DANILO NOGUEIRA DA CRUZ

Industry 4.0 adoption at SMEs: assessment of POLI-USP Learning Factory based on the Italian recreational boating sector

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I owe my deepest gratitude,

To my family and friends.

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Danilo Nogueira da Cruz

RESUMO

Esse trabalho é dedicado ao estudo da Indústria 4.0 no contexto do setor recreacional náutico italiano e na comparação dos *gaps* de conhecimento e implementação de tecnologias 4.0 com aquelas presentes na Fábrica do Futuro da Escola Politécnica da USP. O método de pesquisa consiste em revisão bibliográfica, análise bibliográfica sistemática, *survey*, entrevistas semi-estruturadas e um estudo de caso de uma *Learning Factory* – a Fábrica do Futuro da USP. As principais tipologias de empresas no setor e outras características de mercado foram encontradas. A pesquisa no setor foi mapeada utilizando métodos quantitativos que incluem o *software* de visualização *VOSViewer*. Utilizando modelos teóricos de referência sobre Indústria 4.0, um questionário foi desenvolvido e aplicado em empresas do setor para avaliar o nível de conhecimento e implementação das tecnologias 4.0. Os resultados da *survey* foram explorados em maior profundidade em entrevistas semi-estruturadas. Um contraste foi encontrado entre a teoria da quarta revolução industrial proposta na literatura e a realidade do setor, em que há adoção gradual de tecnologias específicas pelas pequenas e médias empresas que o caracterizam. Finalmente, o nível de conhecimento e implementação das empresas analisadas para cada um dos sete grupos de tecnologias 4.0 propostos foram comparados com os demonstradores presentes na Fábrica do Futuro, permitindo a discussão sobre como essa infraestrutura poderia promover maior conhecimento e adoção de Indústria 4.0 em setores compostos por pequenas e médias empresas. Pesquisas futuras são necessárias para precisar quanto iniciativas como a Fábrica do Futuro podem contribuir para o desenvolvimento e a adoção da Indústria 4.0 em diferentes setores.

Palavras-chave: Indústria 4.0. Manufatura Avançadas. Setor recreacional náutico italiano. Learning Factory.

ABSTRACT

This project is dedicated to the study of Industry 4.0 in the context of the Italian recreational boating sector and the comparison of the knowledge and implementation gaps of 4.0 technologies with the ones available in the POLI-USP Learning Factory in Brazil. The research method consisted of literature reviews, systematic bibliometric analysis, survey research, semi-structured interviews and a case study of POLI-USP Learning Factory. The main players of the sector and other quantitative market characteristics were found. Research on the field was mapped using quantitative methods which include Scientometrics software VOSViewer. Using as a reference theoretical models on Industry 4.0, a questionnaire was designed and applied to companies in the sector to evaluate their knowledge and implementation of 4.0 technologies. Results of the survey were explored in higher depth in qualitative semi-structured interviews. A contrast was found between the theory of fourth industrial revolution proposed in the literature and a gradual adoption of specific technologies by the Small and Medium Enterprises (SMEs) which characterize the studied sector. Finally, the implementation and knowledge in the sector for each of the seven identified groups of 4.0 technologies was compared with the demonstrators present in the Learning Factory, discussing how such infrastructure could promote a higher adoption and awareness of Industry 4.0 in sectors composed SMEs. Further research is necessary to better understand the potential of Learning factories in increasing the development and adoption of Industry 4.0 in different sectors.

Keywords: Industry 4.0. Advanced Manufacturing. Italian recreational boating sector. Learning Factory.

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LIST OF ABBREVIATIONS AND ACRONYMS

AIDA	*Analisi Informatizzata delle Aziende Italiane*
CAM	Computer Aided Manufacturing
CCO	Chief Communications Officer
CEO	Chief Executive Officer
CINO	Chief Innovation Officer
CM	Cloud Manufacturing
COO	Chief Operations Officer
CPPS	Cyber-Physical Production Systems
CPS	Cyber-Physical Systems
CRM	Customer Relationship Management
DES	Discrete Event Simulation
ERP	Enterprise Resource Planning
ETO	Engineer to Order
I4.0	Industry 4.0
IaaS	Infrastructure-as-a-Service
ICT	Information and Communications Technology
IIoT	Industrial Internet of Things
IoS	Internet of Services
IoT	Internet of Things
IT	Information Technology
M2M	Machine-to-Machine
MES	Manufacturing Execution Systems

MTO	Make to Order
PaaS	Platform-as-a-Service
PNI 4.0	*Piano Nazionale Impresa 4.0*
R&D	Research and Development
RFID	Radio-Frequency Identification
SaaS	Software-as-a-Service
SMEs	Small and Medium Enterprises

SUMMARY

1 Introduction

The digital innovations summarized by the term *Industry 4.0* will reshape many industries in the following years, increasing their efficiency and competitiveness. It represents an enormous potential in many areas and its implementation will have impacts in the entire value chain, improving production and engineering processes, enhancing the quality of products and services, optimizing the relationship between customers and organizations, bringing new business opportunities and economic benefits, changing the education requirements and transforming the current work environment (Pereira & Romero, 2017).

This work was developed in two different moments. Firstly, in the context of the project "*Nautica 4.0*", an initiative of the *Osservatori Digital Innovation*, a research group at Politecnico di Milano which studies the application and knowledge of Industry 4.0 in the Italian recreational boating sector. It was done under the supervision of Professor Sergio Terzi and co-supervision of Lucia Ramundo. The work was subsequently developed under the supervision of Professor Eduardo Zancul in the "Fábrica do Futuro" at Escola Politécnica da Universidade de São Paulo, a factory model built with the objective of teaching and researching the applications of Industry 4.0.

1.1 Relevance

Industry 4.0 is a growing trend in the manufacturing industry, a "trillion-dollar opportunity for the industrial sector" which can enable 3-10% revenue growth and 4-9% margin expansion for companies which are able to adopt it successfully (Atluri, Sahni, & Rao, 2018).

Many governments have recognized the importance of the 4.0 transformation to maintain or grow competitiveness of their manufacturing sectors. In Italy, the federal incentives on Industry 4.0 have been growing with the *Piano Nazionale Industria 4.0,* which was first presented in 2016, and has been renewed yearly since then. In Brazil, initiatives to promote Industry 4.0 such as the POLI-USP Learning Factory have received governmental financial incentives, and its importance has been justified by the recent deindustrialization process the country is currently going through. In the 2006-2016 period, for example, the industrial productivity has fallen more than 7% (Ministério da Indústria Comércio e Serviços, 2016).

The choice of the Italian recreational boating sector as a starting point is justified by its economic importance for the country, which accounts for a high portion of the country's GDP: in 2017, it was responsible for 1.87% of the Italian economy (UCINA Confindustra Nautica, 2017). Moreover, it was found that there are no specific studies to evaluate the implementation and knowledge of Industry 4.0 in the sector.

In this context, the study of the maturity of the Italian nautical sector with respect to Industry 4.0 and its comparison with the Learning Factory initiative in Brazil is relevant for many reasons. Firstly, it is an important sector for Italy, both as producer and as consumers, which wants to keep its position of market leader. Secondly, it is the opportunity to explore a technologically immature sector, identifying barriers and possible directions for implementing 4.0 solutions. Third, it allows to identify insights and methodological tools that can be helpful for analyzing other manufacturing industries in other countries – especially those composed mainly by Small and Medium Enterprises (SMEs) – providing better understanding of the Industry 4.0 transformation. Finally, the assessment of POLI-USP Learning Factory contributes to understanding if such initiatives are aligned with market demands and could promote a faster transition to the new manufacturing paradigm.

1.2 Objectives

This research's objectives are two-fold:

I. To provide a detailed analysis of the current state of the recreational boating sector in Italy through the optics of the Industry 4.0 transformation, understanding its knowledge and implementation level, possible barriers to implementation and directions for adoption of Smart Technologies;

II. To describe the POLI-USP Learning Factory, classifying its technologies according to the literature and analyzing them by comparing with the results found for the Italian recreational boating sector and the research on Industry 4.0 applications in the maritime industry.

1.3 Structure

This dissertation is divided into eight sections. A literature review on Industry 4.0 is presented. The research questions and methodology for inquiry are derived subsequently. The research consists of a bibliometric analysis, literature review and market analysis of the Italian recreational boating sector, a survey and case studies on the sector, confronted with the description and analysis of the POLI-USP Learning Factory, as well as a qualitative assessment of the findings. Results are then summarized, and conclusions are drawn in the last section. The first six sections were developed mainly at Politecnico di Milano. At Universidade de São Paulo, the work was adapted, and the two last sections were developed and modified.

