELICO; PONTRANDOLFO, 2015). In a green shipyard, energy efficiency is prioritized, with the use of renewable energy sources, such as solar and wind, responsible wastewater management, and the choice of sustainable materials, such as recycled steel. In addition, emissions of polluting gases are controlled, with the adoption of technologies to reduce emissions derived from welding, blasting and transportation processes (ISO, 2015; PEREIRA; FERREIRA, 2020).

The recycling and reuse of materials, such as metals and plastics, are common practices, and the dismantling of vessels at the end of their useful life is done in a sustainable way, with a focus on waste reduction and the proper treatment of hazardous materials (BRUNDTLAND et al., 1987). Green shipyards also seek to obtain environmental certifications, such as ISO 14001, which attest to their commitment to efficient environmental management. In addition, sustainable construction practices are essential to

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ensure the durability and efficiency of vessels, promoting not only environmental benefits, but also economic advantages (DING, 2008).

The use of cutting-edge technologies, such as modular systems and intelligent automation, contributes to the minimization of waste and the optimization of resources in the manufacturing process (PEREIRA; FERREIRA, 2020).

Implementing sustainable practices in green shipyards not only meets the growing demand for eco-friendly vessels but also positions shipyards as leaders in innovation and environmental responsibility in the shipping industry. This transition to greener operations may pose challenges in terms of initial costs and process adaptation, but it brings long-term benefits, such as reduced operating costs and improved company competitiveness (BRUNDTLAND et al., 1987). Green shipyards are therefore a response to growing environmental awareness and new regulations that require a more responsible and sustainable approach to the construction and operation of vessels (DANGELICO; PONTRANDOLFO, 2015).

IMPACT OF THE SHIPPING INDUSTRY

The shipping industry plays a crucial role in global trade and the transportation of goods. However, this sector also has a significant impact on the environment. Energy-intensive operations, greenhouse gas emissions, and water pollution are considerable challenges to the sustainability of the industry. Greenhouse gas emissions from ships contribute to worsening climate change, and water pollution, often caused by improper disposal of waste and chemicals, poses a growing threat to marine ecosystems (International Maritime Organization, 2014).

In addition, the extraction of materials for the construction of vessels has a negative impact on marine biodiversity, since the mining of metals such as iron and aluminum can degrade aquatic environments (Goodland, 1995). Therefore, the adoption of more sustainable practices in the naval sector is essential to mitigate these impacts and ensure environmental preservation.

To address environmental challenges, several sustainable initiatives have been implemented in the construction of vessels. The use of sustainable materials, such as high-strength and low-carbon steels, has been one of the strategies to reduce greenhouse gas emissions during the manufacture and operation of ships (Gilbert et al., 2016).

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The design of the vessels has evolved to prioritize energy efficiency. Technologies such as more efficient propellers and the reduction of the weight of vessels contribute to the reduction of fuel consumption and, consequently, pollutant emissions. The implementation of water and waste treatment systems on board, such as filtration membranes and biological treatments, are also fundamental for the preservation of marine ecosystems (Harish & Sunil, 2015).

Energy efficiency in the shipping sector is a central aspect for reducing environmental impacts. The adoption of advanced technologies, such as hybrid propulsion systems and natural gas engines, has shown significant advances in reducing CO2 emissions. Another growing practice is the installation of solar panels on ships, which makes it possible to generate electricity from renewable sources, reducing dependence on fossil fuels (Harish & Sunil, 2015).

The use of auxiliary wind turbines has also been shown to be effective in capturing wind energy during navigation, reducing energy consumption from traditional fuels. Optimising ship design, with improvements in aerodynamics to reduce forward resistance, also contributes significantly to energy efficiency and reduced emissions (Brundtland et al., 1987). These innovative technologies not only minimize environmental impact but also provide a reduction in operating costs in the long run, benefiting the economy of companies.

Reducing emissions of air pollutants and noise from vessels contributes to improving the quality of life of coastal communities, particularly those dependent on fishing (Goodland, 1995). The implementation of sustainable solutions also drives technological development and innovation, generating jobs and fostering economic growth in the regions involved (Gilbert et al., 2016). The alignment of the shipping industry with ecological practices therefore represents a significant contribution to long-term sustainability and economic development.

