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RESEARCH PAPER

Digital transformation in naval industry

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ABSTRACT

Goal: The purpose of this article is to analyze how digital transformation can contribute to increasing the sustainable competitiveness of the shipbuilding industry in a developing country like Brazil.

Design / Methodology / Approach: To achieve this, a conceptual model was proposed, built from a literature review and interviews with 14 experts in the naval and offshore industry. The model was then validated through structural equation modeling, considering 326 responses from professionals in the researched sector.

Results: As a result, a model was developed, suggesting that to establish a Shipyard 4.0, enhancing the sustainable competitiveness of shipbuilding, it is necessary to align corporate strategic management with sustainable management of complex projects. This alignment should focus on the qualification of specialized labor to execute the entire Smart product lifecycle, encompassing intelligent design, manufacturing, assembly, and operation, all of which are integral to a Shipyard 4.0.

Limitations of the investigation: Bibliography searches on the topic were limited to thematic areas such as: digital shipyard, shipbuilding, digital transformation, intelligent manufacturing, automation, management, productivity, sustainability, people, security, labor, engineering, energy, computer science, economics, mathematics. The research aimed to provide results that characterized the application of a model that integrated digital transformation into the shipbuilding industry, in the thematic areas considered in the bibliographical research.

Practical implications: It is expected that this model will be applied in a shipyard as a pilot for validation through a case study, aiming to enhance the competitiveness of companies in the sector while considering the sustainable aspects associated with such endeavors.

Originality / Value: In this exploratory essay, we seek the intersection of themes such as Effective Management, Smart Manufacturing, Sustainable Project and Digital Shipyard. Brazil in 2018 had around 42 shipyards as Sinaval (2018) indicates on its website, through the map of shipyards and it is believed that the research can meet future demands of the sector. It is noted that there is no digital production line in Brazil at the end of 2018, therefore the thesis proposal is innovative.

Keywords: Shipbuilding; Smart Manufacturing; Sustainability; Industry 4.0; Digital Transformation.

1 INTRODUCTION

Among the means of transport for international trade, ships are more eficiente and sutainable, compared to land and air transport and are responsible for 90% of this international trade, this fact is obtained through various publications and parts of the website of the International Chamber of Shipping which is in London.

The "International Energy Outlook 2016" report from the U.S. Energy Information Administration (EIA) offers an assessment of the prospects for international energy markets until in 2012 to 815 quadrillion Btu in 2040. This document details energy consumption projections (International Energy Outlook 2016; Ang *et al*, 2017).

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"Energy efficiency is an important factor in the marine industry to help reduce manufacturing and operating costs, as well as the impact on the environment. Faced with global cost-benefit competition, ship builders and operators today require a major overhaul of the entire ship design, manufacturing process and operation to achieve these goals" (Ang *et al.*, 2017, p. 1).

Nearly all major players in the shipbuilding industry are preparing for the changes that will come in the next 10 to 20 years, actively working towards the fourth Industrial Revolution (Stanić *et al.*, 2018).

However, the reality of the Brazilian shipbuilding industry reveals a sector that is still very conservative, indicating a growing need for structural changes to improve performance indices in the face of challenges posed by the fourth industrial revolution (Goulart Filho, 2014). There is an aggravating shortage of qualified labor in Brazil due to a lack of interest in training individuals in the naval area in recent years, given the minimal investment in the sector (Dores *et al.*, 2012). According to Sinaval (2022), the historical series of jobs in the shipbuilding and offshore sector from 2020 to 2022 in May 2022 the number of employees in the sector was 21,447. The 'Readiness for the Future of Production' report, which evaluates the 100 countries representing around 96% of the world's GDP, Brazil ranks 41st in the 'production structure' category and 47th in the 'conducting factors of production' sphere (Figueiró *et al.*, 2020).

To reduce costs, improve productivity, and enhance competitiveness, it is necessary to integrate new sustainable technologies into the production process, driven by a shift in the sector's culture (Goulart Filho, 2014). Survey carried out by the Brazilian Oil and Gas Institute (IBP), launched this Thursday (04/18/2024), mapped 48 Brazilian shipyards. The finding is that at least six are deactivated and nine are active, but currently have no demand for naval projects. This survey highlights the need for demand to return to being competitive with the 1970s when Brazil ranked second in the world's shipbuilding scene. Business norms have shifted across all sectors, including the marine sector, with the proliferation of new digital technologies and the emergence of disruptive threats transforming business models and processes, rapidly capturing perceived societal value (Rogers, 2017).

In complex project environments such as the naval sector, the efficiency of results - increased competitiveness in quality, costs, and delivery - is tied to its ability to make appropriate decisions and solve various problems that arise throughout the life cycle of a naval project. However, this decision-making capacity is limited due to a combination of constraints present in the sector, including low technical levels of production facilities and the practices, techniques, and tools available to employees (Sánches-Sotano *et al.*, 2020).

It is within this context that this article aims to analyze how digital transformation can contribute to increasing the sustainable competitiveness of Brazilian shipbuilding, seeking to address the following research question: 'How can digital transformation enhance the competitiveness and sustainability of the Brazilian naval industry?' Therefore, a model is proposed based on the following constructs: Strategic Management (GEST), Sustainable Management of Complex Projects (GESPC), Skilled and Trained Workforce (MOQC), Smart Product Life Cycle (CVPS), and Shipyard 4.0 (EST40).

This research is unprecedented in Brazil, as no articles were found in the Scopus database that address the constructs used in this research, considering the Brazilian naval sector, The sector is in need of demand and one proposal for when it returns is to provide the market with a shipyard model that makes a difference in terms of productivity and that starts to incorporate industry 4.0 technologies. Here is the originality in the proposal presented. This is also a topic that has been relatively underexplored academically, with only around 20 articles identified related to digital transformation in the shipbuilding industry, with a concentration of publications from 2018 to 2020. Therefore, this research contributes by proposing a unique conceptual model, stimulating discussion on the topic of digital transformation in the shipbuilding sector of an emerging and developing country.

In 2014, Brazil had approximately 42 shipyards, and up until that point, there was no ship production line based on a 4.0 digital shipyard (Sinaval, 2014). Hence, this article contributes not only academically but also managerially by shedding light on relevant aspects that organizations in the Brazilian naval sector must consider enhancing their performance and sustainable competitiveness through technology adoption. The shipbuilding industry lags behind other manufacturing industries when it comes to digitalization (Sanchez-Gonzalez *et al.*, 2019; Stanic *et al.*, 2018).

2 THEORETICAL MODEL

Based on the findings resulting from the exploratory research and literature review carried out, a set of manifest variables were defined that support and were considered in the objective of this study. These variables and their theoretical framework are presented in Table 1.