1.4 Author's Contributions

The author was responsible, after conducting a literature review, of defining the research questions that would guide the inquiry of the project. In an effort to answer the research questions, the author contributed with many studies which have never before been made on this specific sector. These include a map of the main companies in the sector classified according to their types of services, a bibliometric analysis of the research in the maritime sector with respect to Industry 4.0, a survey (which had as a starting point a survey that had been designed for the general manufacturing industry, but that has been adapted for higher customization of response paths and to better fit the reality of the recreational boating sector based on the knowledge gathered in the previous steps) and case studies (semi-structured based on the Survey's questions and responses). The author was responsible for adapting, managing and gathering responses for the survey, with the support of experienced researchers of the *Nautica 4.0* group. The outlines for the semi-structured interviews of the case studies were derived from the survey's questions and answers. A description of the Learning Factory, the classification of its technologies and comparison with the results obtained for the recreational boating sector was also performed. Results were analyzed by the author and the research groups both in Italy and Brazil to draw final conclusions.

2 Literature Review: Industry 4.0

2.1 Industry 4.0: an overview

At the end of the 18th Century, the First Industrial Revolution began with the introduction of mechanical production based on water and steam. The Second Industrial Revolution, traced back to the start of the 20th Century, is particularly characterized by the introduction of new production organization (e.g. Fordism) and four main technological advances: electricity (1); the internal combustion engine (2), chemicals and pharmaceuticals, including petroleum and natural gas (3); and entertainment, communication and information innovations with the telephone, radio and cinema (4) (Gordon, 2000). The Third Industrial Revolution started in the beginning of the 70s with the introduction of Information and Communications Technology (ICT), which enabled a higher level of production automatization.

All three Industrial Revolutions were associated with strong waves of productivity increase (Bergeaud, Cette, & Lecat, 2016). Productivity is one of them main drivers of economic growth in a macro level and is intrinsically associated with any company's competitive advantage. Thus, an early and strong participation in an Industrial Revolution has the potential of bringing economic welfare for a country's population and superior performance for the participating companies.

The Fourth Industrial Revolution, or "Industry 4.0", represents a vision of the future in which the industrial companies, thanks to digital technologies, will increase their competitiveness through an increasing interconnection of their resources (e.g. assets, people, information), either inside their factories or at any other part of the value chain. It was first proposed as "*Industrie* 4.0" by Kagermann et al. (2011) and has since then received an increasing attention from organizations, governments and the scientific community[1].

There is still no common definition of Industry 4.0 in the scientific literature, and the phenomenon is called by different names (e.g. Advanced Manufacturing) depending on the author and country (Kang et al., 2016). One possible description is "as a shift in the manufacturing logic towards an increasingly decentralized, self-regulating approach of value creation, enabled by concepts and technologies such as Cyber-Physical Systems (CPS), Internet of Things (IoT), Internet of Services (IoS), Cloud computing or Additive manufacturing and Smart Factories[2], so as to help companies meet future production requirements" (Hofmann & Rüsch, 2017). The basis of I4.0 implementation is based on digital design and simulation, highly automated manufacturing processes, production data management and networking, production process management and on the CPS, which uses computing, communications and control technologies in tight collaboration to achieve real-time sensing intelligent production systems, dynamic control, and information services (Zhou, Taigang Liu, & Lifeng Zhou, 2015). Its purpose is "to build a highly flexible production model of personalized and digital products and services, with real-time interactions between people, products and devices during the production process" (Zhou et al., 2015).

Industry 4.0's consequences can be observed in four aspects (Qin, Liu, & Grosvenor, 2016):

- **Factory:** under the new paradigm, current factories will evolve into Smart Factories, which can be defined as "a Factory that context-aware assists people and machines in execution of their tasks" (Lucke, Constantinescu, & Westkämper, 2008). All the resources of the future factory will be connected, exchanging real-time information and thus enabling a high level of automatization in the production management. Deep

[1] A bibliometric study identified an exponential growth in the number of publications per year on the topic, from only 3 papers in 2012 to more than 500 in 2016 (Muhuri et al., 2019).
[2] These concepts are explained in detail in the next section, "**Main Industry 4.0 Concepts**"

transformations will happen as a result: for example, “a factory that accepts consumer orders and directly produces, and ships the required product will dispense of separate sales and circulation channels, which will have a strong impact on the traditional e-commerce sales model” (Zhou et al., 2015);

- **Business:** the exchange of information between resources will not be limited to inside the factories, but instead there will be an integrated network between all the stakeholders inside companies and the value chains. The future business network is influenced by each cooperating section, which could achieve a self-organizing status and transmit real-time responses (Wahlster et al., 2013). Connected supply chains also have many potential benefits in terms of logistics efficiency, both at the operative and cross-organizational levels (Hofmann & Rüsch, 2017). This paradigmatic change will require substantial changes to business’s strategies and enable new business models: companies will need virtual and physical structures that allow for close cooperation and rapid adaption along the whole lifecycle from innovation to production and distribution (Gligor & Holcomb, 2012);
- **Product:** product customization will be possible at a much lower cost. Product design and innovation will stem from the creative use of smart manufacturing intelligence gathered from every point of the supply chain, from consumer preferences through production and delivery mechanisms (Chand & Davis, 2010);
- **Customer:** a higher integration of the value chain will represent many advantages to customers, such as higher customization and shorter product delivery times. The benefit of Smart Products also enables customers not only to know the production information of the product but also to receive the advice of utilization depending on their own behaviors (Schlechtendahl, Keinert, Kretschmer, Lechler, & Verl, 2014).

Still, most of the technology in production nowadays is aimed at increasing efficiency in manufacturing processes, focusing on improvements on individual firms rather than on the whole supply chain. These advances, also present on the organizational-economic level (e.g. Lean Management) and information technology level (e.g. Radio-Frequency Identification, or RFID), have led to isolated gains in efficiency, but are only the tip of the iceberg when compared to the potential transformation of Industry 4.0 technologies (Schumacher, Erol, & Sihn, 2016).

2.2 Main Industry 4.0 Concepts

There has been a growing effort in trying to classify and define the main concepts that collectively represent the Industry 4.0 transformation. Most of those still do not have a consolidated definition and, in some cases, there are overlapping terms with no commonly agreed hierarchy.

Roblek, Meško, & Krapež (2016) propose that the four key components of Industry 4.0 are *Cyber-Physical Systems* (connections between the real and virtual world), the *IoT*, the *IoS* and the Smart Factory. Machine-to-Machine communications (M2M) and smart products are not considered as independent parts, because the M2M is an enabler of *IoT* and smart products are a subcomponent of the cyber-physical systems. Finally, *Big Data* and *Cloud Computing* are services which utilize the data generated in Industry 4.0 implementations, but not independent I4.0 components (Hermann, Pentek, & Otto, 2016).

Kang et al. (2016) uses the terms “Industry 4.0” and “Smart Manufacturing” interchangeably and proposes that “smart factories are the ultimate realization of Smart Manufacturing”, proposing five essential technologies for the realization of Smart Manufacturing: *CPS, Cloud manufacturing (CM), IoT*, *Big Data Analytics* and *Smart Sensors*. According to them, *Additive Manufacturing* and *Augmented Reality* are additional technologies which are more related to the applied levels of *Smart Manufacturing*. However, some authors use the terms “Smart factory”, “Smart Manufacturing”, “Intelligent Factory” and “Factory of the Future” as synonyms (Roblek et al., 2016).

The challenge of precisely defining the relationship between all the above-presented concepts and reaching a common definition of Industry 4.0 is clearly not solved yet. However, a precise understanding of the meaning of each of them individually is a necessary step to better understand the development of the Industry 4.0 development in general and in the recreational boating sector. Ten of the main ideas on top of which Industry 4.0 is built are defined and explained in the next sub-sections.

2.2.1 Smart Products

Under the Industry 4.0 paradigm, many products will become Smart Products, which contain sensors and have the capability of transmitting information between users and companies (such as manufacturer of the product, manufacturers of complementary products, insurance companies).