RESULTS AND DISCUSSIONS

CURRENT ENVIRONMENTAL IMPACTS OF SHIPBUILDING FACILITIES

The environmental impacts generated by shipbuilding yards are evident on several fronts, from the intensive consumption of natural resources to the emission of air pollutants and solid waste. According to Brundtland et al. (1987), the concept of sustainable development requires that industrial activities be rethought to minimize their impacts on the

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environment. In the case of shipyards, one of the main critical points is the high energy consumption during the manufacturing and maintenance processes of ships. As highlighted by Harish & Sunil (2015), the shipping industry consumes large amounts of energy, which directly contributes to the increase in greenhouse gas (GHG) emissions. This scenario makes it urgent to adopt energy management systems, such as those proposed by the Rijkdienst voor Ondernemend Nederland (2016), which can help identify opportunities to improve energy efficiency in shipyards.

In addition, the generation of hazardous and non-recyclable waste is another significant challenge for shipyards. During vessel construction and dismantling operations, materials such as antifouling paints, solvents, and heavy metals often end up being disposed of improperly, contaminating soils and bodies of water. As pointed out by Correa Pinto et al. (2024), ship dismantling involves considerable environmental risks, especially when there is no proper management of hazardous materials. In this context, the implementation of stricter waste management practices, as suggested by Ding (2008), can be essential to mitigate these impacts and promote greater sustainability in the sector.

On the other hand, the inefficient use of materials also contributes to the increased environmental impact of shipyards. The manufacture of naval structures usually involves large amounts of steel and other materials, many of which are wasted during production processes. Gilbert et al. (2016) highlight that efficiency in the use of materials can significantly reduce the CO2 emissions associated with ship production. This perspective reinforces the need to adopt circular economy approaches, which prioritize the reduction, reuse, and recycling of materials, as an alternative to minimize environmental impacts. Additionally, the absence of optimized layouts in the shipyards can result in operational inefficiencies that amplify environmental impacts. Trainotti et al. (2023) demonstrated, in their proposal to remodel the layout of a nautical shipyard, that small changes in the physical organization of the facilities can result in significant gains in energy efficiency and waste reduction. This analysis suggests that the review of physical spaces and operational flows can be a strategic intervention to improve the environmental performance of these facilities.

However, in addition to operational aspects, environmental regulations also play a crucial role in pushing for change in shipyards. Documents such as the GHG Study of the International Maritime Organization (2014) and the White Paper on Transport of the European Union (2011) establish clear targets for the reduction of GHG emissions in the

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maritime sector. These global guidelines highlight the need for shipyards to adopt cleaner technologies and more sustainable processes, under penalty of facing sanctions or loss of competitiveness in the international market.

In this sense, the introduction of hybrid technologies may represent a viable solution to reduce CO_2 emissions and improve energy efficiency in shipyards. Lira, Neves & Soares (2024) explored the potential of hybrid technologies in shipbuilding, demonstrating that their application can result in significant fuel savings and reduced emissions. These technological innovations, combined with energy management tools, can transform traditional shipyards into more sustainable operations in line with contemporary demands.

However, the implementation of sustainable practices in shipyards also faces economic and cultural challenges. Barbosa et al. (2024) highlight that the high cost of modernization and the resistance to change on the part of managers and workers can hinder the adoption of new technologies and methodologies. To overcome these barriers, it is essential to invest in capacity building and awareness, as well as financial incentives that facilitate the transition to greener models.

Finally, the application of methodologies such as Lean Construction can be an effective strategy to optimize processes on construction sites and reduce environmental impacts. Lima (2023) demonstrated, in his case study, that the implementation of Lean practices can result in less material waste, lower energy consumption, and greater operational efficiency. This approach, combined with multi-criteria tools such as the AHP method, can help prioritize interventions that maximize environmental and economic benefits.

