Chapter

Trends of Digital Transformation in the Shipbuilding Sector

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Abstract

The new paradigms of Industry 4.0 force all the industrial sectors to face a deep digital transformation in order to be on the edge in a competitive and globalized scenario. Following this trend, the shipbuilding industry has to establish its own path to adapt itself to the digital era. This chapter aims to explore this challenge and give an outlook on the multiple transformative technologies that are involved. For that reason, a case of study is presented as a starting point, in which the digital technologies that can be applied are easily recognized. A social network analysis (SNA) is developed among these key enabling technologies (KETs), in order to stress their correlations and links. As a result, artificial intelligence (AI) can be highlighted as a support to the other technologies, such as vertical integration of naval production systems (e.g., connectivity, Internet of things, collaborative robotics, etc.), horizontal integration of value networks (e.g., cybersecurity, diversification, etc.), and life cycle reengineering (e.g., drones, 3D printing (3DP), virtual and augmented reality, remote sensing networks, robotics, etc.).

Keywords: digital transformation, key enabling technologies, shipbuilding 4.0, Industry 4.0, artificial intelligence, complex projects

1. Introduction

In the twenty-first century, industrial organizations are expanding their business lines to offer maintenance, repair, and checkup services related to their products, as well as technical support, and are paying more and more attention to these services [1]. In this environment, shipyards nowadays comprise of designing, engineering and building, procurement and logistics, assembling and commissioning, as well as maintaining and repairing and transforming and advancement of vessels and marine equipment, among many others.

Ships, ferries, and offshore platforms are complex products with long service lives and high costs of construction, manning, operating, maintaining, and repairing [2]. In addition, these are usually built to order and involve complex production processes, with large-scale but short series production, high degree of customization, and intensive labor. In return, they provide high value-added but requiring large and fixed capital investments although they have long life cycles [3]. However, most of them do not always evolve in line with the development of the latest technology [4].

Due to the aforementioned context, productivity in shipbuilding sector is developing slower than other manufacturing industries. Many factors may be identified as the root causes for this lack of timing, as companies are focusing on their short-term profits, usually ignoring outside benchmarks. This creates a barrier to change, in addition of conservative regulations, that makes difficult the entry of disruptive innovations, causing a lack in terms of competitiveness [5].

This lack of productivity, which affects project-based industries (as shipbuilding), has been steadily discussed by both academics and practitioners [6–8], which have been suggesting and proposing measures to increase their performance. At an early stage, innovative working methods from better organization of the processes are involved [9], such as the promotion of a more efficient split of work in order to improve the coordination within and across companies involved through the supply chain [10]. Then, due to the introduction of the Industry 4.0 paradigm, emerging technological capacities, to design better products, improve the efficiency of their services, and offer new value-added processes, were applied. As a consequence, self-managed processes, people, machines, and systems are communicating and cooperating [11].

To achieve the Industry 4.0 paradigm, a number of key enabling technologies (KETs) are used. These technologies, both from real and virtual world, were first described by the Boston Consulting Group [12]. With the aim of transforming the current production system, technologies like autonomous robots, additive manufacturing, horizontal and vertical integration, Big Data, Internet of things, cybersecurity, cloud, augmented reality, and simulation were included.

In addition to the initial set of KETs, other technologies, such as autonomous guided vehicles [13], blockchain (BCH) [14], or artificial intelligence (AI) [15], own a great potential to be crucial in the digital transformation of industries. Particularly, a European Commission report [16] arises the AI as a transverse technology both to be applied in software-based systems (virtual world) and be embedded in hardware devices (real world). Using data gathered from the available sources, the integration of the AI with the other KETs will improve overall performance through better automatic decision-making based on analyzed data.

This chapter is structured as follows: Section 2 presents the objectives of the research. Section 3 develops the literature review. Section 4 relates the research method. Section 5 describes its implementation in a case study. Section 6 shows its findings, discussing the results obtained. Section 7 concludes the chapter, summarizing the contributions and proposing further research.

2. Objectives

The main purpose of this research is to explore the challenge of facing a deep digital transformation by the shipbuilding industry, in order to be on the edge in a competitive and globalized scenario. This chapter also aims to give an outlook on the multiple and transformative technologies that are involved, analyzing the importance of the digital transformation (digitalization, automation, exploitation, and integration) in complex projects and its application in the context of Industry 4.0, discussing the results of its potential implantation.

For that reason, a case of study is presented as a starting point, in which digital technologies applied are recognized. Afterwards, a social network analysis (SNA) is developed, in order to highlight the correlations and links between KETs, aiming to confirm the AI as a support to the others. Among those, vertical integration of production systems, horizontal integration of value networks, and life cycle reengineering are stressed. The research framework is summarized in **Figure 1**.