Table 1 - Constructs and manifest variables

CONSTRUCTS AND MANIFEST VARIABLES OF THE MODEL		
Constructs	**Manifest Variables**	**Reference**
Exogenous		
Strategic management	Long term vision	Rogers, D. L. (2017), Transformação digital: repensando o seu negócio para a era digital, Autêntica Business.
	Organizational Transformation aligned with preparation for a Digital Transformation	Rogers, D. L. (2017), Transformação digital: repensando o seu negócio para a era digital, Autêntica Business.
	SDG (17 Principles and their consequences)	Strandhagen, J. W., Buer, S. V., Semini, M., Alfnes, E., Strandhagen, J. O. (2022), "Sustainability challenges and how Industry 4.0 technologies can address them: a case study of a shipbuilding supply chain", Production Planning & Control, Vol. 33, No. 9-10, pp. 995-1010.
Endogenous		
Sustainable Management of Complex Projects	Methodologies for Complex and Sustainable Products and Projects	Sánchez-Sotano, A., Cerezo-Narváez, A., Abad-Fraga, F., Pastor-Fernández, A., Salguero-Gómez, J. (2020), "Trends of digital transformation in the shipbuilding sector", in New Trends in the Use of Artificial Intelligence for the Industry 4.0, Intech Open.
	Complex Product and Project Management	Sánchez-Sotano, A., Cerezo-Narváez, A., Abad-Fraga, F., Pastor-Fernández, A., Salguero-Gómez, J. (2020), "Trends of digital transformation in the shipbuilding sector", in New Trends in the Use of Artificial Intelligence for the Industry 4.0, Intech Open.
	Triple Bottom Line	STRANDHAGEN, Jo Wessel et al. Sustainability challenges and how Industry 4.0 technologies can address them: a case study of a shipbuilding supply chain. Production Planning & Control, p. 1-16, 2020.
Qualified and Qualified Labor	Professional with knowledge (Hard skills and Soft skills) integrating Automation, Robotics and IT	Ang, J. H., Goh, C., Saldivar, A. A. F., Li, Y. (2017), "Energy-efficient through-life smart design, manufacturing and operation of ships in an industry 4.0 environment", Energies, Vol. 10, No. 5, pp. 1-13.
	Capabilities that enable Organizational Transformation aligned with Digital Transformation	Ang, J. H., Goh, C., Saldivar, A. A. F., Li, Y. (2017), "Energy-efficient through-life smart design, manufacturing and operation of ships in an industry 4.0 environment", Energies, Vol. 10, No. 5, pp. 1-13.
Exogenous		
Qualified and Qualified Labor (Cont.)	Continuing training	Ang, J. H., Goh, C., Saldivar, A. A. F., Li, Y. (2017), "Energy-efficient through-life smart design, manufacturing and operation of ships in an industry 4.0 environment", Energies, Vol. 10, No. 5, pp. 1-13.
	Disruptive Processes	Rivas, Á. R. (2018), "Navantia's Shipyard 4.0 model overview", Ciencia y tecnología de buques, Vol. 11, No. 22, pp. 77-85. Sánchez-Sotano, A., Cerezo-Narváez, A., Abad-Fraga, F., Pastor-Fernández, A., Salguero-Gómez, J. (2020), "Trends of digital transformation in the shipbuilding sector", in New Trends in the Use of Artificial Intelligence for the Industry 4.0, Intech Open.
Smart Product Life Cycle	Smart Design	Ang, J. H., Goh, C., Saldivar, A. A. F., Li, Y. (2017), "Energy-efficient through-life smart design, manufacturing and operation of ships in an industry 4.0 environment", Energies, Vol. 10, No. 5, pp. 1-13.
	Smart Manufacturing	Ang, J. H., Goh, C., Saldivar, A. A. F., Li, Y. (2017), "Energy-efficient through-life smart design, manufacturing and operation of ships in an industry 4.0 environment", Energies, Vol. 10, No. 5, pp. 1-13.
	Smart Operation (Circular Economy)	Ang, J. H., Goh, C., Saldivar, A. A. F., Li, Y. (2017), "Energy-efficient through-life smart design, manufacturing and operation of ships in an industry 4.0 environment", Energies, Vol. 10, No. 5, pp. 1-13.
Shipyard 4.0	Qualified people for industry 4.0	Rivas, Á. R. (2018), "Navantia's Shipyard 4.0 model overview", Ciencia y tecnología de buques, Vol. 11, No. 22, pp. 77-85.
	Disruptive Processes	Rivas, Á. R. (2018), "Navantia's Shipyard 4.0 model overview", Ciencia y tecnología de buques, Vol. 11, No. 22, pp. 77-85. Sánchez-Sotano, A., Cerezo-Narváez, A., Abad-Fraga, F., Pastor-Fernández, A., Salguero-Gómez, J. (2020), "Trends of digital transformation in the shipbuilding sector", in New Trends in the Use of Artificial Intelligence for the Industry 4.0, Intech Open.
	Organizational Transformation aligned with Digital Transformation	Rogers, D. L. (2017), Transformação digital: repensando o seu negócio para a era digital, Autêntica Business.

Source: Prepared by the Authors.

A theoretical relationship between five constructs was proposed: Strategic Management (GEST), Sustainable Management of Complex Projects (GESPC), Skilled and Trained Workforce (MOQC), Smart Product Life Cycle (CVPS), and Shipyard 4.0 (EST40). This enabled the construction of a theoretical model that addresses the research problem proposed in this paper, as illustrated in Figure 1.

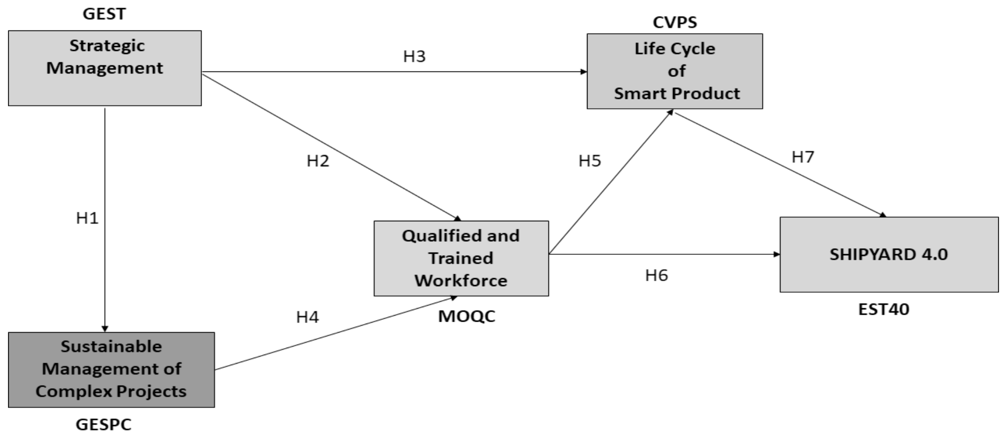

Figure 1 - Proposed theoretical model, variables (dependent and independent) and research problem
Source: Proposed by authors.

From the model proposed in Figure 1, which seeks to suggest how the digital transformation can contribute to the competitiveness and sustainability of the Brazilian shipbuilding industry, it is possible to establish a theory, which was statistically validated in this work. The model deals with the relationships between the pillars of the current need for shipbuilding aligned with industry 4.0: Strategic Management and Sustainable Management of Complex Projects indicate the naval companies need to have a Qualified Workforce to operationalize smart manufacturing through the Life Cycle of a Smart Product, where they would support a Shipyard 4.0. Table 2 details each of the hypotheses that were statistically tested, which were used to formulate the proposed theoretical model, as well as the theoretical framework.