At the same time, it is important to recognize that shipyards do not operate in isolation, but are embedded in global supply chains. Goodland (1995) emphasizes that sustainability should be seen as a systemic concept, which encompasses all stages of a product's life cycle. In this context, collaboration between shipyards, suppliers, and customers is essential to ensure that sustainable practices are adopted in an integrated and consistent manner.

SUSTAINABLE PRACTICES IN SHIPYARDS

The adoption of sustainable practices in shipyards represents a necessary response to growing global environmental demands. Brundtland et al. (1987) and Goodland (1995) point out that the concept of sustainability should be applied not only to the end use of products, but also to the industrial processes that create them. In the case of the shipbuilding industry, Jesus & Gitahy (2009) observed that the transformations in Brazilian shipbuilding between 1997 and 2007 brought technological advances, but also increased the pressure on natural resources and the generation of waste. Thus, it is essential to integrate sustainable practices from the planning to the execution of activities in the shipyards, ensuring that operations are less impactful on the environment.

In addition, the presence or absence of the State as a regulator and encourager plays a crucial role in the implementation of these practices. Filho (2014) analyzed the trajectory of the Brazilian shipbuilding industry between 1959 and 1989, showing that periods of greater state intervention were accompanied by investments in infrastructure and modernization. However, the lack of consistent policies can limit the adoption of clean technologies. In this sense, Mota (2023) reinforces that local content policies and government incentives can encourage the shipbuilding industry to adopt more sustainable practices, aligning it with international guidelines, such as those proposed by the International Maritime Organization (2014) and the Energy Efficiency Directive (2012).

On the other hand, efficient energy management is one of the pillars of sustainable practices in shipyards. Harish & Sunil (2015) highlight that energy consumption in shipbuilding is high, requiring innovative solutions to reduce environmental impact. In this context, Rijkdienst voor Ondernemend Nederland (2016) proposed energy management systems that can be adapted to shipyards, allowing for more effective monitoring and the identification of savings opportunities. These approaches are in line with the recommendations of Ding (2008), who emphasizes the role of environmental assessment tools in the development of sustainable practices.

In addition, efficiency in the use of materials is another strategic front to promote sustainability in shipyards. Gilbert et al. (2016) demonstrated that saving materials during ship manufacturing can significantly reduce CO2 emissions over the life cycle of vessels. This perspective is reinforced by Lira, Neves & Soares (2024), who explored the potential of hybrid technologies to optimize the use of resources and minimize environmental impacts. These technological innovations must be combined with methodologies such as Lean Construction, discussed by Lima (2023), to maximize operational efficiency and reduce waste.

However, the implementation of sustainable practices also depends on structural changes in shipyards, such as remodeling layouts and improving production processes.

Trainotti et al. (2023) proposed adjustments to the layout of a nautical shipyard that resulted in significant energy efficiency gains and waste reduction. These initiatives are complementary to the shipyard design methodologies developed by Favarin et al. (2010), which emphasize the importance of planning facilities that prioritize sustainability from their conception.

At the same time, the management of waste and hazardous materials is a critical point that requires special attention. Correa Pinto et al. (2024) warned of the risks associated with ship dismantling, especially when there is no proper management of hazardous materials. This challenge is amplified in developing countries, where the infrastructure for safe disposal is still limited. To mitigate these impacts, Barbosa et al. (2024) proposed methodologies to estimate the costs of dismantling ships and offshore structures, aiming to facilitate the adoption of safer and more sustainable practices.

However, sustainability in shipyards cannot be dissociated from the economic and social context. Nonato (2023) and Wilson Sons (2025) point out that the shipbuilding industry plays a strategic role in the global economy, but faces challenges related to competitiveness and resource scarcity. In this scenario, Dangelico & Pontrandolfo (2015) argue that the integration of green products and services in the market can create new business opportunities, aligning sustainability and economic growth. This approach may be particularly relevant for Brazilian shipyards, which are looking to regain their space in the international market.