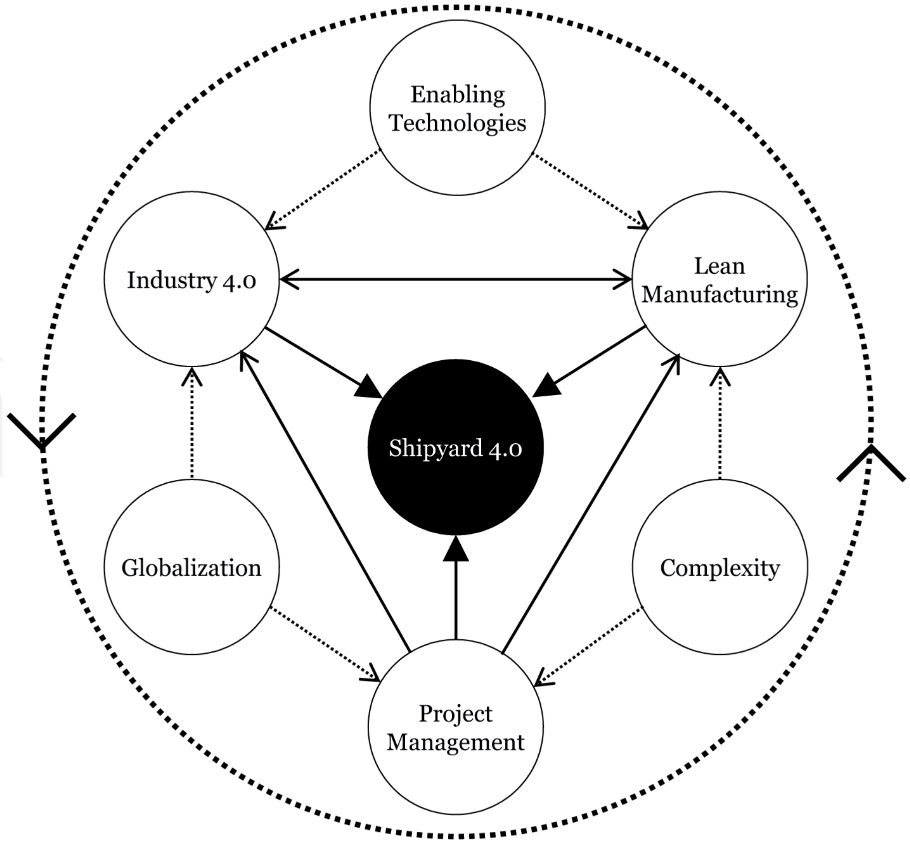

Figure 1.
Research framework.

3. Literature review

The shipbuilding sector is characterized by complex manufacturing processes, with a wide range of involved elements, low-volume serial production, and results of a high added value [17]. Faced with unpredictable conditions and intense competitors, the sector is forced to restructure its long-term objectives [18], as the most dynamic shipyards, which show a greater adaptation to the global market, get better results. In order to achieve this, they adopt research, development, and innovation (RDI) philosophies, launching bold business initiatives to counter these uncertainties using technology-driven practices that create infrastructure and empowerment, preparing them for the upcoming challenges [19].

3.1 Complexity in shipbuilding projects

Complexity is the property of projects that make them difficult to understand, foresee, and keep under control their overall behavior, even when given reasonably complete information about the system [20]. Every project has a degree of complexity, becoming one of the most important factors of their failure. Furthermore, project complexity presents additional challenges to achieve objectives, although some significant indicators can be chosen to measure and asses it [21], such as compliance and authorization, project organization, targets, resources, change orders, technology familiarity, and location, among others.

The two most common types of complexity within projects concern the organization and the technology [22]. Organizational complexity is caused by the engagement of several diverse and separate organizations for a limited period of time (both suppliers and consultants as well as temporary structures to manage the projects), depending on the hierarchical structures and organizational units [23].

In contrast, technological projects depend on the result produced, mainly due to the diversity of tasks [24]. Furthermore, although complexity is usually expressed by the means of cost, duration, or people involved, these criteria do not correlate well with how they are managed [25].

In summary, complex projects consist of ambiguity and uncertainty, interdependency, nonlinearity, unique local conditions, autonomy, emergent behaviors, and unfixed boundaries. According to these properties, projects can be classified as simple, complicated, chaotic, and complex [26]. On the other hand, complex projects are also influenced by significant external changes [27], from misaligned stakeholders' view of success, in which current tools and decision processes are unsuitable for analyze it. To respond positively to this complexity, it is necessary to imply both organizations and practitioners [28].

It can be noticed that complex projects undertaken by traditional methods, practices, and frameworks usually result inadequate in terms of scale, rate of change, heterogeneity, multiple pathways, and ambiguous objectives [29]. In this context, project management decouples and modularizes the complexity, freezing its components and controlling the variability associated [30]. In addition, the understanding of project complexity helps to identify problems, develop the business case and choice processes, and improve managerial capacities [31].

Increasing competitiveness on product quality, cost, and delivery while maintaining flexibility during the whole project (including design, engineering, and production) are a few of the challenges that many organizations currently encounter in the shipbuilding industry [32]. In settings of complex projects (as those from shipbuilding sector), the ability to make proper decisions when solving problems is essential in the production efficiency of the derived operations. In this context, shipyards must face these challenges from a combination of constraints, among which the technical level of their production facilities and the practices, techniques, and tools at the disposal of their staff stand out [33].