These connected products have three core elements: *physical* components (such as mechanical and electrical parts); *smart* components (sensors, microprocessors, data storage, controls, software, an embedded operating system, and a digital user interface); and *connectivity* components (ports, protocols, and networks that enable communication between the product and the product cloud, which runs on remote servers and contains the product's external operating system) (M. Porter & Heppelmann, 2015).

The capabilities of smart products can be grouped into four areas: monitoring, control, optimization, and autonomy. Each one of those builds on top of the one before (e.g. to have control capability a product must have monitoring capability), which is shown in the **Figure 1:**

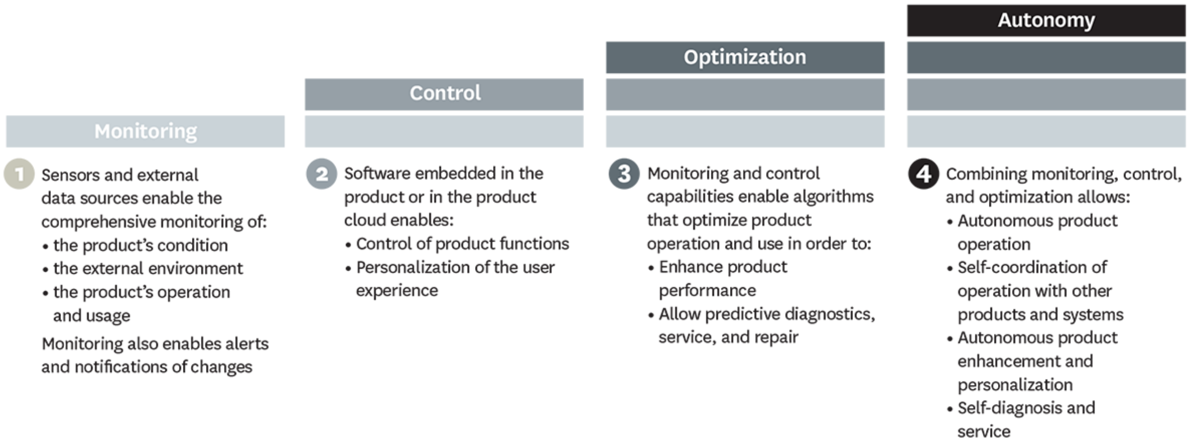

Figure 1: Evolution of Smart Products. ***Source: Porter & Heppelmann (2014).***

Some consequent applications of the development of Smart Products include the offering of additional services by the product manufacturer, such as guidance on how to better use the product or gathering user data to provide predictive maintenance services.

2.2.2 Simulation Modelling and Digital Twin

Simulation modelling is understood as the use of models of a real or imagined system or a process to better understand or predict the behavior of the modelled system or process. As an analogue representation, a physical, mathematical or another type of model is constructed (Rodič, 2017). Though it can be argued that simulations under this definition have been first used thousands of years ago, this term is generally used nowadays as referring to modern mathematics-based simulation.

Simulations will be used more extensively in plant operations to leverage real-time data to mirror the physical world in a virtual model, which can include machines, products, and humans, thereby driving down machine setup times and increasing quality (Gerbert et al., 2015). Uses of simulations of production processes can not only shorten the down times and changes but also reduce the production failures during the start-up phase. (Simons, Abé, & Neser, 2017). It can also bring productivity improvements through an enhancement of the decision-making ability (Schuh, Potente, Wesch-Potente, Weber, & Prote, 2014).

A particular type of simulation is the Discrete Event Simulation (DES), which will contribute to the industrial revolution on three main aspects (Vieira, Dias, Santos, Pereira, & Oliveira, 2018):

- **Automated data exchange:** data exchange is performed through data collection (received from real objects such as machines, sensors and other) and its subsequent automated insertion into the simulation model. This is increasingly important since data is being produced at increasing rates through the growth in utilization of sensors;
- **Automatic model generation: i**n the context of I4.0 where factories are very dynamic, the systems being modelled may require frequent changes, which optimally will be done in an automated way;
- **Visualization:** analysis of complex systems is often facilitated by the ability to represent them in a visual way, which can be achieved through the ability to immerse users in a virtual reality environment, or through integration with *Augmented Reality*.

The Industry 4.0 paradigm will result in an increased capability of self-organization of manufacturing and other systems, which requires their digital modelling (i.e. virtual factory) and the use of advanced artificial intelligence (cognitive) for process control (Rodič, 2017). Assets will have a unique digital representation, called *Digital Twin,* that alters its properties, condition and behavior by means of models, information and data. It consists of a Digital Master – a unique instance of the universal model of the asset (machine), its individual Digital Shadow and intelligent linking (algorithm, simulation model, correlation, etc.) of the two elements above)" (Stark, Kind, & Neumeyer, 2017). The *Digital Twin* is also applied to product development and testing in a virtual environment. Information gathered from previous product life cycle phases is used for a better realization of further stages. (Rodič, 2017)

The evolution process of simulation models until the concept of Digital Twin is presented in **Table 1** (Rosen, Von Wichert, Lo, & Bettenhausen, 2015)**:**

The next wave in modelling and simulation: the "Digital Twin Concept"			
Individual Application (1960+)	**Simulation Tools (1985+)**	**Simulation-based System Design (2000+)**	**Digital Twin Concept (2015+)**
Simulation is limited to very specific topics by experts (e.g. mechanics)	Simulation is a standard tool to answer specific design and engineering questions (e.g. fluid dynamics)	Simulation allows a systemic approach to multi-level and disciplinary systems with enhanced range of applications (e.g. model based systems engineering)	Simulation is a core functionality of systems by means of seamless assistance along the entire life cycle (e.g. supporting operation and service with direct linkage to operation data)

Table 1: Evolution of simulation models. ***Adapted from Rosen, Von Wichert, Lo, & Bettenhausen (2015)*****.**

A particular application of *Digital Twin* is in the product itself. Inside (in the manufacturing process) or outside (during logistics or after-sales) the factory boundaries, data makes the digital version of the product evolve to reflect how the physical product has been altered and used. It allows the organization to observe the status of a product at any moment of its life cycle, even during manufacturing. By allowing integration and storage of information on product usage *Digital Twins* may also provide new insights into how products can be better designed, manufactured, operated and serviced. (M. Porter & Heppelmann, 2015)

2.2.3 Virtual Reality and Augmented Reality

Augmented reality refers to the integration of additional computer-generated information into a real-world environment (Paelke, 2014). While its potentials have yet not been fully explored due previous technological limitations, mobile technological advances are unlocking a myriad of application opportunities. A more general term that groups Virtual Reality and Augmented Reality is Advanced Human-Machine Interface.

This interface technology is increasingly being applied to products. Through a smartphone or tablet pointed at the product, or through smart glasses, augmented reality applications tap into the product cloud and generate a digital overlay of the product. This overlay contains monitoring, operating and service information that makes supporting or servicing the product more efficient. (M. Porter & Heppelmann, 2015).

Workers can receive repair instructions on how to replace a particular part as they are looking at the actual system needing repair. This information may be displayed directly in worker's field of sight using devices such as augmented-reality glasses (Gerbert et al., 2015)**.** Augmented reality and virtual reality can also be applied to product design and sales, creating a visualization of its *Digital Twin* which enables, for example, potential customer to visualize and build a relationship with their products before they are built.

2.2.4 Smart Sensor

To understand what a Smart Sensor is, it is necessary first understand the definition of a standard sensor. In general, "a sensor is a device that is designed to acquire information from an object and transform it into an electrical signal. A traditional integrated sensor can be divided into three parts: (1) the sensing element (e.g. resistors, capacitor, transistor, piezoelectric materials, photodiode); (2) signal conditioning and processing (e.g. amplifications, linearization, compensation, and filtering); and (3) a sensor interface (e.g. the wires, plugs and sockets to communicate with other electronic components)" (Kirianaki, Yurish, Shpak, & Deynega, 2002).

The essential difference between a smart sensor and a standard integrated sensor is its intelligence capabilities, which can facilitate self-diagnostics, self- identification, or self-adaptation (decision making) functions (Spencer, Ruiz-Sandoval, & Kurata, 2004). *Smart Sensors* are the most important technology at the device or hardware level in realizing IoT, CM, CPS and Smart Manufacturing because they are the most basic technology for collecting and controlling data in real time (Kang et al., 2016). The trend in reduction of sensor's cost and size is, thus, an important driver for the Industry 4.0 transformation.

