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1.- INTRODUCTION

One of the most relevant industrial sectors worldwide is the naval sector, being involved in multiple commercial activities. According to data from UNCTAD (United Nations Conference on Trade and Development) [1], it is important to have a large enough naval fleet to meet maritime needs. This includes the shipbuilding sector, which is responsible for the manufacture and repair of the different types of ships and structures in order to respond to the commercial activities that make up this industry.

The paradigm of today's economy manifests itself in a global market, where, particularly in shipbuilding, leads to shipyards in different parts of the world competing with each other to increase their order book. On the other hand, one of the characteristics of shipbuilding is its cyclical behaviour, with ups and downs in the demand for products as can be seen in Figure 1, which shows the annual worldwide development of new contracts, deliveries and order books in shipbuilding.

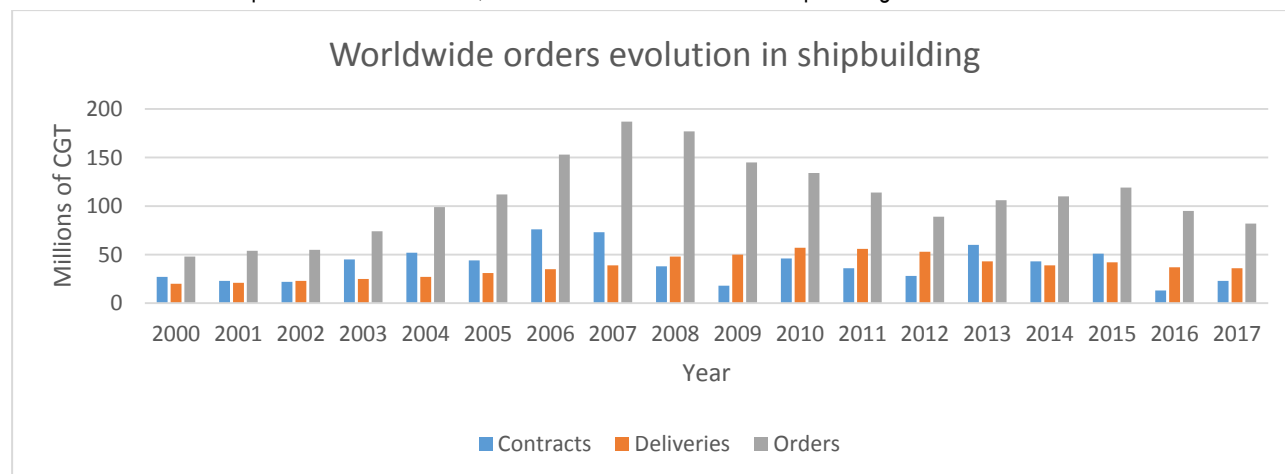


Figure 1. Worldwide evolution of annual ship contracts, adapted from [3].

As can be seen, the annual worldwide development of new orders, deliveries and order book expressed in millions of CGT (Compensated Gross Tonnes, a unit measuring the level of activity in a shipyard) follows a pattern composed of three phases: boom - slowdown - recession [2].

The combination of these two factors generates an environment of very high competitiveness in which it is essential to adapt the business models, seeking greater agility, adaptability, flexibility and productivity, making decisions as quickly and optimally as possible. This set of characteristics is among those of the fourth industrial revolution, also known as Industry 4.0 [4]. This fundamentally European concept has given rise to various initiatives at world level to adapt each industry to the digital transformation.

However, this need contrasts sharply with shipbuilding systems, which have traditionally been very rigid due to the very characteristics of construction. On the one hand, the time span from contracting to delivery of the products can reach two years and, on the other hand, the very rigidity of the ship due to the high regulation and standardisation applied during the whole life cycle of the ship [2], restricting possible innovations in terms of design and manufacturing in order to reduce deadlines. Furthermore, in this sector, manufacturing is carried out in very short series in the best of cases, which makes it difficult to implement automated solutions.