3.2 Lean manufacturing in the shipbuilding sector

Lean manufacturing has been the most remarkable methodology for improving the operational performance in manufacturing organizations in the last two decades [34], increasing their productivity and decreasing their costs [35]. Lean manufacturing helps industrial companies to transform themselves in order to add higher value, due to the use of a considerable set of tools, methodologies, and procedures focused on boost their performance [36], waste reduction, and better communication. This combination of information acquisition and management with new design and manufacturing techniques allows companies to redirect towards new trends that respond quickly to market changes [37]. If new features must be introduced to meet these demands, companies cannot compromise their efficiency. In fact, they will try to improve it despite these challenges [38].

There are different points of view in the literature related to how lean manufacturing and Industry 4.0 interact together to influence the performance of processes involved. Some studies suggest that lean manufacturing is a mediator of their relationship [39, 40], while other suggests that Industry 4.0 is a moderator [41]. Others investigate their supportive effects without hypothesizing which of the two is the moderator [42, 43], and even other studies emphasized the interaction between them in many contexts, depending on industry and company size [44].

If shipbuilding manufacturers want to operate with lean production principles, they must establish the shipbuilding project management plan based on optimized production and overall resource balance, decomposing product tasks according to zone, stage, and type and clarifying the relationship between tasks and resources [45]. In this context, Industry 4.0 opportunities are used as a methodological and strategic tool to accelerate the engagement of shipbuilding suppliers. In these cases, lean tools mostly aim to introduce and motivate the implementation of these concepts into practice through the entire supply chain, whereby the objectives are needed to be fully understood and cross-functional teams are expected to be active in the value stream creation [46]. However, other requirements are needed, as design and assembly building methods [47].

If arbitrariness and uncertainty (affecting quality, production, operation, and logistics) are not faced, low productivity and management efficiency are the most probable result. To successfully address these challenges, shipbuilding companies must enhance their technology and management innovation, as well as actively adopt advanced production systems, for improving their efficiency [48].

3.3 Industry 4.0 in the shipbuilding sector

Industry 4.0 is a vital evolution for the survival of any industrial organization. Particularly those which target global markets, pursue a strategic distinction that supports the necessary excellence in their deliverables [49]. This implies a top-down transformation that applies to a wide range of methods, tools, and techniques involved in production management, improved processes and workplaces, and developing staff's skills [50]. Industry 4.0 modernizes the organizational processes and makes them more efficient. This involves the entire company, from operational to strategic management. In this competitive context, industrial companies need to redesign their strategies, enabling not only better resource allocation but also infrastructure investment and quality systems [51].

Industrial companies aiming to reach flexible manufacturing, with very low waste and high quality in their deliverables, are constantly evolving, in order to set them apart from their competitors. In that sense, they try to get higher levels of efficiency and productivity, associating new technologies within their processes. This use of disruptive methodologies helps them to create value, connecting and sharing information between companies and customers [52] and increasing also their applied innovation to offer complete solutions [53].

Among the Industry 4.0's main points of interest for the shipbuilding industry are artificial intelligence (pattern recognition, process automation, simulation, etc.), compatibility systems and task reassignment (occupational health and safety, decision-making, etc.), virtual and augmented reality, additive manufacturing and Internet of things, and more, specifically, the automatic generation of timelines, the creation of mathematical analysis models and evaluation of production processes, the integration of high-quality algorithms with computer-aided design (CAD) and with product life cycle management systems (PLM). In this context, the digital transformation of the shipbuilding industry optimizes the production and the operational efficiency, through the analysis and integration of storing, connecting, and organizing the information generated by different sources [17, 54].

This necessary transformation has led the shipbuilding sector to adopt the concept of Industry 4.0. The concept of "Shipyard 4.0" [55] is described as the result of the application of the Industry 4.0 to this sector. The Shipyard 4.0 involves deep changes in the shipyard production system including facilities, advanced product design, management changes, and the implementation of the digital technologies. Therefore, the Shipyard 4.0 initiative has to be the response of the shipbuilding sector to the digital transformation.

4. Case study

This research has opted for a case study since there is almost no previous research on the topic and the empirical observations are insufficient to turn it into a quantitative study. Probably, this is expected mainly due to confidentiality and competitive reasons. Companies do not tend to share the information that would be required for a more extensive analysis. In fact, when there is only limited theoretical knowledge, an inductive strategy leads to an emerging theory from a case study which can be a good starting point [56].

Building a theory from a case study is a research strategy that involves using the case to create theoretical constructions, propositions, and/or empirical evidence of midrange theory [57]. If a theoretical sampling of a single case is chosen, they must be unusually revelatory and extremely exemplar or represent unique opportunities to acquire research insights [58].

The case company is Navantia, a Spanish state-owned (and worldwide as well) reference in the design, construction, and integration of high technology military and civilian naval platforms [19]. Navantia is an ETO manufacturer that offers design, engineering, manufacturing, and project management of products (e.g., frigates, aircraft carriers, submarines, patrol vessels, logistic ships, defense systems, and wind power) and services (e.g. life support, repairs, maintenance, modernization, training, and simulation) [59]. Navantia has facilities in Spain and Australia. It also has offices in Brazil, India, Norway, Saudi Arabia, Turkey, and the USA.

The organization model applied by the company is mostly a line organization, in which department leaders are part of the project team and allocate tasks to their own staff on a periodic basis type with only a few people allocated specifically per each project. However, this type of organization is not usually associated with engineering to order contexts, where large and complex project environments have already been usually adopted [60].