2.2.5 Big Data and Data Analytics

The ever growing use of sensors and networked machines has resulted in the continuous generation of high volume data which is known as Big Data (Lee, Bagheri, & Kao, 2015). *Big Data* generally means a data set that is inappropriate to be used by traditional data process methods due to their wide range, complex structure, and size. Therefore, technical and special systems, and methodologies, such as analysis, capture, data curation, search, sharing, storage, transfer, visualization and information privacy, are required to perform predictive analytics, extract value from data, and seldom to a particular size of data set, among others (Kang et al., 2016).

Big Data analytics employ a family of new techniques to understand patterns which correlate a variety of product sensor's individual readings with useful insights on maintenance and product usage. The low-level granular data captured by sensors consumed by analytics and modelling applications to enable manufacturers to develop a better understanding of their activities and processes to derive insights that can improve existing operations. (O'Donovan, Leahy, Bruton,

& O'Sullivan, 2015). Porter & Heppelmann (2015) propose a framework for applying *Big Data* in an *Industry 4.0* scenario:

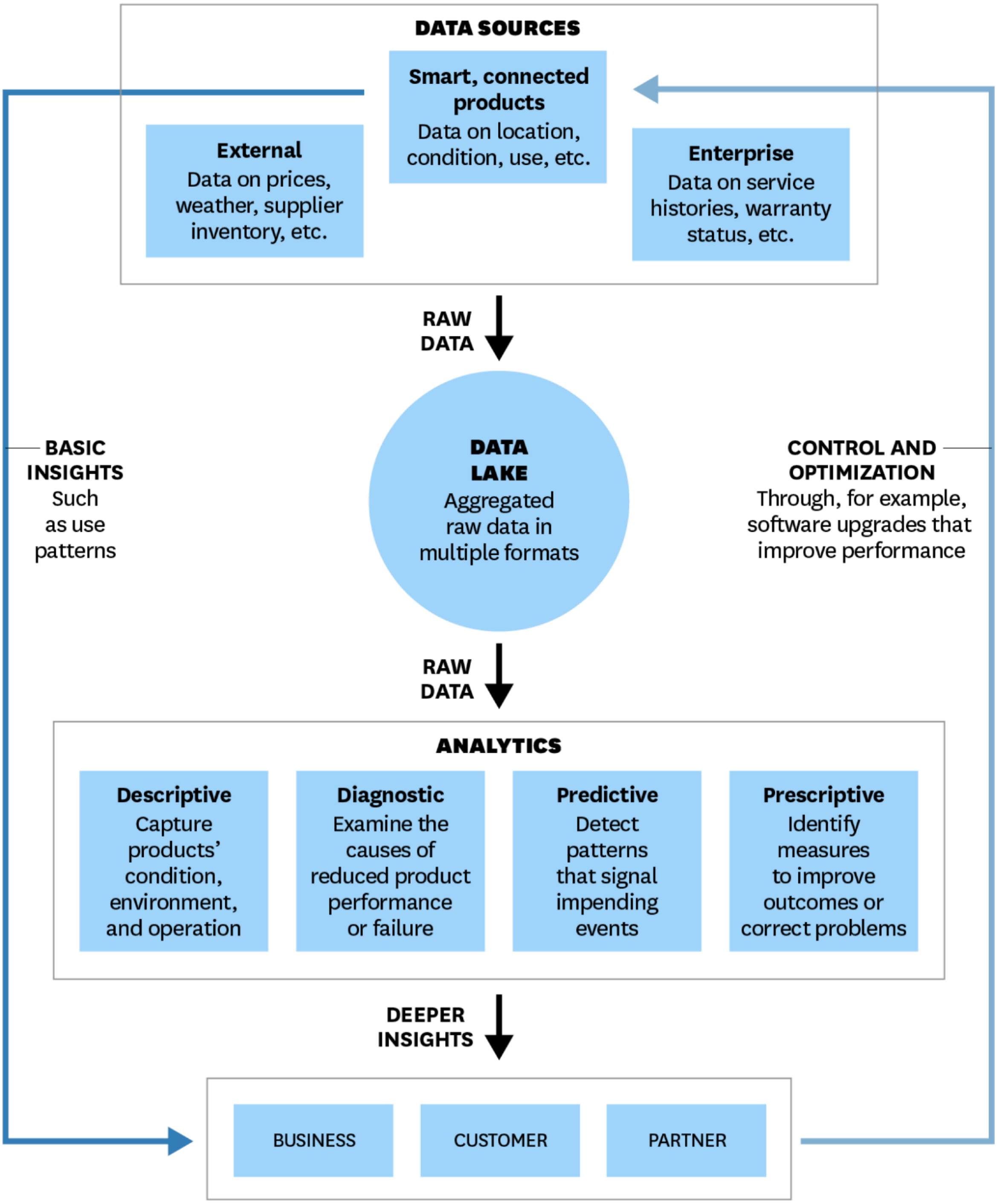

Figure 2: Smart products and Big Data in the Industry 4.0 framework. ***Source: Porter & Heppelmann (2015).***

This framework highlights the importance of Smart Products, which enable traditional sources of data (e.g. internal operations and transactions across the value chain) to be supplemented by another source: the product itself. The variety and volume of information generated by Smart, connected products are unprecedented. While this data is valuable by itself, its integration with traditional sources of data increases exponentially its potential value. Data on warranty status, for example, becomes more valuable when combined with data on product use and performance, since knowing that a customer’s heavy use of a product is likely to result in a premature failure covered under warranty, for example, can trigger preemptive service that may preclude later costly repairs (M. Porter & Heppelmann, 2015).

The analytics divided into descriptive, diagnostic, predictive and prescriptive, are crucial components for the self-regulating vision of the future factory. Thus, organizations must be able to work with *Big Data* technologies to meet the demands of Smart Manufacturing (O’Donovan et al., 2015).

2.2.6 Cyber-Physical Systems

Cyber-Physical Systems can be defined as “a new generation of systems which integrate physical assets and computational capabilities and are able to interact with humans” (Baheti & Gill, 2011). In general, a CPS consists of two main functional components: (1) the advanced connectivity that ensures real-time data acquisition from the physical world and information feedback from the cyber space; and (2) intelligent data management, analytics and computational capability that constructs the cyber space (Lee et al., 2015).

In a manufacturing environment, Cyber-Physical Systems comprise smart machines, storage systems and production facilities capable of autonomously exchanging information, triggering actions and controlling each other independently (Kagermann, Wahlster, & Helbig, 2013). This facilitates fundamental improvements to the industrial processes involved in manufacturing, engineering, material usage and supply chain and life cycle management through decentralization and increased autonomy, which are important components of Cyber-Physical Systems and drivers of their increased performance (Ivanov, Sokolov, & Ivanova, 2016). CPS can be further developed for managing Big Data and leveraging the interconnectivity of machines to reach the goal of intelligent, resilient and self-adaptable machines (Lee et al., 2015).

Some authors also use the term Cyber-Physical Production Systems (CPPS), which can be defined as “an applied version of CPS to manufacturing area with various root technologies”. CPPS consists of autonomous and cooperative elements and sub-systems that are getting into connection with each other in situation-dependent ways, on and across all levels of production, from processes through machines up to production and logistics networks (Monostori, 2014).

2.2.7 Internet of Things and Internet of Services

The CPS connected to the Internet is often referred to as the "Internet of Things" (Jazdi, 2014). The IoT was first conceived as an abstract idea that captures a movement that started when we began integrating computing and communication technology into many of the "things" that we use at home and work. It started with the idea of tagging and tracking "things" with low cost sensor technologies such as RFID devices. However, the paradigm shifted as the market began delivering low-cost computing and Internet-based communication technologies, simultaneously with the rise of ubiquitous smartphone (Thames & Schaefer, 2016).

IoT can be defined as "networks of electricity, software, sensors, network connectivity and embedded 'things' or physical objects. IoT collects or exchanges data acquired from smart sensors, enables big data analytics, and realizes CPS and Cloud Manufacturing" (Kang et al., 2016).

IoT relies both on smart objects and smart networks, since they are physical items enriched with embedded electronics and connected to the Internet (Shrouf, Ordieres, & Miragliotta, 2014). The IoT sensors can be smart sensors, actuators or wearable sensing devices, such as RFID sensors that will send storage, processing analysis information (Al-Fuqaha, Guizani, Mohammadi, Aledhari, & Ayyash, 2015), (H. Dutton, 2014)

IoT has numerous possibilities for applications in an Industry 4.0 environment. Customer Relationship Management (CRM) will be deeply transformed, allowing companies to understand customers and offer proactive support by leveraging IoT data to create improved, automated customer support environments. IoT also allows monitoring of all manufacturing processes with the purpose of maintenance, production quality and energy management optimization, improving the ERP (Roblek et al., 2016).