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In this article it is intended to show a vision of the state of the naval sector developments in front of the Industry 4.0, making a small review of the state of the art both in scientific databases and by the initiatives that are being carried out currently by the main world shipyards. Next, the challenges that the sector must face will be shown, and finally a series of lines of work will be proposed.

2.- SYNTHESIS OF POTENCIAL 4.0

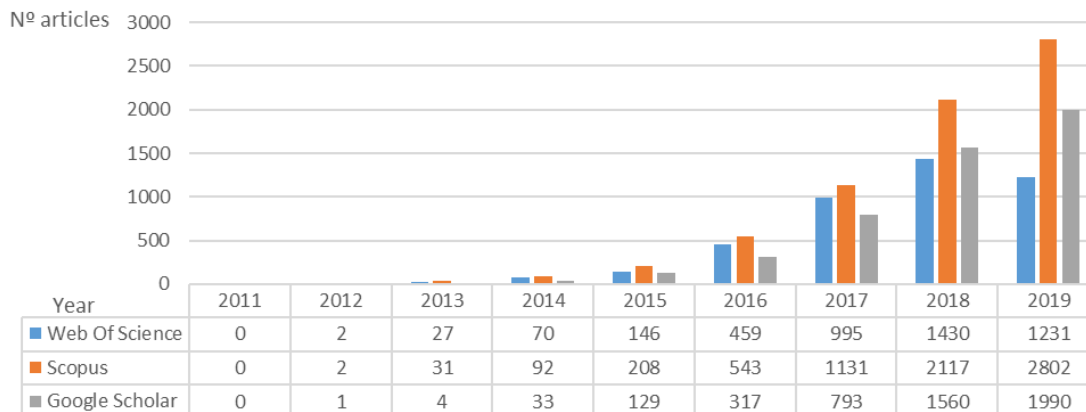
Industry 4.0 refers to a new technological paradigm thanks to the integration of the physical world with the virtual world [5], also considered as the digital transformation revolution, having a great potential of development in which they are included [4]:

- Customization of requirements by the client, thanks to the ability to influence design criteria
- Flexibility, by basing the industry on cyber-physical systems, allowing dynamic configuration of processes.
- Optimization in the decision making process, by being able to monitor the process in real time and adapt it, providing flexibility to the system.
- Improving the efficiency and productivity of resources, adding value through the use of cyber-physical systems in manufacturing processes.
- Generating opportunities to create added value through new services.

This transformation is supported by a series of enabling technologies, so that they contribute to achieve higher levels of productivity for companies, optimizing the value chain of products and processes involved [6]. Therefore, Industry 4.0 has a direct impact, in addition to industry, on products and services, which will become increasingly complex, intelligent and modular.

In academic terms, Industry 4.0 has generated a growing scientific interest, as can be seen in the evolution of articles published from 2011 to 2019, based on data obtained from Web Of Science, Scopus and Google Scholar using "Industry 4.0" as a search criterion. (Figure 2A). In order to specify the bibliographic search on the naval sector, the search in the databases cited is specified with the keywords "shipbuilding 4.0", "maritime 4.0", "shipyard 4.0", "smart yard" and "smart shipyard", resulting in a reduced number of articles (Figure 2B). After a review of these, it is found that those that are directly related address the problem from two different points of view. On the one hand, a more generic vision that relates Industry 4.0 and the naval sector and, on the other hand, specific applications of 4.0 technologies.