Table 2 – Hypotheses created from the proposed theoretical model

Hypotheses	Authors
H1 – Strategic Management (GEST) is positively related to Strategic Management of Complex Projects (GESPC).	Rogers (2017), Strandhagen *et al.* (2022), Sánchez-Sotano *et al.,* (2020), Ang *et al.* (2016), Rivas (2018).
H2 – Strategic Management (GEST) is positively related to Qualified and Trained Labor (MOQC).	
H3: Strategic Management (GEST) is positively related to the Smart Product Life Cycle (CVPS).	
H4: The Sustainable Management of Complex Projects (GESPC) is positively related to Qualified and Qualified Workforce (MOQC).	
H5 – Skilled and Skilled Workforce (MOQC) is positively related to the Smart Product Life Cycle (CVPS).	
H6 – Skilled and Trained Workforce (MOQC) is positively related to Shipyard 40 (EST40).	
H7 – Smart Product Life Cycle (CVPS) is positively related to Shipyard 4.0 (EST40).	

Source: Proposed by authors

In the following chapter, the theoretical framework that supports the theoretical model and research's hypotheses will be presented, as well as the details of the variables and sub variables - dependent and independent variables - of each of the constructs that was considered in the theoretical model.

3 LITERATURE REVIEW

According to SofExpert (2021), it is expected that with Digital Transformation (DT), there will be a reduction in operational costs, elimination of productivity barriers, ease in monitoring processes and detecting variations, improved operations, reduced manufacturing deviations, accelerated problem resolution, enhanced factory efficiency and productivity, and simplified management.

The shipbuilding industry has faced difficulties due to the large number of design changes or customer reviews during construction, which often leads to loss of control over costs and quality and discussions around "Shipbuilding 4.0" involve integration of advanced digital technologies, automation and cyber-physical systems in the shipbuilding process, potentially leading to significant improvements in efficiency and productivity. The weight of the crisis generated great losses, strongly affecting shipyards that were unable to fully meet the requirements of quality, safety, cost efficiency and fluctuations in the shipbuilding market (Stanić *et al.*, 2018).

Considering this context, in the following, each variable that was considered in the proposed model will be explained, showing its significate and the connection between them.

3.1. Strategic Management

According to Rogers (2017), digital transformation is not about technology, it is about strategy and new ways of thinking. Transforming to digital requires the business to update its strategic mindset, much more than its Information Technology (IT) infrastructure. In the same vein, Kane *et al.* (2015) states that the strength of digital technologies is not in the technologies per se. Instead, it stems from how companies integrate them to transform their businesses and the way they work (Kane *et al.*, 2015).

Rogers (2017), points out that business rules have changed, since in all sectors of activity, the diffusion of new digital technologies and the emergence of new disruptive threats are rapidly transforming business models and processes, capturing the perceived value society faster. The digital forces are reshaping five fundamental strategy domains: customers, competition, data, innovation, and value. Digital transformation is not, basically, about technology, but rather about strategy, with a long-term vision. Although it may require you to update your IT architecture, the most important thing is to improve your strategic thinking (Rogers, 2017).

Due to economic pressure on the shipbuilding industry, there has also been a consistent increase in focus on a more ecological and socially responsible environment in the maritime industry (Strandhgen *et al.*, 2022; Para-Gonzalez *et al.,* 2020). According to Strandhagem *et al*. (2022), to improve sustainability and meet the Sustainable Development Goals (SDGs) proposed by United Nation (UN), the impact companies have on sustainability there must be a holistic assessment of supply chain sustainability, requiring a look at all phases of the supply chain through which products pass.

Digitalization can play a very important role in overcoming the challenges faced in ship remanufacturing or recycling, also known as ship dismantling. The possibility of having a complete view of the process, that is, a complete digital view of a ship and its components, including material tracking, disassembly design, logistics, among others, can help companies overcome obstacles related to remanufacturing (Strandhagen *et al,* 2022).

In this context and in view of the plurality of definitions, the choice of variables in Table 3 was chosen to characterize the strategic management construct.

Table 3 - Strategic Management sub variables

GEST sub variables	Authors
Long term vision	Rogers (2017), Strandhagen *et al*. (2022) e Kane *et al*. (2015).
Organizational Transformation aligned with the preparation for a Digital Transformation	
Sustainable Development Goals (SDGs)	

Source: Proposed by authors.

3.2. Sustainable Management of Complex Projects

According to Strandhagen *et al.* (2022), the characteristics of shipbuilding are similar to the manufacture of large and highly customizable products. Of great importance for the management of shipbuilding operations is the supply chain which has a huge amount of materials with various types of purchase/sales volume specifications and compliance with tight deadlines, resulting in more uncertainty and complicated flow of materials and information.

Because ships are complex, highly customized products that are manufactured in low volume, the degree of customization of finished products is high and often unique.

According to Para-Gonzalez *et al.* (2020), shipyards are organized where the product is fixed, that is, the ship. Workers and materials move to the product where its logistics are quite complex, this type of layout is called fixed positional, a typical model of non-repetitive production systems and this type of production makes process automation difficult and finds the massive use of manual labor in this type of manufacturing.

In order to achieve a project that is sustainable or green, Toledo *et al.* (2021), understand that it is necessary to combine green project management processes, with the development and management of a sustainable supply chain, plus life cycle management. of the product and project considering sustainability issues. From this vision, project’s results must be measured by three factors, that must interact holistically, which constitute the triple bottom line concept: Social (people), Environmental (planet) and Economic (profit) (Silvius, 2015).

In this context and in view of the plurality of definitions, the choice of variables in Table 4 was chosen to characterize the construct sustainable management of complex projects.

Table 4 - Sustainable Management of Complex Projects

GSPC sub variables	Authors
Methodologies for Complex and Sustainable Products and Projects	Strandhagen *et al.* (2022), Para-González *et al.* (2020), Silvius (2015).
Complex Product and Project Management	
Triple Bottom Line	

Source: Proposed by authors.

3.3. Qualified and Trained Labor

In the era of Shipbuilding 4.0, shipyards need qualified engineers proficient in technical sciences, as well as information technology experts, and access to all relevant technical data of successful ship classes. During the design phase, it is essential to minimize both the design period and engineering costs for future ship classes. This comprehensive solution encompasses the entire shipbuilding enterprise and lifecycle, enabling shipbuilders to integrate their organizational knowledge (Stanić *et al.,* 2018). According to Erol *et al.* (2016), engineers need to possess personal competence, which can be understood as an individual's ability to act reflexively and autonomously. Personal competence also includes the ability to learn, develop one's own attitude, and establish a system of ethical values; in essence, it involves both soft and hard skills.

Among a series of technologies that facilitate the implementation of industry 4.0, the following can be highlighted as the main ones, among others: Internet of Things (IoT); cyber-physical systems, smart factories, visual computing, semantic technologies, product lifecycle management, industrial big data, cybersecurity, intelligent robotics (autonomous and collaborative), augmented reality and industrial automation; cloud computing, data analysis, integrated product production, simulation and additive manufacturing (Ang *et al.*, 2017; Hermann *et al.,* 2015; Kagermann *et al.*, 2013; Posada *et al.*, 2015).