The Industrial Internet of Things (IIoT) is a subset of what we have come to know as the Internet of Things", with more specific "things" (e.g. sensors, actuators, robots and 3D printers), and goals related to the Industrial applications (Thames & Schaefer, 2016).

Some authors also refer to the Internet of Services, which is based on the idea that services are becoming easily available through web technologies, allowing companies and private users to combine, create and offer new kind of value-added services. It can be defined as "a commercial transaction where one party grants temporary access to the resources of another party in order to perform a prescribed function and a related benefit. Resources may be human workforce and skills, technical systems, information consumables, land and others" (Barros & Oberle, 2012). It is conceivable that this concept will be transferred from single factories to entire value added networks in the future, which will result in a new way of distributing individual value chain activities (Hermann et al., 2016).

2.2.8 Cloud Computing and Cloud Manufacturing

Cloud computing can be defined as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (Mell & Grance, 2011). In Cloud computing, the software, platform and infrastructures are provided by suppliers as services (*SaaS, PaaS, IaaS*) to their customers. The application of Cloud computing in traditional manufacturing can produce savings in functions that were traditionally performed internally in the IT department (Xu, 2012)**.**

A further stage of development of Cloud Computing into manufacturing is *Cloud Manufacturing.* It can be defined as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources (e.g. manufacturing capabilities) that can be rapidly provisioned and released with minimal management effort or service provider interaction)" (Xu, 2012). It is a network manufacturing model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources, forming temporary and reconfigurable production lines that enhance efficiency, reduce product lifecycle costs, and allow for optimal resource loading in response to variable-demand customer generated tasking (Thames & Schaefer, 2016), (Wu, Greer, Rosen, & Schaefer, 2013).

In Cloud manufacturing, distributed resources are aggregated and represented as cloud services and managed in a centralized way. Clients can use the cloud services according to their requirements. Cloud users can request services ranging from product design, manufacturing, testing, management and all other stages of a product life cycle. A cloud manufacturing service platform performs search, intelligent mapping, recommendation and executing of a service (Xu, 2012). Its characteristics include networked manufacturing, scalability, agility, ubiquitous access, multi-tenancy and virtualization, big data and the IoT, everything-as-a-service, scalability and resource-pooling (Thames & Schaefer, 2016).

2.2.9 Smart Factory

Factories will be completely equipped with sensors, actors and autonomous systems. An application of “smart technology” related to holistically digitalized models of production and various technologies of ubiquitous computing develops into the concept of Smart Factories, which are autonomously controlled (Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014). A possible definition classifies the Smart Factory as “a manufacturing cyber-physical system that integrates physical objects such as machines, conveyers and products with information systems such as Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP) to implement flexible and agile production” (Wang, Wan, Zhang, Li, & Zhang, 2016). A Smart Factory is a manufacturing solution that provides such flexible and adaptive production processes that will solve problems arising on a production facility with dynamic and rapidly changing boundary conditions in a world of increasing complexity (Radziwon, Bilberg, Bogers, & Madsen, 2014).

A Smart Factory provides the customers with smart products and services which will be connected to the internet. The analysis of data collected from smart product and related smart applications enables the factories to better define customer’s behaviors and needs, and to provide them with new and more sustainable products and services. In addition to that, IoT technology enables the customers to be involved in the production design process (Shrouf et al., 2014). The integration of IoT, IoS and the Smart Factories can be seen in the **Figure 3**:

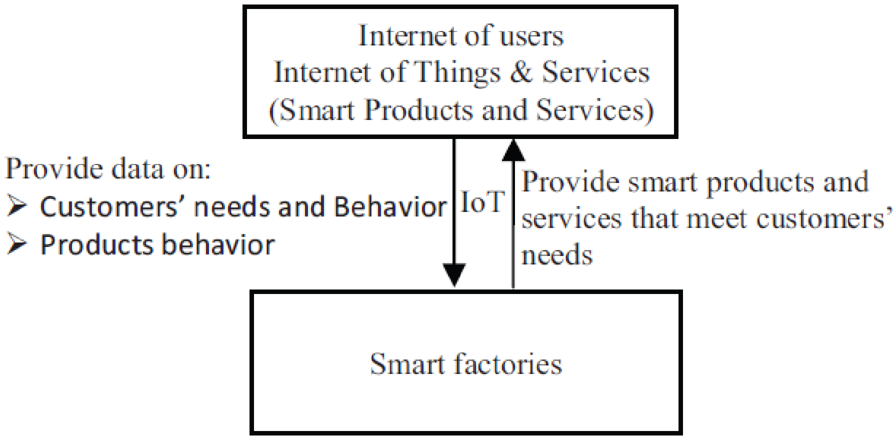

Figure 3: Integration of IoT, IoS and the Smart Factories. ***Source: Shrouf et al. (2014).***

The goal of the Smart Factory is to connect all smart devices with higher decision making (Dutta & Bose, 2015). Exchange of real-time data in the next generation of smart factories means those will have to be able to adapt, almost instantaneously, to changes in market demand, technology and regulations (Azevedo & Almeida, 2011).

For smart factory to be implemented, it should combine the smart objects with big data analytics. The smart objects can dynamically reconfigure to achieve high flexibility whereas the big data analytics can provide global feedback and coordination to achieve high efficiency, promoting vertical integration for a smart production. Therefore, the smart factory might be able to produce customized and small-lot products efficiently and profitably (Wang et al., 2016). A framework of the Smart Factory proposed Wang et al. (2016) is shown in **Figure 4:**

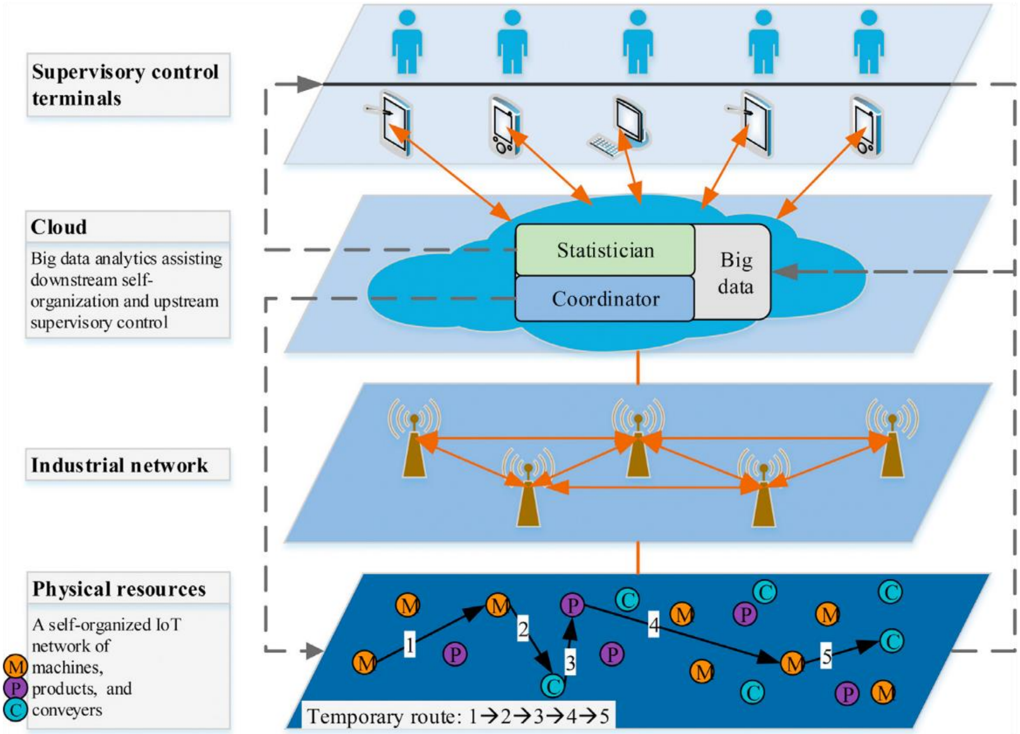

Figure 4: Framework of the Smart Factory in the Industry 4.0 paradigm. ***Source: Wang et al. (2016).***

Wahlster (2012) proposes that the Smart Factory is characterized by five characteristics: (1) Smart Networking; (2) mobility; (3) flexibility; (4) integration of customers and (5) new innovative business models. Shrouf et al. (2014) proposes that its implementation results in mass customization, factory visibility, optimized decision-making, new planning methods for factories, creation of value from big data collected, creation of new services, remote monitoring, automation and change role of man, proactive maintenance, connected supply chain and improved energy management.