A) Evolution of the number of articles related to Industry 4.0



B) Articles that relate Industry 4.0 to the naval sector

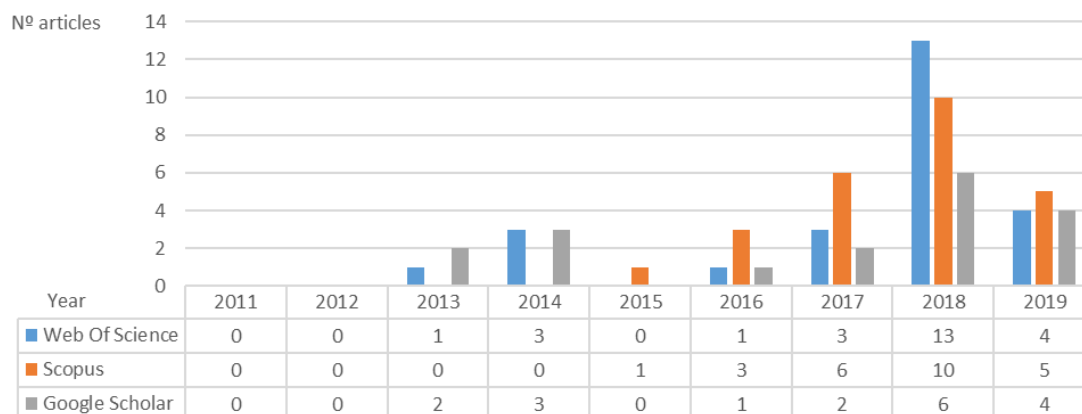


Figure 2. A) Evolution of the number of articles related to Industry 4.0 (top). B) Articles that relate Industry 4.0 to the naval sector (bottom).

This analysis reveals, on the one hand, the growing interest that the Industry 4.0 per se has aroused and, on the other hand, the evident contrast with the reduced number of specific publications in the naval sector. Thus, it reveals the need to make an effort by the academy and the naval industry together, focused on the development of the disruptive technologies of the Industry 4.0, with the objective of increasing the added value of the manufactured products and looking for the sustainability of a highly competitive global sector.

3.- SHIPBUILDING INITIATIVES

The high competence in the shipbuilding sector increases, even more so, the tightness of the leading shipyards, which keep the progress made to themselves, avoiding the dissemination of their research and development. Therefore, the information available on the degree of implementation of 4.0 technologies is rather scarce, and can only be obtained from annual reports or the shipyards' information websites, where they briefly show the technologies they use in order to get a competitive advantage over the competition and to attract orders.

In general terms, the use of CAD/CAM/CAE technologies and systems is common in the shipbuilding industry through the use of different software applications, so the industry can be considered to start from a certain level of digitisation at design level. On this basis, the most advanced shipyards have their own approach to Industry 4.0.

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Daewoo Shipbuilding & Marine Engineering (DSME) is considered one of the most advanced shipyards worldwide, dedicating a division to development and research in its facilities. In it, they have work teams dedicated to the progress in intelligent factory systems, deepening mainly in the areas of robotics, automation and optimization of manufacturing processes. Additionally, it has development teams towards 4.0 products under the name of intelligent ships, in which Big Data technologies, integrated sensors and advanced communication technologies are incorporated in order to confer intelligence to the product.

Despite the difficulty of including automation to processes in the shipbuilding industry, the Samsung Heavy Industries (SHI) shipyard claims to be a world leader in process automation in the naval sector, valuing 68% of automation in its production process thanks to internal developments robots, incorporating them in different stages, highlighting automated welding, pipe inspection or hull cleaning operations before final delivery to customers, making this shipyard one of the most productive worldwide. They also promote the digital transformation of their facilities by including advanced communication technologies and the integration of cyber-physical systems. In addition, they have adapted a concept of intelligent factory (Figure 3) in which changes are contemplated both at the operations and plant levels, in which different technologies would be implemented with a view to achieving the final objective of intelligent factory [7].