Navantia is immersed in a major transformation process directed towards to increase the company sustainability in the twenty-first century market, in which technological innovation and digitalization are essential to change, encompassing all areas of the organization. The key to transformation lies not only in the implementation of innovative solutions but also in the transformation of processes and people themselves: a more agile organization, an interactive management culture, and a renewed talent management, both internally and externally, are fundamental to success [61]. Since 2015, Navantia has been striving to shape digitalization in the shipbuilding sector. This new concept of the connected Industry 4.0 emphasizes the exploitation of the potential of new technologies based on product and service innovation, client-centric approach, data value, and operational excellence.

Navantia's Shipyard 4.0 concept includes processes and products, which are integrated to operate ecologically, efficiently, and flexibly, and has an advantage over traditional systems, which are based on [62]:

- Vertical integration of the shipbuilding production processes (connectivity, additive manufacturing, Internet of things (IoT), radiofrequency, collaborative robotics, etc.), to guarantee production that is safe, fast, and adapted to the context, with a better price-performance ratio, operates online, consumes less energy, and better protects the environment

- Horizontal integration of value creation networks (cybersecurity, innovation, diversification, etc.), to attend to the needs of the interested parties in an integrated way, responding individually to them

- Reengineering of the value chain (drones, 3D/4D printing, artificial intelligence (AI), virtual and augmented reality (VAR), remote sensing networks, robotics, etc.), introducing changes that affect the lifecycle

Navantia's transformation involves an improvement in its tools and processes throughout the value chain and renewing its production centers, fully integrating them in a new digital ecosystem: the Shipyard 4.0. This change to smart factories is carried out focusing on equipment and products, applications, the company itself, and people as the main field of action [61]. At the moment, Navantia consider 13 KETs, as shown in **Figure 2**. Through these technologies, which are described below, the company is facing the digital transformation in different areas of the system and manufacturing process, regardless of whether new emerging technologies can also be introduced in the future.

4.1 Navantia key enabling technologies

4.1.1 3D printing (3DP)

3D printing is a new manufacturing process which is also known as additive manufacturing. It consists on the manufacturing of a part adding material layer by layer. This technology is getting a lot of attention nowadays, and it is expected