2.2.10 Additive manufacturing (3D Printing) and Digital Manufacturing

Additive Manufacturing is a way to convert a 3D model, such as a CAD file, into a physical object by bonding or joining materials through light, ultrasonic vibration, laser and electron beam. The realization of it through a cutting-edge technology is the 3D printing technology. (Kang et al., 2016). While in the beginning it was mainly for prototyping, its technological development is promising to enable manufacturing of a wide variety of final products.

The main advantages, as compared to the existing manufacturing methods, are (1) material efficiency, (2) resource efficiency, (3) part flexibility, and (4) production flexibility, while the main weaknesses are (1) size limitation, (2) imperfection, and (3) cost (Wong & Hernandez, 2012), (Huang, Liu, Mokasdar, & Hou, 2013).

Moreover, 3D printing enables production of highly customized products with more generic raw materials when compared to existing manufacturing models. Thus, "the promise of 3D printing is based on custom products that are made to order, and low-turnover replacement parts: these are typically ordered in unique configurations and in very small quantities" (Berman, 2012).

3D printed products are also easier to integrate in a Smart Factory, unlocking possibilities which include the complete separation of design, which could be done by customers, and manufacturing. Still, prices of 3D printers are still too high for many industrial applications and in many cases are not able to produce objects of certain shapes or of the correct material.

Additive manufacturing relates to Industry 4.0 through the concept of Digital Manufacturing (or Direct Digital Manufacturing). It can be defined as an interconnection of (decentralized) additive manufacturing equipment and modern information and communication technology (Chen et al., 2015). This creates new possibilities such as that parts no longer being produced in a factory, assembled to final products and shipped to customers. Instead, these products would be manufactured right at or close to the customer utilizing additive manufacturing and directly derived from a digital model (Gibson, Rosen, & Stucker, 2015).

2.3 The 4.0 Transformation

The digitization consists in convergence between physical and virtual worlds and will have a widespread impact in every economic sector (Kagermann, 2015). The economic impacts of Industry 4.0 can be divided into two parts: (1) in the competitive market structure and (2) inside each organization's operations (Porter & Heppelmann, 2015).

2.3.1 Impacts on Competition

The state of competition in an industry depends on five basic forces: the bargaining power of buyers, the nature and intensity of the rivalry among existing competitors, the threat of new entrants, the threat of substitute products or services, and the bargaining power of suppliers (M. Porter, 1979). Thus, it is also possible to divide the Industry 4.0 impact on the competitive landscape in the transformations into those same five forces (M. Porter & Heppelmann, 2014):

1. **Bargaining power of buyers:** on the company's side, companies can leverage on Smart Products, Big Data and IoT to better segment customers and improve CRM. This can be achieved through the ability of targeting each customer individually based on their preferences, purchasing habits and other integrated information, bringing extra value for customers (Morabito, 2015) and thus increasing their switching costs. On the other hand, the access to Smart Product's data can give customers a better understanding of their performance and reduce their dependency on the manufacturers for support. The emerging "product as a service" model can increase the bargaining power of buyers by reducing switching costs related to ownership (M. Porter & Heppelmann, 2014). At the same time, building a sustainable competitive advantage will increasingly come from offering a system of connected and complementary products, and from creating a platform with strong network effects that increase consumers' switching costs (Gupta, 2018);
2. **Rivalry among competitors:** mass customization first-mover advantages can prove important sources of competitive advantage, since companies may get well entrenched in this position and start being seen by people as innovative and customer-driven (Da Silveira, Borenstein, & Fogliatto, 2001). Competitive rivalry will increasingly shift from company-versus-company to a competition between vertically integrated value chains (M. Porter & Heppelmann, 2014);
3. **Threat of new entrants:** the intensity of the threat of new entrants is strictly associated with the barriers to entry (M. Porter, 1979), which will be profoundly affected by the Industry 4.0 transformation. New obstacles include high fixed costs of a more complex product design, its embedded technology and a sophisticated IT infrastructure. Barriers to enter may rise when incumbents capture their first-mover advantages by collecting product data and quickly adapting to the new markets demand but may go down when smart products invalidate their strengths and assets (M. Porter & Heppelmann, 2014);

4. **Threat of substitutes:** companies able to adapt to the ever-changing customer demand by collecting and analyzing market and product data may have extra protection against substitute products. However, a trend of widening product capabilities may represent a threat to conventional products, which could have their function performed by another which was previously not related. An example is the smartphone, which is a substitute for a myriad of products, from clocks to computers (M. Porter & Heppelmann, 2014);
5. **Bargaining power of suppliers:** the 4.0 transformation will shift part of the physical value from products to software, and in some cases the first will suffer a commoditization process (Shih, 2015). Thus, traditional suppliers may face a decline in their bargaining power. However, suppliers of the essential technologies for the Smart Factories and Smart Products (e.g. providers of sensors, software, operating systems, analytics etc.) may have an increase in their bargaining power, especially in concentrated markets, due to their greater importance, (Russo, Bene, Verma, & Arora, 2016).

2.3.2 Impacts on Companies

The Industry 4.0 will represent transformations both at each firm's internal organizational level and at value chain level. At the organizational level, the classical structure of manufacturing businesses in functional units (e.g. R&D, manufacturing, logistics, sales), in which these can substantial autonomy and integration is only tactical, will become obsolete. Intense coordination integration, between functional units will be necessary to provide more agility and use analytics to provide continuous improvement, given the overwhelming amount of data collected through Smart Products. Some business units will merge, and the first ones may be R&D and IT (M. Porter & Heppelmann, 2015).

At the companies and value chain level, six main transformation areas are discussed (M. Porter & Heppelmann, 2015), (Pereira & Romero, 2017):

1. **Product development** will be increasingly multidisciplinary, and software will constitute a large part of it, which allows companies to offer a higher customization of products at a lower cost. Upgraded versions of Smart Products can be offered continuously through upgrades, rather than discretely in another physical device. New interfaces with other devices will allow Smart Products to be controlled by, for example, a smartphone, which enables new design opportunities. Finally, product development will be able to leverage on data from real users, rather than only testers, allowing companies to identify and address design problems that testing failed to expose,

allowing product design changes to be incorporated at the last minute, even after delivery. Direct contact with the customer engaged in Industry 4.0 will allow for the assessment and the perceived value of products and services (Roblek et al., 2016);

2. **Manufacturing** will be performed in the Smart Factories, which employ a new approach to production and contain embedded manufacturing systems, which are vertically networked with business processes within factories and enterprises and horizontally connected to dispersed value networks that can be managed in real time (Kagermann et al., 2013). The complexity of physical components also tends to decline, while at the same time software becomes increasingly elaborate;
3. **Supply chain and logistics** will use continuous tracking of connected products, which can also provide information such as their condition and their surrounding environment. Optimization opportunities in the logistics (e.g. management of large fleets of vehicles) through IoT and Big Data will be increasingly relevant in the competition against value chains. By providing logistics and supply chain information in a more detailed and up to date than currently, it is possible to mitigate the bullwhip effect (Yan & Huang, 2009), reduce counterfeiting and improve product traceability (Zhengxia & Laisheng, 2010);
4. **Marketing and sales** will be transformed as the relationships between companies and customers will shift from a one-time transaction focus to maximizing the value added to customers over time. Smart Products, Big Data and IoT allow better segmentation, with consequences on pricing, advertising and CRM (M. Porter & Heppelmann, 2015). Products will gradually become components of larger systems, which means that competition will be more complex (e.g. between individual or family of products, between platforms), which means that sales and marketing teams will need broader knowledge to better position their offers;
5. **After-sale services** will be more efficient, shifting from reactive service to preventive, proactive and remote. Companies which traditionally only sold products can use Smart Product data to offer new after-sale services, such as maintenance or advice on how to better use it. When a repair is needed, technicians can diagnose problems remotely, so they can perform the repair in only one visit since they already have the tools needed for it. Another possibility is remote service, which could be done by customers with remote guidance from a technician through on augmented reality technology. Predictive analytics can anticipate problems, providing maintenance instead of repair and thus reducing downtimes (M. Porter & Heppelmann, 2015);

6. **Skills development and Human Resources** will have to change, since the future work vision (especially in the manufacturing sector) will demand for new competences and it is necessary to create opportunities for the acquisition of the required skills through high quality training (Erol, Jäger, Hold, Ott, & Sihn, 2016). Industry 4.0 will lead to an increased automation of tasks, which means that workers should be prepared for performing new tasks, and increasingly more qualified staff will be required in technological fields to address Industry 4.0 requirements (Pereira & Romero, 2017).