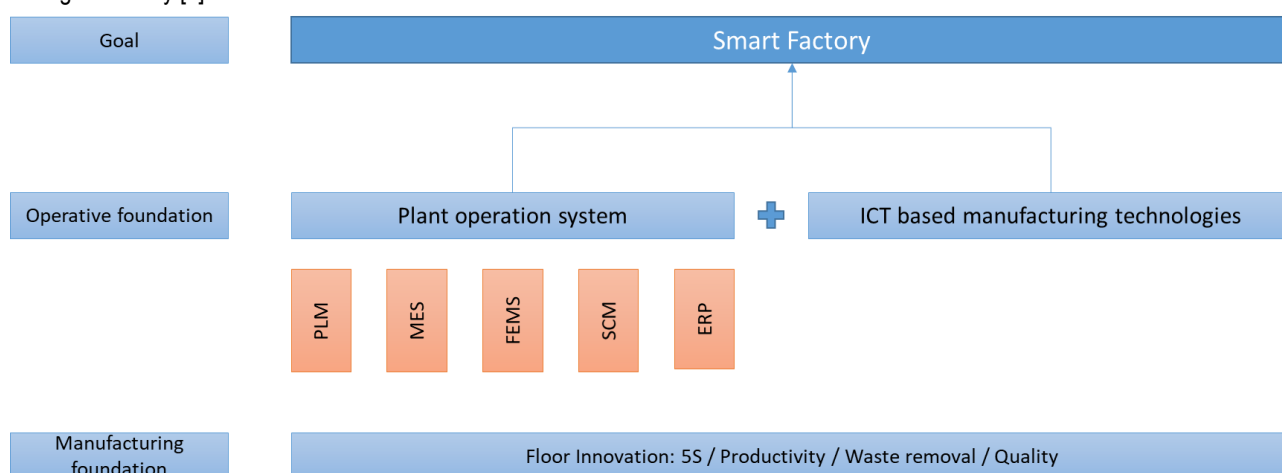


Figure 3. Samsung Heavy Industries Smart Factory concept, adapted from [7].

Hyundai Heavy Industries (HHI) is currently the largest shipyard in the world with a 10% market share. Among their approaches to smart applications, in 2010 they developed a remote ship monitoring system as a first "smart ship connected" approach, later updated to a second version in 2013 with the aim of integrate monitoring services into Hyundai's own platform. At the end of 2015, they presented a more developed concept of the Intelligent Connected Ship, which aims to increase added value by contributing to additional aspects of the ship's life cycle, including support for navigation systems, increased productivity and ship assessment services.

Among the leading shipyards in Europe, the German shipyard Meyer-Werft stands out, making extensive use of digital technologies in a large part of its facilities. In this way, they have replaced paper plans by sets in CAD applications and by simulations of both the process and the product, carrying out tests with different configurations, thus increasing their decision-making capacity. In this way, they have a digital factory with which they reduce operating costs by being able to make decisions early on. In terms of logistics, they also have a material flow control system using radio frequency identification labels, ensuring their location and traceability throughout the factory, and achieving deliveries according to the Just in Time philosophy. They also use Virtual Reality technologies with which they visualize different parts of the product during the development phase, with the aim of improving quality.

Some of the most outstanding initiatives at the Spanish level are those carried out by the public shipyard Navantia, which has defined its roadmap for Industry 4.0 towards what it has called Astillero 4.0 [8]. To that effect, it has identified 13 key enabling technologies in which it is already working with Robotics [9], Polymer-based Additive Manufacturing [10] and Augmented Reality [11], among others (Figure 4). In 2017, M. Otero et al [12] carried out a study on the digital transformation of requirements for naval platforms which shows Navantia's digital maturity level, highlighting strengths and weaknesses on its way to Industry 4.0.

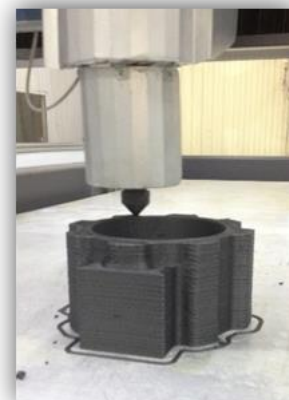


Figura 4. Navantia's identified Key Enabling Technologies and applications in shipbuilding industry.

Among its strategic actions, Navantia has established a partnership with the University of A Coruña called "Unidad Mixta de Investigación" (UMI), and with the University of Cadiz, with which it has established a collaboration framework through the Joint Innovation Unit Navantia-University of Cadiz (Unidad de Innovación Conjunta, UIC), which includes seven lines of research and technological development.