For industry 4.0 workers who will work in smart factories, there will be a need to undergo training to obtain skills and competencies to be able to operate machines that have more advanced technology and this worker will need a lot of knowledge of digital technologies, it is observed that the the basis of this work will be depending on this technology (Erol *et al.*, 2016). According to Kagermann *et al.* (2013), Erol *et al.* (2016), among other knowledge, automation technology systems and data analysis stand out and this will in turn require more decision-making competence from people (Ang *et al.*, 2017).

These skills and competencies can be developed and improved through the application of training and education programs, for example, scenario-based or e-learning (Darban and Ismail, 2012; Erol *et al.*, 2016). In short, companies must work closely with schools and universities so that future employees can receive the skills and competencies required by new job profiles (Kiel *et al.*, 2017).

In this context and in view of the plurality of definitions, it was decided to choose the variables in Table 5 to characterize the construct of skilled labor.

Table 5 - Qualified and trained labor

MOQC sub variables	Authors
Hard and Soft skills integrating Automation, Robotics, and IT	Ang *et al.* (2017), Sánchez-Sotano *et al.*, (2020), Stanić *et al.* (2018).
Enabling capabilities for aligning organizational and digital transformations	
Continuing education	
Disruptive Processes	

Source: Proposed by authors.

3.4. Smart Product Lifecycle

According to Ang *et al*. (2017), to meet changing customer needs and comply with stricter environmental regulations, shipyards must have the ability to anticipate trends and modify designs or manufacturing processes accordingly. While Industry 4.0 technologies can be applied individually at each stage of the life cycle to reduce energy consumption and enhance energy efficiency, the maximum benefit can only be achieved by combining multiple technologies across the entire product life cycle. To achieve this objective, Ang *et al.* (2017) propose a framework called the "Smart Product Life Cycle," illustrated in Figure 2, which integrates various Industry 4.0 technologies and addresses the key challenges in a two-way closed loop for the ship's life cycle.

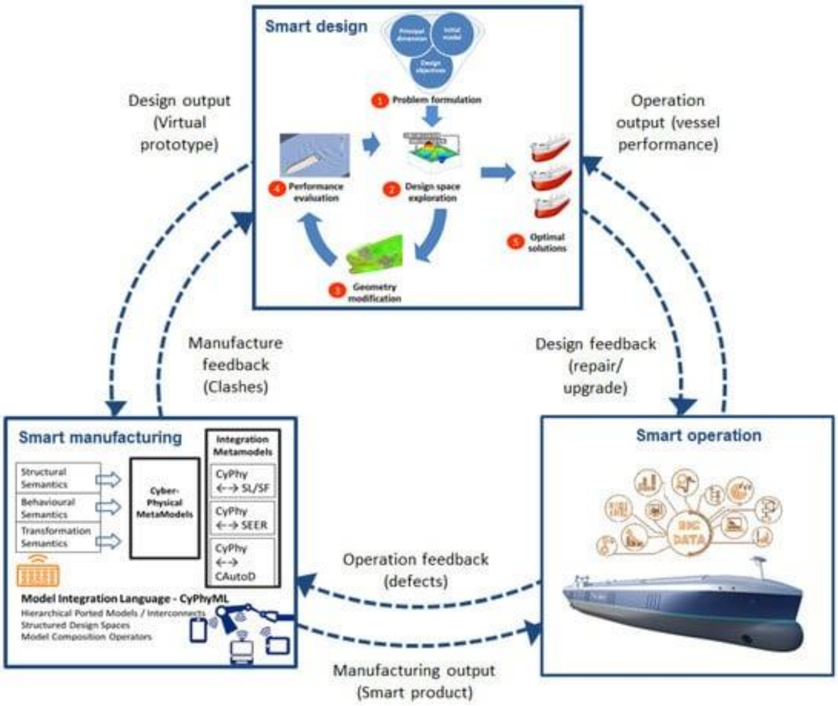

Figure 2 - Smart Product Life Cycle framework
Source: Ang *et al*. (2017).

According to Figure 2, to obtain better results, the application of a supply chain of reliable suppliers linked to the shipyard, schedules and 3D models in all phases of the project aims to reduce the service cycle and review of work, both in manufacturing and ship operation (Ang *et. al*., 2017).

According to Ang *et al*. (2017), Venta (2007), Meyer *et al*. (2009), the incorporation of disruptive technologies such as the internet of things (IoT), big data analysis, among others, allows the segment to be in the context of industry 4.0 and shipyards will build ships as a smart product or smart asset, manufacturing a product seeing the complete cycle from engineering to manufacturing and operation.

In this context and in view of the plurality of definitions, it was decided to choose the variables in Table 6 to characterize the smart product life cycle construct.

Table 6 - Smart product life cycle sub variables

CVPS sub variables	Authors
Smart Project	Ang *et al.* (2017), Venta (2007), Meyer *et al* (2009).
Smart Manufacturing	
Smart Operation (Circular Economy)	

Source: Proposed by authors.

3.5. Shipyard 4.0

The shipbuilding sector has embraced the industry 4.0 concept to adapt and evolve. Specifically, this adaptation is termed as "Shipyard 4.0," an outcome of applying Industry 4.0 principles to this

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industry. Shipyard 4.0 encompasses significant alterations within the shipyard production system, involving advancements in facilities, sophisticated product design, shifts in management, and the integration of digital technologies. Essentially, Shipyard 4.0 represents the shipbuilding sector's response to the imperative digital transformation (Sanchez-Sotano, 2020).

The intelligence and connectivity on board ships and their systems during construction will be maintained after delivery to owners, enabling engagement between the smart ship and shipyard 4.0 throughout its life, enabling smart sustainment and new business models (Rivas, 2018). The highly complex environment – for the technical and management fields – the digital twin or zero ship will be the cornerstone of the Shipyard 4.0 concept. It will allow the simulation of new products and process developments on virtual workstations. This includes personal considerations and the reduction of health and safety risks (Rivas, 2018; Porter and Heppelmann, 2015).

In recent years, with the fourth industrial revolution, several companies have started to adopt this strategy in their businesses, seeking to transform their analogue factories into digital ones and adopting the entire production process cycle ranging from design, manufacturing, operations, transportation, services, production systems, maintenance and value chains in all aspects of the shipbuilding industry. Although there are still problems to be resolved such as: production efficiency, ship safety, cost efficiency, energy conservation and environmental protection. One path to be adopted will be the implementation of shipyard 4.0 and this can present a reduction in production costs and operational and increased production efficiency (Stanić *et al.*, 2018).

In this context and in view of the plurality of definitions, the choice of variables in Table 7 was chosen to characterize the construct shipyard 4.0.

Table 7 - Shipyard 4.0 sub variables

EST40 sub variables	Authors
People trained for industry 4.0	Rivas (2018), Sánchez-Sotano et al. (2020), Rogers (2017)
Disruptive Processes	
Organizational Transformation aligned with Digital Transformation	

Source: Proposed by authors.

Based on the article by Lima *et al.* (2019), the benefits of using collaborative robots, especially in Brazilian companies, are still not clear. This article contributed to the discussion about collaborative robots and consequently to the implementation of Industry 4.0. The use of collaborative robots appears to be a new frontier of use in 4.0 shipyards, a topic that is still controversial due to the possible increase in productivity, but with the possibility of using less labor in the shipbuilding sector.