3 Methodology

After revising the literature on Industry 4.0, it is clear that the fourth industrial revolution is expected by the scientific community to deeply transform manufacturing in the next years. Industry 4.0 can be divided in groups of key technologies, which, when combined, are expected to create Smart Factories that are integrated with their supply chains.

3.1 Research Question, Goals and Methodological overview

There are a multitude of research documents focused on the envisioned future and application frameworks for the 4.0 technologies. However, the current state of the transformation is unknown in many industries, among which the shipbuilding, a sector that in Italy is mainly composed by the recreational boating sector. Finally, the alignment of the POLI-USP Learning Factory with the market demand has not yet been fully explored. The research questions, thus, are:

Q1) What is the current state of the Italian recreational boating Industry with respect to the knowledge and utilization of Industry 4.0 and its technologies?

Q2) Which factors can possibly explain their knowledge and implementation level?

Q3) Which technologies are present in the POLI-USP Learning Factory and how do they compare to the identified gaps in the Italian recreational boating sector?

However, every method of scientific inquiry is subject to limitations. With the objective of reaching the most solid results possible, a combination of multiple quantitative and qualitative methods was used. The main activities performed during the development of this work and the associated goals in each phase are summarized in a structured approach for answering the research questions:

A. **Literature review** on Industry 4.0 to understand the importance of the fourth industrial revolution, its general impact on manufacturing and explain the main technologies which are associated with the transformation:
    i. **Goal 1:** justifying the research in terms of the expected transformations synthetized in the concept of Industry 4.0.
    ii. **Goal 2:** identifying key technologies that compose Industry 4.0 to further investigate the current state of the recreational boating sector.
    iii. **Goal 3:** identifying main possible drivers for adoption of 4.0 technologies in terms of their impacts inside companies.
B. **Bibliometric analysis** on the global scientific research that addresses the maritime sector from the perspective of Industry 4.0 and its main technologies, with the objective of mapping the research on the field:
    i. **Goal 4:** developing a robust and replicable research procedure to find documents which are related both Industry 4.0 and the maritime sector.
    ii. **Goal 5:** analysis of the research results, identifying the technologies which have been most studied in terms of total number of documents and research growth.
    iii. **Goal 6:** mapping the research in terms of its keywords to get insights on how the technologies and applications interact in the maritime context.
    iv. **Goal 7:** identify main countries, type of documents and research areas that constitute the state-of-the-art scientific production on Industry 4.0 in the maritime.
C. **Literature review** of the bibliography on the Italian recreational boating sector and market analysis to identify the sector's characteristics and main representative players to be subsequently studied in depth:
    i. **Goal 8:** identify the market characteristics of the recreational boating sector, such as market concentration and value chain structuring.
    ii. **Goal 9:** analyze the characteristics of the main representative typologies of companies and develop an insightful map, for each type of player, of the companies which belong to it.
D. **Quantitative cross-sectional survey research** to gather and analyze that that enables the identification of the knowledge and implementation level of the recreational boating sector's main players, as well as to inquiry possible reasons which explain these results:
    i. **Goal 10:** develop a replicable questionnaire to be used in this work and further research projects.

ii. **Goal 11:** gather quantitative information to understand the knowledge level of the Industry 4.0 topic in the recreational boating sector for each type of player and in overall.

iii. **Goal 12:** map the implementation of 4.0 technologies in absolute values and for each implementation area.

iv. **Goal 13:** formulate and apply hypothesis-driven questions to explore possible reasons and obstacles to implementation.

v. **Goal 14:** understanding the impact of governmental programs such as the *Piano Nazionale Impresa 4.0* in the recreational boating sector.

vi. **Goal 15:** Analyze obtained data, segment it according to the main players and compare it to benchmarks.

E. **Semi-structured interviews** with selected representatives of different segments to gather qualitative data that leverages on the results of the survey research to increase their explanatory capability:

i. **Goal 16:** investigate in further depth the reasons behind respondent's answer in the survey to expand it with explanatory values and detect possible flaws in quantitative data;

ii. **Goal 17:** understand the mechanisms that lead companies to having a determined implementation level, including but not limited to drivers for innovating, obstacles and their collaboration networks;

F. **Case study** of the POLI-USP Learning Factory to understand how this initiative relates to the market demands such as the ones of the Italian recreational boating sector:

i. **Goal 18:** understand the concept and general objectives of Learning Factories;

ii. **Goal 19:** describe and analyze the implemented technologies and associate them with the different Industry 4.0 technological categories

iii. **Goal 20:** compare the results found with the research done on 4.0 technologies in maritime and the technologies implemented in the Italian recreational boating sector;

G. **Results assessment** to analyze the partial results obtained in each section, comparing them and, if necessary, to the appropriate scientific literature:

i. **Goal 21:** summarize results found in all sections;

ii. **Goal 22:** provide answers to the three research questions, highlighting limitations of the study and suggesting future steps.

Table 2 summarizes the characteristics of the methods used:

Methodology		
Method	**Quantitative Research**	**Qualitative Research**
Textual analysis	Content analysis, i.e., counting in terms of researchers' categories	Understanding participants' categories
Interviews	Survey research: mainly fixed-choice questions to bigger samples	Open-ended questions to small samples

Table 2: Different uses of methods and methodologies. ***Adapted from Silverman & Marvasti (2008, p. 145)***

The literature review is qualitative and is used to understand the two objects of study and their relationships (Industry 4.0 and the Italian recreational boating sector). The analysis of documents and in-person evaluation of the POLI-USP Learning Factory consisted also of a qualitative research. A bibliometric analysis of the research on Industry 4.0 and the Maritime, was also performed and is a quantitative research which involves textual analysis.

Quantitative research based on the interview method is performed in the Survey research, in which the objective is to obtain the most statistically significant data possible. On the other hand, the semi-structured case interviews are qualitative and aim to obtain information with higher explanatory capabilities and depth of fewer samples.

A combination of qualitative and quantitative methodological perspectives has been used to complement each other in the inquiry of the research questions, which is conceived as a complementary compensation of the weaknesses and blind spots of each single method, which is defined by some researchers as *triangulation*. Some authors define the association of quantitative and qualitative methods as *mixed methods research*, "an approach to knowledge that attempts to consider multiple viewpoints, perspectives, positions and standpoints, always including the standpoints of qualitative and quantitative research". It can be defined as "the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g. use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for broad purposes of breadth and depth of understanding and corroboration" (Johnson, Onwuegbuzie, & Turner, 2007).

This combination is usually pursued with the objectives of obtaining knowledge about an issue which is broader than the single approach and to mutually validate findings of both approaches (Flick, 2009).

3.2 Methodological Steps

These methodological steps are further explained in the next sub-sections.

3.2.1 Literature review

The literature review is used in this work in two different moments. Firstly, it aims to provide understanding on the called "fourth industrial revolution", defining its main concepts, technologies and proposing possible impacts. Secondly, to review the literature on the Italian recreational boating sector, identifying its main players and value and supply chain characteristics. In both moments, the identification and characterization of the phenomenon and the sector to be studied provides a background for subsequent research in the other steps. It was performed mainly using the *Scopus* platform, from which documents and their citations were retrieved and analyzed, which enabled the discovery of the most important documents that explain either Industry 4.0 and its implications or one of its technologies.

Fink (2005) defines a literature review as "a systematic, explicit and reproducible method for identifying, evaluating and synthesizing the existing body of completed and recorded work produced by researchers, scholars and practitioners". Okoli & Schabram, (2010) propose that a special case of the literature review is the use as "an anchor for an academic thesis or dissertation", which is the case of this work.

Hart (1999) argues that there are four purposes for the literature review in a thesis. It synthesizes the understanding a student has on the subject and is a proof of a student's dedication to understand the topic of the research. Moreover, it justifies further research, which includes the thesis itself, and welcomes a student into scholarly tradition and procedures. These are consistent and add up to the previously mentioned objectives of understanding the studied phenomena and the gaps from which the research question is derived.