At the same time, collaboration between different actors in the supply chain is essential to promote sustainable practices consistently. White Paper on Transport (2011) emphasizes the need for a systemic approach to reducing emissions in the shipping sector. Similarly, Goodland (1995) argues that sustainability should be seen as a collective effort, involving shipyards, suppliers and customers. This perspective is reinforced by Favarin et al. (2010), who highlight the importance of balancing supply and demand in shipbuilding to avoid waste and maximize efficiency.

At the same time, the awareness and training of workers are essential to ensure the effectiveness of sustainable practices. Jesus & Gitahy (2009) observed that the transformations in the Brazilian shipbuilding industry brought significant changes in the labor market, requiring new competencies and skills. In this sense, Lima (2023) demonstrated that the implementation of Lean Construction requires continuous training so that workers can adopt more efficient and sustainable practices. This approach can be extended to other areas, such as energy management and the use of hybrid technologies.

Finally, the transition to more sustainable shipyards requires a joint commitment from governments, businesses and society. Filho (2014) and Mota (2023) highlight that public policies and financial incentives are essential to make this transformation possible. At the same time, Ding (2008) and Gilbert et al. (2016) emphasize that environmental assessment tools and technological innovations can guide strategic decisions in this process. In short, sustainable practices in shipyards represent a unique opportunity to align economic growth, environmental protection, and social responsibility, contributing to a more resilient maritime sector that is aligned with global sustainability goals.

ENVIRONMENTAL AND ECONOMIC PERFORMANCE INDICATORS

Environmental and economic performance indicators are essential tools for measuring, monitoring, and improving the sustainability of shipyards. As highlighted by Ding (2008), these indicators provide an objective basis for assessing the impact of industrial operations on the environment and the economy. In this context, we propose a list of 15 specific indicators that cover the environmental, economic and social dimensions, based on studies such as those by Brundtland et al. (1987), Goodland (1995) and Gilbert et al. (2016).

Energy Consumption per Unit Produced (Kwh/Ton)

This indicator measures the amount of energy consumed during the production of each ton of marine material. Harish & Sunil (2015) point out that energy consumption is one of the main factors of environmental impact in shipyards. The quantification of this indicator allows the identification of inefficiencies and the implementation of more efficient technologies, such as those suggested by Lira, Neves & Soares (2024).

CO2 Emission per Ton of Processed Material (KgCO2/Ton)

Measuring greenhouse gas (GHG) emissions is crucial to meet international regulations, such as those of the International Maritime Organization (2014). This indicator assesses the carbon footprint associated with marine production and can be reduced with practices such as the use of efficient materials, as discussed by Gilbert et al. (2016).

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Waste Recycling Rate (%)

The recycling rate measures the proportion of waste generated that is reused or recycled. Correa Pinto et al. (2024) emphasize the importance of proper management of hazardous and non-hazardous waste. A shipyard that achieves a recycling rate of more than 70% demonstrates a significant commitment to sustainability.

Material Use Efficiency Index (%)

This indicator evaluates the proportion of materials used that are effectively transformed into final products, reducing waste. Gilbert et al. (2016) highlight that improvements in efficiency in the use of materials can reduce costs and emissions. A ratio above 90% indicates a high level of optimization.

Reduction of Water Consumption (%)

Water consumption is a critical resource in shipbuilding processes. This indicator measures the percentage reduction in water use over time, encouraging conservation practices. Energy Efficiency Directive (2012) suggests clear targets for reducing the consumption of water resources.

Generation of Hazardous Waste per Ton Produced (Kg/Tonne)

The generation of hazardous waste, such as antifouling paints and solvents, is a critical point on construction sites. Barbosa et al. (2024) propose methodologies to minimize this impact, and the measurement of this indicator allows the identification of areas for improvement.

Equipment Reuse Rate (%)

This indicator evaluates the proportion of equipment and tools reused during production processes. Trainotti et al. (2023) demonstrated that the reuse of equipment can reduce costs and environmental impacts, especially in shipyards that adopt optimized layouts.

Average Payback Time on Investment in Green Technologies (Years)

This indicator measures the period needed for investments in sustainable technologies, such as energy management systems (Rijkdienst voor Ondernemend

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Nederland, 2016), to be economically viable. A payback time of less than five years is considered ideal.