Within the shipyard 4.0 scenario, there is the application of IOT, as mentioned by Miranda Junior *et al.* (2017, p. 573):

- Personal: Sensors with the support of cloud computing and data mining can be used to monitor and quantify quickly and accurately the entry and location of employees in construction sites.
- Health: it is possible to verify the reduction of hours lost in the absence to the work and the decrease in the number of trips to the doctor due to health problems through controls of the vital signs of the worker, such as temperature and blood pressure control through the use of skin pads and RFID system.
- Enviromental: The quantitative and qualitative controls of the emission of gases, the consumption of electric energy and compressed air can be carried out by IoTS, which allows greater economy, in addition to comply with legal environmental requirements.
- Automation: The quality of some of the welding processes can be significantly improved with their respective automation and robotization. Such improvements are based on the use of IoTS for the positioning of parts and activation and shutdown of welding equipment.
- Building: The use of tagging technology in tracking and locating equipment, such as cranes, trucks, and other vehicles or mobile equipment for assembling subsystems can improve resource utilization and reduce task execution times at the construction site.
- Transportation: The shipment, transportation, storage, distribution and application processes of parts and systems are better fulfilled and monitored with the support of IoTS technologies. The loss rates of parts and rework are significantly reduced, in addition to improving the space management of the site with the use of IoTS.

4 METHODOLOGICAL PROCEDURES

In this research a mixed approach was used, combining qualitative and quantitative methods. With the objective to propose the Shipyard 4.0 model presented in Figure 1, the methodological framework proposed by Marchisotti and Farias Filho (2022) was adopted. This framework is composed of a literature review on the researched topic, and by conducting interviews with specialists from the researched sector, using the grounded theory assumptions to code the data, both from the literature and from the interviews (Glaser; Strauss, 1967), in order to identify the direct and indirect variables used for the construction of the theoretical model. For this purpose, NVIVO software was used for lexical and content analysis of selected articles and interviews with industry experts (Dhakal, 2022).

The literature review was carried out through the application of a Boolean formula - *Digital Transformation AND Effective Management AND People AND Labor Safety AND Productivity AND Sustainability AND Industry 4.0 AND Intelligent Manufacturing AND Automation AND Digital Shipbuilding* - , in the SCOPUS database, in order to address two thematic axes - Effective Management and Industry 4.0 -, initially identifying 8059 articles, which after applying a sequence of filters - articles reviewed by peers, most recent and that are aligned with the research theme - 44 articles were effectively analyzed. Subsequently, 14 interviews were conducted with specialists in the areas of digital transformation and lean production, using a semi-structured script for data collection, focusing on identifying the critical success or failure factors for carrying out a digital transformation in construction sites/ shipyards & offshore in Brazil.

Both the 44 articles from the literature review phase and the 14 interviews with specialists were effectively incorporated into the NVIVO software for lexical and content analysis, with the identification of categories, which made it possible to identify both the research question and the proposition of the research. proposed theoretical model, through the analysis of the causal relationship between the different categories identified (Marchisotti and Farias Filho, 2022).

Once the theoretical model was built, the structured equation modeling technique (SEM) was used for the statistical validation of the theoretical model of Shipyard 4.0, containing the categories identified as the most relevant. A survey was carried out containing an online questionnaire, which was sent to several contacts of the authors who work or had experience in the researched area, and which was disseminated on social networks, such as LinkedIn, Facebook, Instagram, WhatsApp, and Twitter, using the Snowboll technique (Marchisotti and Farias Filho, 2022).

To analyze the relationships between different equations, the multivariate SEM technique was used, where each one has a different dependent variable, which in turn has different independent variables; being the appropriate and efficient estimation technique to estimate multiple regression equations simultaneously, as is the case in this research. Thus, SEM is an approach used to examine how a set of independent variables works - also called manifest variables or observed variables , which in the case of this research are GEST1, GEST2, GEST3, GESPC1, GESPC2, GESPC3, MOCQ1, MOCQ2, MOCQ3. , MOCQ4, CVPS1, CVPS2, CVPS3, EST401, EST402, EST403 - is associated with different dependent variables - also called constructs or latent variables, which in the case of this research are GEST, GESPC, MOCQ, CVPS, EST40 (Bollen, 1989; Hair Jr. *et al.*, 2009; Hoyle, 1995; Toledo *et al.,* 2021).

In this research, two basic components characterize the SEM methodology: 1) The Measurement Model (MM), which aims to estimate the causal relationship between the dependent variables and their independent variables and 2) The Structural Model (SM), which aims to estimate the causal relationship between the latent variables for one or more independent variables (Bollen, 1989; Toledo *et al.*, 2021; Varela *et al.*, 2019; Marchisotti *et al.*, 2022). To process the data and establish the causal relationship between MM and SM, the IBM SPSS Amos software, version 24 (IBM, 2016) was used, as it is one of the best-known software for operationalizing SEM (Castro, 2018). Table 8 presents all the dependent and independent variables that make up the theoretical model of shipyard 4.0 tested.

Table 8 - Dependent and independent variables

Dependent Variables	Independent variables
Strategic management (GEST)	Long term vision (GEST1)
	Organizational Transformation aligned with the preparation for a Digital Transformation (GEST2)
	Sustainable Development Goals (GEST3)
Sustainable Management of Complex Projects (GESPC)	Methodologies for Complex and Sustainable Products and Projects (GESPC1)
	Complex Product and Project Management (GESPC2)
	Triple Bottom Line (GESPC3)

Qualified and Trained Workforce (MOCQ)	Professional with knowledge (Hard skills and soft skills) integrating Automation, Robotics, and IT (MOCQ1)
	Capabilities that enable Organizational Transformation aligned with Digital Transformation (MOCQ2)
	Continuing education (MOCQ3)
	Disruptive Processes (MOCQ4)
Smart Product Lifecycle (CVPS)	Smart Project (CVPS1)
	Smart Manufacturing (CVPS2)
	Smart Operation (Circular Economy) (CVPS3)
Shipyard 4.0 (EST40)	Skilled Individuals for Industry 4.0 (EST401)
	Disruptive Processes (EST402)
	Organizational Transformation Aligned with Digital Transformation (EST403)

Source: Prepared by the Author.

The sample size is a critical aspect to be considered and should be established at a minimum value, which according to Westland (2010) is 200 respondents for surveys involving the SEM (Anderson, 1989). According to Hair et al. (2009), MEE models containing five or less constructs each, with more than three items - observed variables - and with a high degree of convergence - 0.6 or more - can be adequately estimated with small samples between 100 and 150 respondents. Thus, the sample population obtained from 326 respondents effectively used to validate the theoretical model of the shipyard 4.0 are adequate to guarantee the reliability of the results.

5 DATA ANALYSIS

5.1. Qualitative Analysis

The profile of the literature review sample of the 44 selected articles presents content focused on the following themes, that are aligned with the objective of this article - Digital Shipbuilding/ Shipbuilding 4.0 and Shipyard 4.0 Shipbuilding -, represented in the word cloud in Figure 3. It was identified that Rogers (2017), Strandhagen *et al.* (2022), Ang *et al.* (2017), Rivas (2018) and Sánchez-Sotano *et al.* (2020) presented themselves as the most aligned with the objectives of this research.