Table I shows the main actions of each one of the analysed shipyards, showing the tendency of the sector to focus on Industry 4.0. As can be seen, the large shipyards analysed have an application concept of Industry 4.0 both for their facilities and their products, approached from different points of view but that seek to adapt to the digital transformation and to Industry 4.0.

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Actions				
Shipyards	Smart Factory Concept	Smart Product development	Incorporation of advanced Information and Communication Technologies and own platform	Other specific actions
DSME	x	x	x	
SHI	x		x	High level of automation with robots
HHI		x	x	Added value of the product during the entire life cycle
MEYER-WERFT	x	x		Use of virtual reality technologies in the design phase
NAVANTIA	x	x	x	Incorporation of 13 Key Enabling Technologies

Table I. Compilation of actions focused on Industry 4.0.

4.- CHALLENGES OF THE INDUSTRY 4.0 IN THE NAVAL SECTOR

The digital transformation carries a number of challenges that industries will have to face on their way to Industry 4.0. The Spanish initiative "Industria Conectada 4.0", whose objective is to achieve the sustainability of the system, defines in its preliminary report industrial challenges that can be particularised to the case of the shipbuilding industry [13]. Table II shows these challenges and how they would affect this sector. Given the particular characteristics of the sector, some of these challenges become more relevant and should be prioritised, as they are aimed at sustainability by increasing productivity and the perceived quality of the product delivered.

However, not all of the challenges that will be presented by the digital transformation will be technical. As the Boston Consulting Group points out, after conducting a study on companies that are moving from pilot programs to fully embracing the digital transformation, they identified that those that had a "digital culture" in place were five times more successful than those that did not [14]. In addition, the study also points out that companies with a strong digital culture show earlier and more consistent results, so the additional challenge of how to prepare the company's employees for the change must also be considered.

This need for digital culture is similar to the Lean philosophy. In recent years, companies have adapted to the quality techniques of Lean Manufacturing as a tool for improving their production processes. This philosophy leads to a change in the mentality of the workers, with awareness being a fundamental pillar. That is why Lean methodologies must be maintained as the basis of the digital culture. For instance, an article published by the consultancy firm McKinsey & Company in 2017 [15], relates the digital transformation as the next step in improvement techniques based on Lean Manufacturing, thanks to the amount of data that can be obtained and analysed, providing new solutions and alternatives to the problems that exist in the ecosystem of the company.

The naval sector must also face the social challenge of implementing a digital culture, taking into account the principles of Lean philosophy, which are still applicable and are a basis on which to work in search of efficiency of the entire production system. These challenges need to establish some lines of action that give an answer to them and allow the digital transformation to be carried out.

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Nº	Challenges	Actions
1	Use collaborative methods to enhance innovation.	Involve other actors with similar interests in the value and development chain. Participation in innovation HUBs.
2	To combine flexibility and efficiency in the productive means.	Seeking to increase productivity and reduce production times.
3	Manage series sizes and shorter response times.	Adjusting capacities with the order book by seeking optimization in shorter delivery times.
4	Adopt intelligent logistics models.	Integrate suppliers into the supply chain with the aim of increasing the value chain.
5	Adapt to channel transformation (digitalization and omnicanality).	Increase the relevance of communication through digital channels and service integration.
6	Use the information to forecast the needs of the client.	Take a proactive approach to future customer needs based on prior information.
7	Adapt to the client's hyperconnectivity.	To offer valuable information at any stage of the product life cycle, improving the relationship with the customer.
8	Manage multidimensional end-to-end traceability.	Determine and track the materials used in each part of the product as well as the whole.
9	Manage specialization by coordinating valuable industrial ecosystems.	Specialization in types of products in collaboration with other actors in the sector, enhancing their expertise.
10	Ensure long-term sustainability.	Design considering the different impacts and performances of the products and processes used.
11	Offer customized products.	Individualize products based on customer needs to increase added value.
12	Adapt the product catalogue to the digital world.	Development of the Intelligent and Connected Vessel.