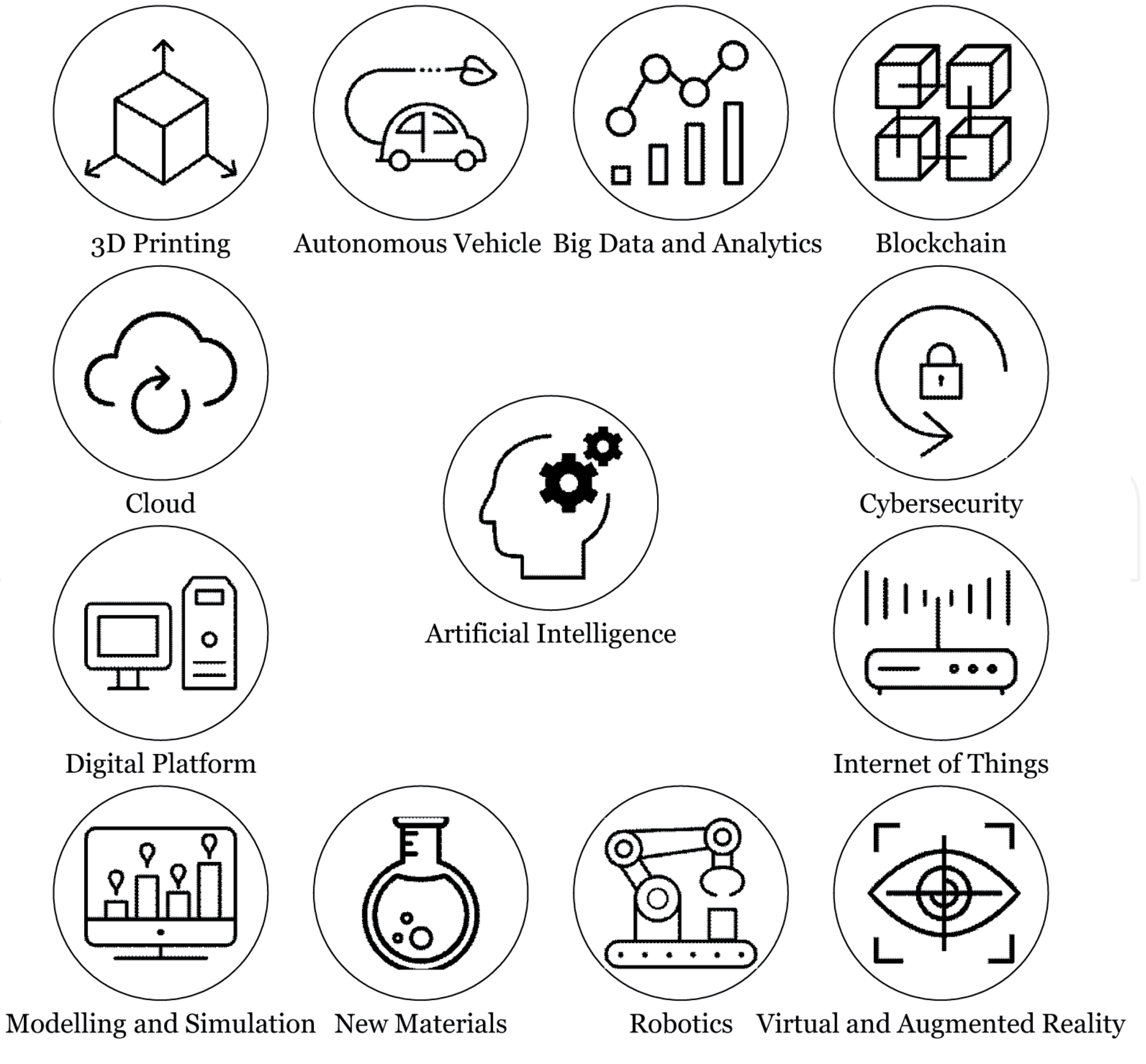

Figure 2.
Key enabling technologies by Navantia. Based on [61].

to become a major revolution in different industrial sectors. Particularly, in the shipbuilding industry, there are recent studies in which they use a polymeric-based additive manufacturing technology [63]. This technology is being used to make large, nonstructural parts, reducing the overall manufacturing costs, which also reduces the manufacturing time.

On the other hand, wire arc additive manufacturing (WAAM) technology is also under research. In this case, the polymer is replaced by a metal wire melt due to the heat produced by an electric arc [64]. This technology has the potential to replace components of the vessels which still needs to be made of metal, reducing the manufacturing costs. This assumption leads to the inevitable redesign of the ship to evaluate which parts are able to change its manufacturing technology. Therefore, it is clear that this technology still needs other changes to have the impact it is supposed to have.

4.1.2 Autonomous guided vehicles (AGV)

Autonomous guided vehicles are used for processing and transporting goods inside a factory environment [65]. They are considered smart due to their capability onboard of making decentralized decision to avoid collisions and stablish the best path planning possible to reach its destination.

Therefore, the technology of the autonomous guided vehicles makes the smart factory possible due to the flexible logistic and transport of materials within the workshop. Its application mainly affects the internal supply chain, with the aim of delivering components just in time, which has implications with the lean manufacturing system and a direct impact on the overall performance. The use of these technologies, along with simulation and artificial intelligence [13], makes the decision-making more reliable.

4.1.3 Big Data analytics (BDA)

The growing expansion of the information available due to the evolution of systems, digital products, and the development of the IoT has introduced the concept of Big Data. These are technologies which allow the capture, aggregation, and processing of the amount of the ever-growing data received by the different systems [66]. This volume of data is increasing at higher speed than the previous technologies which were capable of processing and getting valuable information of it. For that reason, the Big Data analytics is needed.

Big Data analytics is the set of techniques that make the vast amount of information generated by the other KETs manageable. At the same time, it models the data in order to get knowledge, supporting the decision-making process and even generating new solutions [66].

This amount of data, mainly gathered by sensors and the IoT, is usually storage and can be analyzed in the cloud (in real time or later) [67], which makes a very close relationship between these three technologies. Moreover, Big Data analytics has implications with other KETs too, such as additive manufacturing [68], AI [69], or simulation [70], which make the Big Data analytics one of the core driver technologies of the Industry 4.0, having also connections in the shipbuilding industry [71].

4.1.4 Blockchain (BCH)

Blockchain is a technology that can be used in any digital transaction that ends up taking place in the future Shipyard 4.0. As it is a decentralized data base in which all data are checked and confirmed by different actors before adding new information ("blocks") to the data chain, this technology improves tracking and reliability of the information due to the impossibility to change isolated information [72].

Blockchain has capabilities to promote resilience, scalability, security, autonomy, and trustworthiness [14] to every information exchange. Therefore, applications in the supply chain operation can take advantage of this technology through the smart contracts, increasing the automation and avoiding the use of intermediaries [73].

4.1.5 Cloud

The cloud is essentially a network infrastructure that supports the interconnection of Industry 4.0 through servers and cloud computing technologies [74]. It allows large data applications such as storage space, computing capacity, and resource sharing, among others. It also provides worldwide access to the information accordingly with specific access type and service provided, which can be split in different layers, named as infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS), granting different kinds of access to the cloud [75].

As the industry becomes increasingly digital in manufacturing environments, the cloud computing concept has evolved into cloud manufacturing, in which users can request services during the whole lifecycle of the product. This is a change of mind-set for industrial companies as the approach differs from the previous production-oriented to the newly service-oriented concept of manufacturing, increasing flexibility during the design process [75].

Due to the remote access to the information and the application of cyber-physical systems in distributed manufacturing systems, the concept of collaborative cloud manufacturing is possible. This means that organizations with different production units connected through a collaborative network are able to synchronize themselves, multiplying the overall capacities without further investment [76]. According to this, the cloud has a fundamental role in the smart factory concept for the shipbuilding industry, in which complex projects that are undertaken in long-term can reduce the overall production time to meet on-demand expectations.

4.1.6 Cybersecurity (CS)

The huge amount of information that is sent from different devices to the cloud and backwards creates new opportunities and vulnerabilities to the industrial companies. This scenario compromises confidential information due to the banishment of the physical boundaries [77]. For this reason, the evolution of security towards the virtual world is needed, giving birth to the cybersecurity, which aims to increase the security levels in IoT environments.