Figure 3 - Cloud of the 500 most frequent words in articles
Source: Prepared by the Author.

In turn, Table 9 presents the sample profile of the interviewees, considering the time of experience, their function at the time of the research, the sector in which they work and the nature of the projects in which they are involved, demonstrating that their profiles are aligned with the research topics.

Table 9 - Experts interviewed

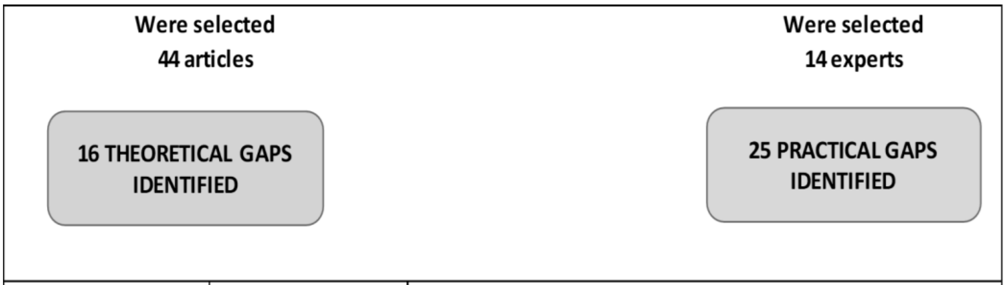
Identification	Years of Work Exp.	Function	Organization	Project's Nature
Interviewee 1	17	President	Manufacturing	Shipbuilding e Offshore
Interviewee 2	51	Director	Manufacturing	Shipbuilding e Offshore
Interviewee 3	45	Director	Manufacturing	Shipbuilding e Offshore
Interviewee 4	42	Director	Technologies	Engineering & Tech.
Interviewee 5	16	Director	Consultancy	Lean Production
Interviewee 6	36	Project Manager	Manufacturing	Oil and Gas
Interviewee 7	30	Project Manager	Engineering	Shipbuilding e Offshore
Interviewee 8	30	IT Manager	Government	TI & Telecom
Interviewee 9	12	IT Manager	Manufacturing	Oil and Gas
Interviewee 10	38	Project Manager	Government	Education
Interviewee 11	15	Project Coordin.	Manufacturing	Energy
Interviewee 12	20	Project Coordin.	Manufacturing	Shipbuilding e Offshore
Interviewee 13	38	Project Manager	Manufacturing	BIM & Planning
Interviewee 14	35	Entrepreneur	Education	Entrepreneurship

Source: Prepared by the Authors.

It was also possible to generate a word cloud of the most frequent expressions in the interviews, highlighting some expressions such as People/Personnel, Knowledge, Projects/Processes, Market Intelligence/Business, and Investment, within the context of digital transformation of the shipyards, subject of the article, as shown in Figure 4.

Figure 4 - Cloud of the 500 most frequent words in interviews
Source: Prepared by the Author.

From the lexical and content analysis it was possible to identify 16 categories in the literature review phase – called theoretical gaps and 25 categories in the interviews – called practical gaps. In order to identify the research problem adopted in this paper: "How can digital transformation improve the competitiveness and sustainability of the shipbuilding & offshore industry in Brazil?", a combination of 3 theoretical gaps and 3 practical gaps was chosen, according to Figure 5 (Bezerra, 2023).



item	Gap	Gap Identification
1	theoretical	Low productivity
3	theoretical	Improve industry competitiveness
4	theoretical	Creating a sustainable shipbuilding industry
16	Practice	technological maturity
23	Practice	Understanding the need for digital transformation
24	Practice	People's training

Figure 5 - Summary of the process of identifying theoretical gaps and practical gaps
Source: Prepared by the Author.

5.2. Quantitative analysis

By processing the data using the IBM SPSS Amos software, it was possible to validate both models, Structure Model (SM) and Measurement Model (MM), and thus verify whether the internal relationships of the independent variables with their respective constructs, as well as the relationship between the different variables among themselves, were statistically

After applying the online questionnaire, 377 responses were obtained, of which 326 (86.5%) were used to analyze the results, eliminating all incomplete responses or with repeated responses. Regarding the result of the statistical reliability of the total number of valid responses received for the 16 independent variables, the calculated Cronbach's alpha was 0.948, indicating a very high reliability of the data.

Considering the sample characteristics, it was identified greater participation of high qualifications respondents, where 14% have a doctorate, 29% have a master's degree and 16% have a postgraduate degree. Regarding the position they occupy/occupied in the company structure, there is also a greater participation of the management level, where 14% were executives/strategic positions and 31% tactical position as coordinator/manager. Regarding the size of the company, 68% work/worked in a large company and 22% in a medium-sized company. Regarding the industry segment where they operate, 11% are from the shipbuilding area, 12% from IT, 28% from Education, 7% from Consulting, 10% from Manufacturing and 7% from Architecture, Engineering & Construction. Furthermore, 41% of respondents work/have worked in Latin America, 52% in North America and 2% in Europe, Asia 3%, Africa. Finally, regarding the length of professional experience, 53% have more than 20 years and another 33% 11-20 years, which demonstrates a sample aligned with the research profile.

The Figure 6 shows the Measurement Model (MM) used, with the 5 constructs defined in the conceptual model, namely: Strategic Management (GEST), Sustainable Management of Complex Projects (GESPC), Qualified and Trained Workforce, Life Cycle of Smart Product (CVPS) and Shipyard 4.0 (EST40) and Qualified Labor (MOQC), where the constructs have a relationship of all for all.

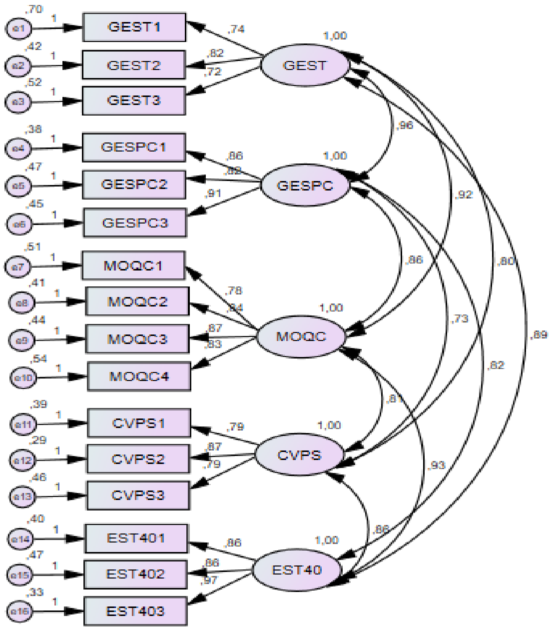


Figure 6 - Measurement Model (MM) and dependent and independent variables
Source: Prepared by the Author.

According to Figure 6, both the dependent and independent variables presented an index of adjustment and validity, due to the factorial weights being greater than 0.25 (Hu & Bentler, 1999). Table 10 presents a list of the evaluation and analysis of the MM parameters, where the manifest variable "EST403 – Organizational Transformation aligned with DT', had the highest factorial weight among the manifest variables, indicating the importance of digital transformation integrated and aligned with the organizational strategy.