Table II. Challenges and actions for the shipbuilding sector.

5.- GUIDELINES OF ACTIONS

In order to answer to the challenges of Industry 4.0, four priority lines of action and future work are proposed, with the aim of establish a path that will help the naval sector industries to transform to the digital era.

5.1.- CULTURE 4.0

The first and perhaps most important line of action is to raise awareness of the company's human capital. There cannot be a successful industrial revolution if the company's personnel do not understand the changes that will take place. Therefore, it is necessary to inform the implementation process and train the staff in the procedures that will be put in place, allowing them to participate in the process. In this sense, there is an equalization with Lean methodologies, which integrates workers in the whole transformation process.

Associated to this point, it is also necessary to train the staff on the concept of Industry 4.0 and its related technologies, and how these impact on the development of their activity, improving their working conditions and enabling them with new skills.

5.2.- INTER-COMPANY AND CUSTOMER COLLABORATIVE ENVIRONMENTS

By increasing horizontal integration between companies, the good relations between the different actors benefit. In this way, it is possible to improve the traceability of the process, as well as to improve the logistics chain, reducing inefficiencies and increasing the value of the product thanks to the continuous feedback between the actors involved.

Additionally, collaborations with other companies in the sector, whether they are suppliers or other productive units, give rise to the creation of collaborative environments in which solutions are found to problems that, individually, would require more resources. The

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creation of a collaborative space with the client will help to predict market changes, as well as to be able to know the needs of the client in order to offer them a better service, making the quality of the product meet their expectations, improving this relationship and, therefore, the sustainability of the sector.

5.3.- DEVELOPMENT OF SPECIFIC APPLICATIONS AND DIGITAL TECHNOLOGIES

The key enabling technologies require specific projects to be implemented in the naval sector. An example of this are additive manufacturing or robotics, of which specific projects are already being carried out to interweave them into the production system and increase the flexibility and efficiency of the processes. The incorporation of these new technologies will allow increasing productivity and managing shorter response times.

Another example of this is the inclusion of new joining technologies, such as hybrid laser welding to join thick sheets in the naval sector [16] which, thanks to the use of simulation technologies, is estimated to result in a notable increase in productivity in the panel manufacturing process.

5.4.- INTELLIGENT PRODUCT DESIGN AND DEVELOPMENT

The development of intelligent products capable of exploiting the entire digital infrastructure is another major challenge facing the digital transformation. Smart vessels must be able to collect sufficient data and, thanks to connectivity technologies, transmit it efficiently and securely to a collaborative platform.

There, data will be processed online, helping and facilitating decision making throughout their life cycle, from the beginning of production to the scrapping of the vessel. In this way, the intelligent product will incorporate functionalities that facilitate its operation, which will increase its added value.

6.- CONCLUSIONS

Industry 4.0 means a change of paradigm in the industrial world in general, and in particular in the shipbuilding sector, whose main exponents have already started the way towards its adaptation. This article shows the importance of the naval sector worldwide and which have been the main approaches of this industry to the fourth industrial revolution. For this purpose, a bibliometric analysis has been carried out, whose results show the delay at the level of scientific publications existing in this field of study.

Furthermore, the analysis carried out on five of the most advanced shipyards worldwide, includes the main initiatives that have been developed related to Industry 4.0, highlighting the gradual incorporation of digital technologies and enablers of Industry 4.0, as well as the development of intelligent products and intelligent factory concepts. In addition, to the technical challenges faced by the industry, an equally important social aspect is added, being in this one where part of the digital transformation is carried out. Thus, both technical and social aspects can be found, although initially only the former are taken into consideration.

The overcoming of all the identified challenges can be carried out based on the four lines of action proposed in the article: Culture 4.0, Collaborative Environments, Technology Development and Intelligent Product Development. These encompass the two major identified 4.0 aspects necessary for effective digital transformation, with the aim of achieving a state that will lead to the leap to the intelligent shipbuilding factory.

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