The cybersecurity, by definition, is a process consisting three objectives: to protect, detect, and respond to cyber-attacks [78]. Particularly, the two main objectives are the ones that rely on data protection and are given more attention since Internet of things networks have to be built in a safe environment that allows a safe interoperability between the facilities. But not only the information is at risk. As the manufacturing units are connected to the network, they can also be shut down, change its normal behavior, or even modify the product design. All of these factors lead to an enormous economic loss and should therefore be avoided [79].

In summary, this technology needs to be addressed and takes an important role in the context of any enterprise, which aims to carry a deep digital transformation out. To achieve a successful smart factory, the concept of "security by design" is mandatory in which both, data and cyber-physical systems, are adequately protected [77].

4.1.7 Digital platform (DP)

The digital platform is the answer that Navantia has given to the horizontal and vertical integration. Horizontal and vertical integrations involve every stakeholder that takes part in the production process, including marketing, supply chain operations, or engineering, among others. Referring to each integration to the intercompany or intracompany, respectively, the global output is a real-time data sharing among every part implied in the process [75].

To make this integration possible, a digital platform, aided by cloud computing, is the perfect answer to gather all the agents, both from the supplier or the client, as it can be accessed remotely from different geographical areas to collaborate in the process, updating the information needed in real time and resulting in a fully updated system, which can give further information according to all the data received. Therefore, Big Data analytics and cybersecurity are also connected with the digital platform.

4.1.8 Internet of things (IoT)

The IoT refers to the connectivity of every device within a network that is able to generate data from sensors or embedded electronic devices, which are sent afterwards to the cloud through a transmission system [80]. As every "thing" is generating data, the connection between IoT and Big Data analytics is clear. This technology also includes the concept of cyber-physical systems, being the gateway to fuse the real world with the virtual world, bringing physical objects into the network.

In the industrial sector, the application of the IoT is known as the industrial Internet of things, having particular implications and principles that must be fulfilled [81]. These principles include, among others, interoperability, wireless communication, decentralization, real-time feedback, or system-wide security to avoid outsider's intromission, which can put all the data on risk. In this way, cybersecurity technology acquires an important role in protecting the industrial environment.

A study on the implications this technology can handle in complex engineering projects, namely, the ones carried out in the shipbuilding industry, is also under investigation [82]. This research concludes that it is possible to create a "digital construction site" for shipbuilding, in which the IoT plays a strategic role as it is being used in specific applications.

4.1.9 Modeling and simulation (M&S)

By definition, a simulation is the imitation of the operation of a real-world process or system over time. Simulation involves the generation of an artificial history of the system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system that is represented [83]. Therefore, almost any real world can be modeled into the virtual one, in order to study and predict its behavior after developing and applying specific events. In this way, many kinds of simulations appear, each regarding one different area of study [84].

Although Industry 4.0 represents a new paradigm, this can be also accomplished by simulation. Due to high levels of digitization and the increased integration of the whole product lifecycle, the traditional stand-alone simulations are not able to fulfill those new requirements.

In this challenging scenario, the concept of digital twin appears, which consists of the digital representation of an asset that can alter its properties and behavior by information and data [85]. This is the result of adopting a system design approach, which allows to train on a virtual machine and to identify potential issues with the real machine if it is combined with a model predictive analysis, deep learning, and AI. Besides, this enables to optimize its own performance, because it will be able to predict faults and coordinate with other machines, thanks to machine-to-machine interaction.

These technologies are being applied also in the shipbuilding industry, in which CAD/CAM/CAE solutions are already in use; meanwhile, discrete event simulation as the previous step of the digital twin is under development. Moreover, the application of finite element methods for new materials is also a technology with a huge potential to advance them.

4.1.10 New materials (NM)

The development of new materials, such as those based on composite carbon fiber- and fiber-reinforced plastic, polymers, or new metal alloys [86], facilitates to redesign the shipbuilding sector's product to add or replace several components. The use of these materials can offer a weight reduction, leading to a decrease in fuel consumption, which would end up making the vessels eco-friendlier.

The advantages of introducing these materials can also strengthen the corrosion resistance [87]. This can be achieved thanks to the use of new materials which are resistant to the corrosive action of salt water, leading to an increase in the added value of the ships provided.

4.1.11 Robotics (robot)

The robotics is one of those technologies from the third industrial revolution that holds a paradigm change with this new industrial revolution. In that sense, the manufacturing paradigm, from mass production towards customized production, makes the robots need to be more flexible and autonomous [75]. On the other hand, the use of advanced sensors makes the integration between robot and operator possible, resulting in collaborative robots or cobots [88].

Despite this technology is mostly used to undertake very easy repetitive actions, like in a production line, advanced shipyards have achieved to introduce this technology within its manufacturing system, increasing drastically its performance [89]. Furthermore, new advances have been managed to develop robots for specific shipbuilding tasks, such as pipe inspection or hull cleaning. In the case study, Navantia has also researched regarding robotic welding [90].

4.1.12 Virtual and augmented reality (VAR)

The VAR could be englobed within modeling and simulation technologies [84]. However, as this technology involves partial or complete human immersion, as well as pursues a different aim, the VAR has been treated separately.