Table 10 - Summary of estimates associated with the Measurement Model (MM)

Manifest variable		Construct	Estimated	EP (Standard error)	Z (Standard deviation)	p-value
GEST1	←	GEST	0,742	0,057	12,985	p<0,001
GEST2	←	GEST	0,819	0,051	16,223	p<0,001
GEST3	←	GEST	0,719	0,051	14,097	p<0,001
GESPC1	←	GESPC	0,863	0,050	17,113	p<0,001
GESPC2	←	GESPC	0,820	0,052	15,731	p<0,001
GESPC3	←	GESPC	0,906	0,054	16,840	p<0,001
MOQC1	←	MOQC	0,782	0,052	15,127	p<0,001
MOQC2	←	MOQC	0,845	0,050	16,838	p<0,001
MOQC3	←	MOQC	0,865	0,052	16,787	p<0,001
MOQC4	←	MOQC	0,830	0,054	15,375	p<0,001
CVPS1	←	CVPS	0,788	0,049	16,068	p<0,001
CVPS2	←	CVPS	0,866	0,048	18,023	p<0,001
CVPS3	←	CVPS	0,793	0,052	15,395	p<0,001
EST401	←	EST40	0,858	0,050	17,110	p<0,001
EST402	←	EST40	0,863	0,053	16,437	p<0,001
EST403	←	EST40	0,968	0,051	18,868	p<0,001

Source: Prepared by the Author, using IBM SPSS Amos software.

In turn, Table 11 presents the values of the goodness of fit indexes obtained in the MM assessment. From the analysis of Table 10 it is possible to confirm the validation of the MM.

Table 11 - Adjustment values obtained for MM validation

Adjustment Indexes	Obtained Adjustment Values	Adjustment Criterion
χ^2 / do	2.391	< 3
GFI	.921	> 0.9
CFI	.961	> 0.9
TLI	.951	> 0.9
IFI	.962	> 0.9
PCFI	.753	> 0.6
PGFI	.636	> 0.6
RMSEA	.065 (p=.000)	< 0.08; p > 0.05
AIC	308.753 < 2507.153	*"Smaller than the Independence model"*

Source: Prepared by the Author, using IBM SPSS Amos software.

The Figure 7 shows the Structure Model (SM) used, with the 16 sub variables that composed each construct defined in the conceptual model.

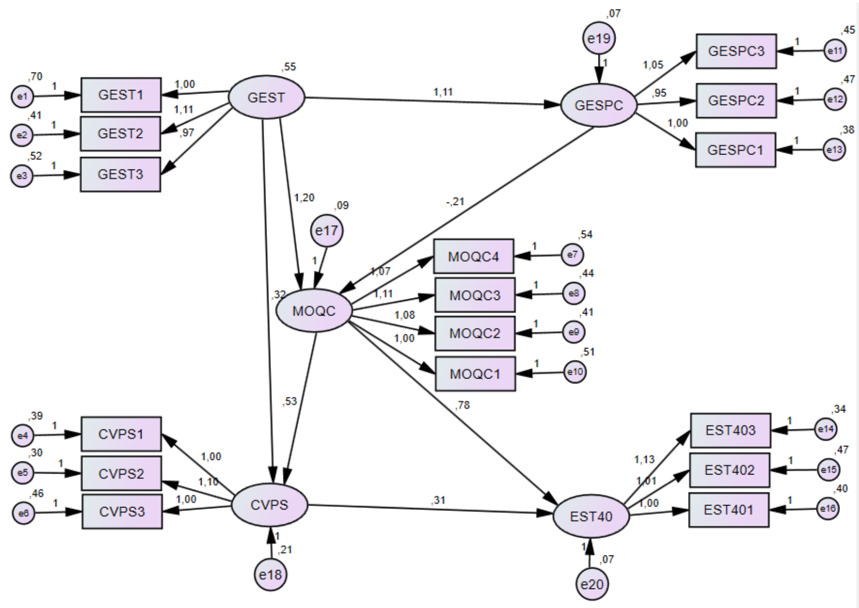


Figure 7 - The Structural Model (SM) used in this research
Source: Prepared by the Author.

Table 12 presents the values of the goodness of fit indexes obtained in the evaluation of the SM. It is noteworthy that the values in Tables 10 and 11 meet the criteria defined in the literature (Varela *et al*, 2019; Toledo *et al.*, 2021; Marchisotti, 2022; Hair *et al,* 2009; Hu and Bentler, 1999; Mulaik *et al.*, 1989; Satorra and Bentler, 1990).

Table 12 - Adjustment values obtained for SM validation

Adjustment Indexes	Obtained Adjustment Values	Adjustment Criterion
□□^{2} / df	2.330	< 3
GFI	.920	> 0.9
CFI	.962	> 0.9
TLI	.953	> 0.9
IFI	.962	> 0.9
PCFI	.777	> 0.6
PGFI	.656	> 0.6
RMSEA	.064 (p=.018)	< 0.08; p > 0.05
AIC	314.029 < 3526.876	"Smaller than the Independence model"

Source: Prepared by the Author, using IBM SPSS Amos software.

Finally, the analysis of the structural relationship between the ME constructs was carried out, according to Table 13, identifying that the research hypotheses: H1, H2, H5, H6, and H7 were confirmed, and the hypotheses H3 and H4 were not confirmed (H3: p = 0.111 > 0.05, H4: p = 0.640 > 0.05).

Table 13 - Validation of MS estimates and hypotheses

Hypoth.	Exogenous Constructs	Endogenous Constructs	Estimate	EP (Standard error)	Z (Standard deviation)	p-Value	Conclusion
H1	GEST	GESPC	1,109	0,095	11,726	P <0,001	Confirmed
H2	GEST	MOQC	1,200	0,529	2,266	p <0,001	Confirmed
H3	GEST	CVPS	0,322	0,202	1,595	0,111	Not Confirmed
H4	GESPC	MOQC	-0,207	0,441	-0,468	0,640	Not Confirmed
H5	MOQC	CVPS	0,533	0,196	2,720	P <0,001	Confirmed
H6	MOQC	EST40	0,777	0,095	8,177	P <0,001	Confirmed
H7	CVPS	EST40	0,312	0,084	3,692	P <0,001	Confirmed

Source: Prepared by the Author, using IBM SPSS Amos software.

According to Brones *et al.* (2014), Silvius and Schipper (2014) the validation of the research hypotheses helps to fill the gap in the literature related between Digital Transformation and Shipyard 4.0. Thus, using the Maximum Likelihood Method, it was possible to define the final validated model as shown in Figure 7 (Bezerra, 2023).