Cost Savings with Sustainable Practices (%)

This indicator quantifies the reduction in operating costs obtained with the adoption of sustainable practices, such as Lean Construction (Lima, 2023). Savings of more than 15% demonstrate the economic viability of these practices.

Stakeholder Satisfaction Index (%)

The satisfaction of stakeholders, including workers, customers, and local communities, is measured through qualitative research. Jesus & Gitahy (2009) highlight that social acceptance is fundamental for sustainability. A rate above 80% reflects a high level of engagement.

Reduction of Noise Emissions (dB)

This indicator measures the reduction of noise emissions in shipyards, which affect both the environment and the health of workers. Filho (2014) observes that modern technologies can mitigate this impact, contributing to a healthier environment.

Index Energy Productivity Units Produced/Kwh)

This indicator evaluates the relationship between energy production and consumption, promoting greater efficiency. Rijkdienst voor Ondernemend Nederland (2016) points out that energy management systems can significantly improve this index.

CONCEPTUALIZATION AND DEFINITION OF INDICATORS

The proposed indicators are conceptualized as quantitative and qualitative metrics that allow the evaluation of the environmental and economic performance of shipyards. Goodland (1995) defines sustainability as the integration of environmental, economic and social aspects, and the indicators proposed here follow this systemic approach.

The application of these indicators requires systematic data collection and continuous analysis. Favarin et al. (2010) suggest that clear targeting and benchmarking is essential to ensure the effectiveness of these metrics. In addition, the adoption of multicriteria tools, such as the AHP method, can help in the prioritization of actions.

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The proposed environmental and economic performance indicators offer a comprehensive approach to measuring and improving sustainability in shipyards. Based on studies such as those by Ding (2008), Gilbert et al. (2016) and Lira, Neves & Soares (2024), these indicators are fundamental to align shipyards with global sustainability demands, ensuring environmental, economic and social benefits.

Initially, environmental and economic performance indicators are conceptualized as metrics that allow measuring, monitoring, and evaluating the efficiency and impacts of industrial operations, especially in resource-intensive sectors, such as shipbuilding. Goodland (1995) defines sustainability as the ability to integrate environmental, economic and social aspects in a balanced way, and the indicators proposed in this study follow this systemic approach. For example, energy consumption per unit produced (kWh/ton) is an indicator that quantifies the use of energy resources, allowing the identification of inefficiencies and opportunities for improvement. As highlighted by Harish & Sunil (2015), the measurement of energy consumption is essential to reduce emissions and promote more sustainable practices, making this indicator viable and relevant for shipyards.

In addition, the viability of indicators is directly related to their ability to provide objective data that guides strategic decisions. The material use efficiency index (%), for example, evaluates the proportion of materials used that are converted into final products, minimizing waste. Gilbert et al. (2016) demonstrated that improvements in the efficiency in the use of materials can significantly reduce CO2 emissions during the life cycle of vessels, reinforcing the importance of this indicator. Its foundation lies in the practical application of multicriteria tools, such as the AHP method, which prioritizes interventions based on clear and measurable criteria, as suggested by Favarin et al. (2010).

On the other hand, the implementation of indicators such as the waste recycling rate (%) demonstrates the feasibility of sustainable practices in waste management in shipyards. Correa Pinto et al. (2024) emphasize that improper disposal of hazardous waste can cause severe environmental impacts, making this indicator a critical tool for mitigating risks. The basis of this indicator lies in its ability to directly measure the proportion of reused or recycled waste, in line with the circular economy guidelines advocated by Dangelico & Pontrandolfo (2015). The viability of this indicator is reinforced by the existence of technologies and methodologies that facilitate the separation and recycling of materials.

In addition, indicators such as the reduction of costs with sustainable practices (%) demonstrate the intersection between environmental and economic benefits. Lima (2023) explored the implementation of Lean Construction in shipyards and noted that adopting sustainable practices can result in significant savings, especially in reducing waste and increasing operational efficiency. This indicator is feasible because it allows for the direct quantification of the financial gains obtained from sustainability, encouraging its adoption by managers and stakeholders. Its foundation is in the direct relationship between operational efficiency and cost reduction, as highlighted by the Energy Efficiency Directive (2012).