On the one hand, the virtual reality implies a full immersion of the human being within a virtual world using a special device connected with a simulation. In this virtual world, the user can interact with virtual elements in order to train and improve the operator knowledge significantly. It has also applications in product testing and validation of complex products [91].

On the other hand, the augmented reality converges the real world with the virtual one through a device, adding data from the virtual system (or digital twin), exactly where needed. This technology is useful not only in the manufacturing processes but also in maintenance tasks. Using augmented reality also offers applications in assuring quality control, location of products and tools, warehouse management, and support for the visualization of hidden areas [92], among others.

In the shipbuilding industry, both technologies are already being used in small applications for training and part positioning.

4.1.13 Artificial intelligence (AI)

The AI is one of the Industry 4.0 driver technologies. According to the European Commission, AI refers to "systems that display intelligent behavior by analyzing their environment and taking actions (with some degree of autonomy) to achieve specific goals" [16]. Its application in the industrial sector has resulted in the "intelligent manufacturing" concept [93], which, along with the other recent emerging Industry 4.0 KETs, will allow more flexible and efficient operations in the smart factory [15]. In order to achieve a good implantation of this technology, the industrial AI framework is also proposed with a clear structure, methodology, and ecosystem [15].

In the shipbuilding industry, there are already some applications in terms of design vessels for optimizing the overall performance [94]. The applications of AI are mainly related with the development of other technologies, acting as an enabler to impulse the potential of each one of the other KETs [95]. This is shown in the interaction between AI and the particular effect it deploys.

4.2 Social network analysis (SNA)

Due to the existing correlation between the KETs selected in this case study, it is possible to develop a social network in order to confirm the links among them. A social network is defined as a finite set of actors (such as people, organizations, or technologies) and the relationship among them [96]. The social network perspective focuses on these relations as an important addition to the standard social research, which is mainly concerned in the attributes of the social units. The social network analysis (SNA) is similar to the mind map technique, which allows to represent the ideas and their relationships. This method has already been used to the study the Industry 4.0 enablers [97]. The SNA is an innovative technique and research tool that has already been successfully used to find the relationship between different technologies and resources relative to the Industry 4.0 [80].

The MoSCoW method is used [98] to establish the network of Navantia's KETs. This method stands for "Must, Should, Could and Won't Have" criteria, and it is mainly used to stablish a priority list. In this case, a variant of the method is considered to weight the different interaction possibilities:

- Must have. Numeric value 3: The technology studied needs the crossed technology one mandatory.

- Should have. Numeric value 2: The technology studied can have major connection with the crossed technology.

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	3DP	AuV	BD	BCH	Cloud	CybS	AI	DP	IoT	M&S	NM	Robot	VAR
3DP	0	0	1	1	1	1	2	1	1	3	2	1	0
AuV	1	0	1	1	2	2	2	0	2	1	0	0	1
BD	0	0	0	2	3	2	2	1	3	0	0	0	0
BCH	0	0	0	0	1	2	2	0	0	0	0	0	0
Cloud	0	0	1	1	0	2	2	1	1	0	0	0	0
CybS	0	0	1	2	1	0	2	1	0	0	0	0	0
AI	0	0	2	1	2	2	0	1	2	1	0	0	0
DP	0	0	1	1	3	1	1	0	1	0	0	0	0
IoT	0	0	2	1	3	1	2	1	0	1	0	0	0
M&S	0	0	1	0	1	0	2	1	1	0	0	0	1
NM	2	0	2	0	0	0	2	0	0	2	0	0	0
Robot	1	1	2	1	1	1	2	0	2	2	1	0	1
VAR	0	0	2	1	2	1	2	1	1	3	0	0	0

Table 1.
Relationship among Navantia's key enabling technologies.

- Could have. Numeric value 1: The technology studied can have minor connection with the crossed technology.
- Won't have. Numeric value 0: The technology studied does not need the crossed technology.

In the first place, a nonsymmetric matrix is created, in which the nonlinear dependencies between the KETs are shown. Each row shows the dependency of a KET with the others. For example, VAR is dependent of M&S, but it is not the same in the other way around. These binary and paired comparison assessments were completed by the expert committee of Navantia, as summarized in **Table 1**. Once the data is ready, it is introduced in the software UNICET (version 6.675) [99], which will return the analyzed data (from the social network) and graphic representation.

5. Results

Once the data is analyzed, the results give information regarding the relationship between KETs, as betweenness, centrality, closeness, or density. However, the measures of centrality and betweenness are the ones to be taken into account. Centrality is the grade of each actor which is linked with the others. In a nonsymmetric matrix, the difference between ins and outs means the necessity of other technologies have of the chosen one (ins) and the necessity of the chosen technologies have of the others (outs). In addition, betweenness is the possibility that an actor has to intermediate the communications between pairs of actors. These are also known as bridge actors. The grade of centrality and betweenness is summarized in **Table 2**, where the main results are shown in bold.