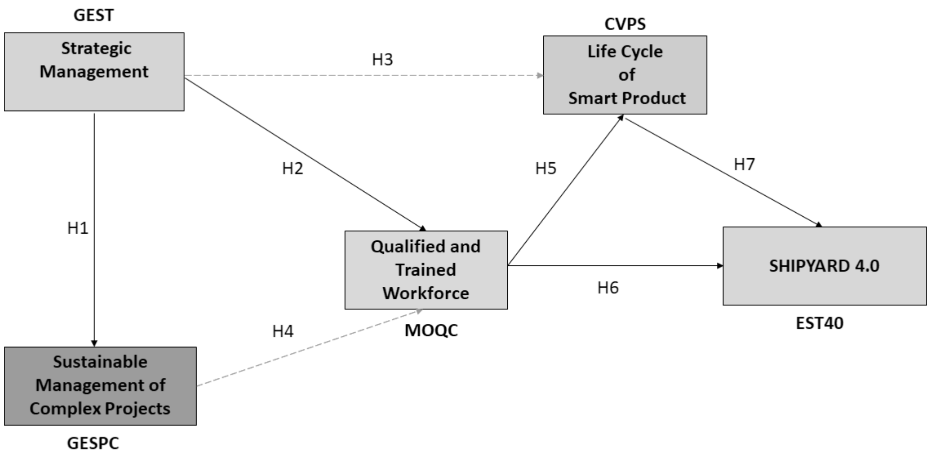


Figure 7 - Final conceptual model after SEM statistical validation
Source: Prepared by the Author.

6 DISCUSSION OF RESULTS

From the statistical analyzes on the theoretical model of the shipyard 4.0 proposed and validated as shown in Figure 7, vis a vis with the theoretical review, it is possible to discuss the analyzed data, to obtain some relevant insights to identify the contribution of this article.

From the analysis of the results of the qualitative analysis, it is noticed that there are relatively few articles that address the subject digital transformation and shipyard 4.0, without the identification of Brazilian articles, which consider the subject within a Brazilian national context, of an emerging country and under development, and with a naval base that is still little digitized.

The non-confirmation of hypotheses H3 and H4, in disagreement with the theory, can be explained by the lack of understanding and interpretation, by the Brazilian respondents who participated in the survey, on the topics Digital Transformation and Shipyard 4.0; that are far from the day-to-day and academic training of most managers and professionals in general.

In fact, as pointed out by the results, the vision of having a workforce - workers, technicians and managers - trained and qualified in the Brazilian naval industry, specific to industry 4.0, is still not perceived, in practice, by the shop floor and at the tactical level associated with it, as something important or relevant to improving the competitiveness and sustainability of the shipbuilding industry; being even more related to a strategic vision, apparently restricted to the top echelon of companies in the sector and in all the main actors of the naval industry, as mentioned by Stanic *et al.* (2018), but not operationalized in practice.

It is also inferred that the lack of a positive relationship between the variables Strategic Management (GEST) and the Smart Product Cycle (CVPS) can be explained by the respondents' lack of knowledge about the concept of a smart product lifecycle. product. According to Ang et al (2017), an intelligent design with energy efficiency throughout the life cycle must have a two-way closed-loop structure for the design, manufacture and operation of ships and the respective disruptive technologies that are currently used in the area of shipbuilding and offshore industry, which are moving from analog to digital shipyards, as addressed by Stanić *et al.* (2018), Ang *et al.* (2016) and Strandhagen *et al.* (2022).

According to Fernandez-Caramés *et al.* (2018), Blanco-Novoa *et al.* (2018), Dallasega *et al.* (2018), Ang *et al.* (2017) the digital solutions applied to the shipyards are still at a conceptual level, in development or at most in the pilot phase, in the world. It is also inferred that, as addressed by Ang et al (2017), the Smart Product Cycle that focuses on aspects related to the cycle of construction and demobilization of a ship - design, construction, operation and dismantling -, in the concept of the digital shipyard 4.0, aspects related to engineering and increased productivity are more evident than, effectively, to strategic approaches, with a long-term vision, with organizational transformations and sustainable concerns, in line with what Rogers (2017) advocates. and Strandhagen *et al.* (2022).

Regarding the lack of a positive relationship between the variables Sustainable Management of Complex Projects (CVPS) and Skilled and Qualified Labor (MOQC), projects classified as complex are thus identified because they are long, high risk and difficult execution, with a very large number of components and suppliers involved and difficult to manage. According to Cavalcante and Farias Filho (2015), projects said to be complex can be defined as those that have a high number of variables to be considered, demanding a high degree of multidisciplinary, duration and diversity of information, thus generating an enormous difficulty in its conduction, requiring robust and detailed management models to be effective, causing aspects related to sustainability not to be effectively considered, as defended by Sanchez-Sotano *et al.* (2020).

Furthermore, as the context of the research is related to the digital transformation in shipyards, aspects related to sustainability in projects, as addressed by Silvius (2015), Toledo *et al.* (2021), and Rumaithi and Beheiry (2016), do not seem to be recognized by respondents as directly associated with a technically qualified workforce – Hard and Soft skills – in the context of potential disruptive technologies used in the digital transformation of a 4.0 shipyard. The agenda defended by Strandhagen *et al.* (2022), Para-Gonzalez *et al.* (2020), of a socially responsible maritime industry, with a concern and focus on a more ecological environment will be part of the challenges for new Brazilian shipbuilding on the way to Shipyard 4.0.

7 CONCLUSION

This article achieved its research objective by proposing a theoretical model, statistically tested, identifying how the digital transformation could improve the competitiveness and sustainability of the Brazilian shipbuilding industry. For this purpose, the model was based on the Strategic Management (GEST), Sustainable Management of Complex Projects (GESPC), Skilled and Trained Workforce (MOQC), Smart Product Life Cycle (CVPS) and Shipyard 4.0 (EST40) constructs, as well as the analysis of the relationship between them. The model could help as a reference on how to migrate from the analogue to digital 4.0 shipyard, in a sustainable way, with gains in performance and productivity.

Regarding the results obtained for the SEM parameters, for the structural relationship between the presented constructs, the research's hypotheses: H1, H2, H5, H6, and H7 were confirmed, and hypotheses H5 and H6 were not confirmed. The calculated Cronbach's Alpha was 0.948, indicating a very high reliability of the data. Therefore, the author concludes that the Shipyard Model 4.0 is valid.

It could also be possible, from the constructs presented and discussed in the proposed theoretical model, to stimulate research together with Brazilian universities, so that it is possible to include the concepts, mainly of Digital Transformation (DT), applicable to the industrial segment, through the implementation of FabLab projects, aiming at the application of innovation and analysis of the sector's productivity.

With the application of the Model of the Shipyard 4.0, it is expected to leverage the productivity of the shipbuilding and offshore industry, with the integration of multiple technologies and the improvement and control of processes in real time, through an effective management of construction projects of a digital shipyard, with improved operational efficiency in all areas of the company.

As for the limitations of the research, we can mention the potential biases of the analyzes carried out by the authors, in the qualitative stage, which somehow could have interfered in some way in the identification and description of the categories and their relationships. Although the Scopus database was consulted using terms in English, it is identified that the Brazilian academic literature on the subject could be better explored in other databases, since the subject was little explored internationally, considering the Brazilian context.

Future research could carry out a multiple Case Study in Brazilian shipyards, to assess the applicability of the proposed model, evaluating in more depth the reasons why hypotheses H3 and H4 were not confirmed, since they were based on the theoretical review and/or in interviews with experts. There would even be the possibility of trying to apply the model in other industrial segments like the naval industry, such as refineries, petrochemicals, and heavy industry in general.

It is expected that this paper will contribute academically and managerially in the field of shipbuilding and offshore, through the discussion and use of the Shipyard Model 4.0 developed.

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