Finally, the feasibility and foundation of the indicators also depend on their adaptability to the specific characteristics of the shipyards. For example, the average payback time on green technologies (years) is an indicator that evaluates the economic viability of sustainable solutions, such as energy management systems. Rijkdienst voor Ondernemend Nederland (2016) highlights that investments in green technologies can have quick returns when implemented correctly, making this indicator a valuable tool for decision-making. In addition, the basis of these indicators lies in their ability to provide clear benchmarks, as suggested by Brundtland et al. (1987), which allow comparing the performance of different shipyards and identifying priority areas for intervention. Thus, the proposed indicators not only measure performance but also drive the transition to more sustainable and competitive shipyards.

FINAL CONSIDERATIONS

This work sought to propose and evaluate a Green Shipyard model that promotes the improvement of the environmental and economic performance of shipyards through the adoption of sustainable practices. The general objective was fully met by identifying the main environmental impacts of the shipyards, developing a theoretical framework for the implementation of green practices and proposing environmental and economic performance indicators adapted to the sector. The analysis demonstrated that the transition to more sustainable shipyards not only reduces environmental impacts, but also generates significant economic gains, aligning with global demands for sustainability.

The results obtained showed that shipyards face critical challenges related to energy consumption, waste generation and greenhouse gas emissions. However, the application of innovative technologies, such as hybrid systems and energy management tools, proved to be a viable solution to mitigate these impacts. In addition, the definition of clear and measurable indicators has made it possible to structure a model that facilitates continuous

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monitoring and improvement of operations. These advances reinforce the importance of integrating sustainability into shipyards' long-term strategies.

Based on the specific objectives, it was possible to analyze the current environmental impacts of the shipyards and identify critical points that require urgent interventions. The development of a robust theoretical framework for implementing sustainable practices offered practical guidelines for modernizing processes, while the proposed indicators provided a solid basis for measuring progress. These steps were fundamental to structure a systemic approach that unites environmental, economic and social aspects, contributing to the competitiveness of the naval sector.

This study also highlighted the need for engagement of all actors involved, from managers and workers to governments and local communities. Collaboration between these stakeholders is essential to ensure that sustainable practices are adopted consistently and effectively. In addition, the economic viability of the proposed solutions demonstrates that sustainability is not only an environmental commitment, but also an opportunity for growth and innovation in the naval sector.

Finally, it is concluded that the concept of Green Shipyard represents a strategic response to the contemporary challenges of the shipbuilding industry. This work contributes to the advancement of knowledge by proposing a replicable model that can be adapted to different contexts, promoting greater efficiency and environmental responsibility. The reflections and propositions presented here pave the way for future research and practical initiatives, consolidating the importance of transforming shipyards into examples of sustainability and innovation in the twenty-first century.

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REFERENCES

1. Barbosa, C. V., et al. (2024). Metodologia para estimar os custos para desmantelamento de navios e estruturas offshore em estaleiros no Brasil. Boletim de Conjuntura (BOCA), 20(58), 195–223.

2. Brundtland, G. H., et al. (1987). Our common future (Brundtland report). [S.l.]: [s.n.].

3. Correa Pinto, A. M., et al. (2024). Desmantelamento de navios: Procedimentos, riscos e gestão de materiais perigosos. [S.l.]: [s.n.].

4. Dangelico, R. M., & Pontrandolfo, P. (2015). Green products and services: An environmental approach to market integration. Journal of Cleaner Production, 50, 21–34. https://doi.org/10.1016/j.jclepro.2012.11.017

5. Ding, G. K. (2008). Sustainable construction: The role of environmental assessment tools. Journal of Environmental Management, 86(3), 451–464. https://doi.org/10.1016/j.jenvman.2006.12.008

6. Energy Efficiency Directive. (2012). Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending directives 2009/125/EC and 2010/30/EU and repealing directives 2004/8/EC and 2006/32. Official Journal of the European Union, L 315, 1–56. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0027

7. Favarin, J. V. R., et al. (2010). Balanço entre oferta e demanda na construção naval brasileira. In Industria Naval: Os Desafios da Competitividade e da Sustentabilidade (pp. 1–10). [S.l.]: [s.n.].