These results show that both the AI and the cloud are the most demanded technologies among the other KETs (more than 0.55 relatively), while the individual

	Outdeg	Indeg	nOutdeg	nIndeg	Betweenness	nBetweenness
3DP	14.000	4.000	0.389	0.111	5.667	4.293
AuV	13.000	1.000	0.361	0.028	0.000	0.000
BDA	13.000	16.000	0.361	0.444	2.250	1.705
BCH	5.000	12.000	0.139	0.333	0.000	0.000
Cloud	8.000	**20.000**	0.222	**0.556**	2.000	1.515
CybS	7.000	15.000	0.194	0.417	0.917	0.694
AI	11.000	**23.000**	0.306	**0.639**	**10.417**	**7.891**
DP	8.000	8.000	0.222	0.222	0.583	0.442
IoT	11.000	14.000	0.306	0.389	3.583	2.715
M&S	7.000	13.000	0.194	0.361	**9.500**	**7.197**
NM	8.000	3.000	0.222	0.083	0.000	0.000
Robot	15.000	1.000	0.417	0.028	2.500	1.894
VAR	13.000	3.000	0.361	0.083	0.583	0.442

Table 2.
Centrality and betweenness grade of Navantia's KETs.

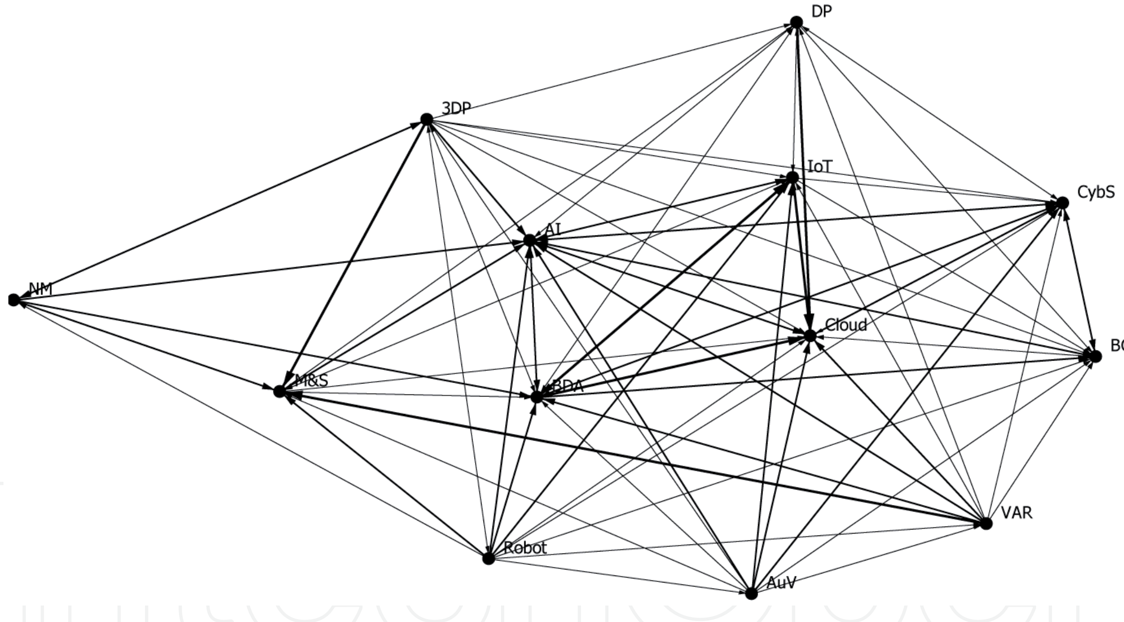

Figure 3.
Social network among Navantia's key enabling technologies.

dependency of each KET on the others is not too high, being robotics the most dependent. In terms of betweenness, the AI stands out again, followed closely by modeling and simulation. These are the two technologies with more capacity to stablish interactions between other technologies, which is an important added value to consider. The social network result is drawn in **Figure 3**, in which the connections between the technologies are represented.

The network shows the four main technologies on which the rest of the technologies revolve: artificial intelligence (AI), cloud, Big Data analytics (BDA), and Internet of things (IoT). This is consistent with the principles of the digital transformation and with the implications that the use of AI has to achieve a further development of the other KETs either due to direct integration or as an enabler linker for other technologies. These results also show the importance each of the technology has in the shipbuilding industry. This could be used to stablish a criterion, in order to support one technology over another.

6. Conclusions

In this book chapter, a state of the art of the shipbuilding industry is carried out. This includes a literature review in shipbuilding complex projects, lean manufacturing implications in shipbuilding, and the introduction of the fourth industrial revolution into this industrial sector, and there is a need to overcome the difficult situation that it is currently facing. To go further in this research, a study case is presented. The Spanish state-owned shipyard Navantia is chosen to study how a shipyard is challenging the digital transformation and introducing KETs in its production system. Afterwards, a revision of the advances and the integration of these technologies in the shipbuilding industry are presented.

Moreover, due to the relationship that exists among the KETs, a SNA is performed. This analysis has confirmed the main technologies that the Industry 4.0 has to prioritize during its implementation. From the nine original technologies, Big Data analytics, Internet of things, and cloud are highlighted. On top of those, artificial intelligence appears to join the cloud as the technology that will have the biggest impact in the Industry 4.0, due to its potential to increase the benefits of the other key enabling technologies.

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Conflict of interest

The authors declare no conflict of interest.

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