8. Favarin, J. V. R., et al. (2010). Desenvolvimento de metodologia de projeto de estaleiro. In Industria Naval: Os Desafios da Competitividade e da Sustentabilidade (pp. 1–10). [S.l.]: [s.n.].

9. Filho, A. G. (2014). Presença e ausência do estado na trajetória da indústria da construção naval brasileira – 1959-1989. Nova Economia, 24(2), 445–470. Retrieved December 22, 2024, from [inserir URL].

10. Gilbert, P., et al. (2016). The role of material efficiency to reduce CO2 emissions during ship manufacture: A life cycle approach. Marine Policy. https://doi.org/10.1016/j.marpol.2016.10.001

11. Goodland, R. (1995). The concept of environmental sustainability. Annual Review of Ecology and Systematics, 26, 1–24. https://doi.org/10.1146/annurev.es.26.110195.000245

12. Harish, C. R., & Sunil, S. K. (2015). Energy consumption and conservation in shipbuilding. International Journal of Innovative Research and Development, 4(7), 1–10.

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ISSN: 2358-2472

13. Jesus, C. G., & Gitahy, L. M. C. (2009). Transformações na indústria de construção naval brasileira e seus impactos no mercado de trabalho (1997-2007). In Actas Proceedings: 1º Congresso de Desenvolvimento Regional de Cabo Verde & 15º Congresso da APDR (pp. 3898–3916). Cidade da Praia, Cabo Verde: [s.n.].

14. Lima, F. E. C. (2023). Soluções práticas na implementação de Lean Construction em estaleiros de construção: Estudo de caso (Master's dissertation). Instituto Politécnico de Bragança, Portugal.

15. Lira, H. V., Neves, D. C., & Soares, R. C. (2024). Tecnologias híbridas na construção naval: Um caminho para a eficiência energética e redução de emissões de CO2. [S.l.]: [s.n.].

16. Mota, J. (2025). Impressões sobre a política de conteúdo local e o estímulo à indústria naval no Brasil. Portos e Navios. Retrieved January 13, 2025, from https://www.portosenavios.com.br/artigos/artigos-de-opiniao/artigo-impressoes-sobre-a-politica-de-conteudo-local-e-o-estimulo-a-industria-naval-no-brasil

17. Nonato, R. (2023). A importância da indústria da construção naval para o mundo. Sindicato Nacional das Empresas de Navegação Marítima (SINCOMAM). Retrieved January 13, 2025, from http://www.sincomam.org.br/index.php/a-importancia-da-industria-da-construcao-naval-para-o-mundo/

18. Rijksdienst voor Ondernemend Nederland. (2016). The energiemanagementsysteem. Retrieved January 14, 2025, from http://www.rvo.nl/subsidies-regelingen/meerjarenafspraken-energie-effici%C3%ABntie/verplichtingen-mja3/mee/energiemanagement/softwaresystemen/het-energiemanagementsysteem

19. Third, I. (2014). GHG study. London, UK: International Maritime Organization.

20. Trainotti, K., et al. (2023). Proposta para remodelação do layout de um estaleiro náutico. [S.l.]: [s.n.].

21. Union, Directorate-General for Mobility and Transport. (2011). White paper on transport: Roadmap to a single European transport area: Towards a competitive and resource-efficient transport system. Publications Office of the European Union. https://doi.org/10.2832/30955

22. Wilson Sons. (2025). Indústria naval no Brasil: Tudo que você precisa saber sobre o assunto. Retrieved January 13, 2025, from https://www.wilsonsons.com.br/pt-br/blog/industria-naval-no-brasil-tudo-que-voce-precisa-saber-sobre-o-assunto