3.2.1 Bibliometric Analysis on Maritime 4.0

To understand the development of Industry 4.0 research on the maritime industry, a bibliometric analysis was performed. In a general sense, bibliometrics are defined as "a statistical analysis of books, articles, or other publications" (Oxford Dictionary, 2019). From a more scientifically-oriented perspective, it can be defined as "the quantitative study of physically published units, or of bibliographic units, or of alternatives of either" (Broadus, 1987). An alternative term is "Scientometrics", which can be defined as "the study of quantitative aspects of the process of science as a communication system" (Mingers & Leydesdorff, 2015).

Bibliometrics augment (meaning they do not replace) the traditional literature review, since it provides a macro and broad focus that provides clues that may suggest vital topic linkages to related findings and issues (A. L. Porter, Kongthon, & Lu, 2002). **Table 3** shows a comparison between the two methods:

Traditional literature review	Bibliometrics and Scientometrics
Micro focus (paper-by-paper)	Macro focus (patterns in the Literature)
Narrow range (~20 references)	Wide range (~20 – 20.000 references)
Tightly restricted to the topic	Encompassing the topic + related areas
Text discussion	Text, numerical and graphical depiction

Table 3: Quantitative and qualitative literature mapping. ***Adapted from Porter et al. (2002)***

By using bibliometrics, it is possible to analyze a greater amount of data, understanding the “big picture” by reducing the depth of analysis. Some other advantages include the quantification of research, which allows a more objective identification of research gaps, comprehensiveness (due to increased number of documents analyzed) in a structured and more replicable process of collecting and analyzing data (Pickering & Byrne, 2014).

Moreover, it was found during the research that there is almost no literature analyzing the implications of Industry 4.0 or its technologies on the maritime sector (i.e. Maritime 4.0). Indeed, most of the documents found in the process are focused on the practical application of one or more technologies, meaning that a deep technical knowledge of these technologies is necessary to perform an in-depth qualitative literature review. For these reasons, a quantitative approach was chosen.

Bibliometric analysis has been mainly applied with two objectives: (1) to measure the “output” of individuals, research teams, institutions and countries (and their networks) and (2) to identify national and international networks, and to map the development of new (multi-disciplinary) fields of science and technology (OECD, 2019). It is now firmly established as scientific specialties, becoming an integral part of research evaluation methodology especially within the scientific and applied fields. The methods are used increasingly when studying various aspects of science and also in the way institutions and universities are ranked worldwide (Ellegaard & Wallin, 2015). In the context of this work, the bibliometric analysis was performed with the latter objective, which is of science mapping.

For a quantitative analysis of citations to be successful, there must be comprehensive and accurate sources of citation data, and *Scopus* is among the databases that have been the traditional source for most major Scientometrics exercises (Mingers & Leydesdorff, 2015). For this reason, and since it has proved superior in terms of comprehensiveness when compared to its main rival, *Web of Science* (WoS), *Scopus* was the chosen database.

The science mapping analysis was then performed by using bibliometrics, which consisted of many steps, among which data retrieval (which was frequently an iterative process to refine the search strategy), data processing (to segment or refine results according to certain criteria), mapping, analysis and visualization, as proposed by Cobo et al. (2011).

The most complex analysis was performed using a Scientometrics software, called *VOSViewer*, which is a tool specifically designed for constructing and visualizing bibliometric maps, paying special attention to their graphical representation (Cobo et al., 2011). This software uses the VOS mapping technique (van Eck & Waltman, 2010), in which a similarity matrix from a co-occurrence matrix is built using a similarity measure known as association strength.

3.2.2 Nautica 4.0 Survey: Methodology and Design

Survey research is a specific type of field study that involves the collection of data from a sample of elements (e.g. Italian companies in the recreational boating sector) drawn from a well-defined population (e.g. all Italian companies in the recreational boating sector) through the use of a questionnaire (Visser, Krosnick, & Lavrakas, 2000).

According to Kerlinger (1986), there are two major types of survey research:

a) **Exploratory**, with the objective of becoming more familiar of the topic. There is usually no model, and the concepts of interest need to be better understood and measured. A particular type is referred as “descriptive”, in which it describes the distribution of phenomena in a population;
b) **Explanatory**, which aims at finding causal relationships among variables, based on hypothesis of those relationships.

The purpose of the performed Survey, entitled in Italian “*Nautica 4.0*”, combines elements from both categories. Most of the questions aim at quantitatively characterizing respondents, which enables their description and the exploration of a sector that has not been studied with this method to understand its knowledge level and usage of Industry 4.0. These applications are mostly associated with the **exploratory** group.

At the same time, many questions are targeted based on previous responses and ask respondents to specify (both by selecting an alternative and by writing) their reasoning or their answers to previous answers. As an example, respondents which replied that have Industry 4.0 projects were asked to briefly describe them in an open-ended format. These questions have an **explanatory** nature.

The design adopted is *cross-sectional*, in which information is collected at one point in time (in this case, a two-months period, in an effort to maximize the number of respondents) from a sample chosen to represent the population. While the lack of temporal dimension makes it difficult to establish causality, the design is appropriate to test differences in population subsets (Malhotra & Grover, 1998). These subsets are the main analyzed players (shipyards, suppliers and design studios), which were previously identified in the market analysis and literature review.

To select the respondents, *non-random sampling*, was used. This method, typically used for exploratory work, deliberately targets individuals within a population. Among the different types of *non-random sampling*, the *purpose sampling* was used, which occurs when the sample is made up of the individuals due to the qualities the participant possesses (Kelley, Clark, Brown, & Sitzia, 2003), which in this case is to be available to provide answers and to work in a company that competes in the Italian recreational boating sector. Unlike *random sampling*, which deliberately include a diverse cross section of ages, backgrounds and cultures, the idea behind *purposive sampling* is to concentrate on people with particular characteristics who will better be able to assist with the relevant research (Etikan, 2016).

Potential respondents were identified by using many different channels, including their relationship with the members of the research group *Nautica 4.0*, the Italian category association for the recreational boating sector UCINA and e-mail addresses associated with companies gathered in the database AIDA. Thus, rather than stratifying potential respondents to obtain the most representative answers for the recreational boating sectors, the objective was to maximize the number of respondents. Results were then stratified according to their characteristics (mainly their type of company) to understand possible differences. Still, it is important to point that this methodology has a considerable risk of presence of bias in their results (Etikan, 2016), which is why it was complemented by other research methodologies.

Response rates are also a potential source of bias, since results from a survey with a large non-respondents rate could be misleading and only representative of those who replied (Kelley et al., 2003). This was reported during data collection and considered in the data analysis.

The Survey was designed with a maximum of 33 questions in Italian language and presented to potential respondents using the electronic platform Survey Monkey[3]. Different responses lead to different paths, which means that most respondents were not presented with all 33 questions. The list with all questions (translated to English) is also available in the **APPENDIX A – Survey Questions**. A flowchart illustrating all questions and the conditions for a respondent to be presented with it, as well as the main sections composing the Survey, is presented in the **APPENDIX B – Survey Structure Flowchart**. The Survey was open for about two months (between March 12th and May 14th, 2019).

The advantages of the survey research include the fact that the breadth of coverage of many people or events means that it is more likely to obtain data based on representative sample. However, the data that are produced are likely to lack details or depth on the topic investigated (Kelley et al., 2003). To balance the last-mentioned disadvantage, an in-depth qualitative research was also adopted: the semi-structured interviews with few selected respondents of the Survey.

3.2.3 Case Studies

Punch (1998) says that “the basic idea [behind the case study methodology] is that one case (or perhaps a small number of cases) will be studied in detail, using whatever methods seem appropriate. While there may be a variety of specific purposes and research questions, the general objective is to develop as full an understanding of that case as possible”. He also proposes three main characteristics:

a) “Each case has boundaries that must be identified at an early stage of the research;
b) Each case will be a case of something in which the researcher is interested, so the unit of analysis must be defined at the outset in order to clarify the research strategy;
c) Case studies seek to preserve the wholeness and integrity of the case. However, in order to achieve some focus, a limited research problem must be established geared to specific features of the case”.

---

[3] In few cases, telephone calls were used to help respodents which requested it or to perform the Survey, which was filled by an interviewer while the interviewee replied verbally.

Case studies were used in two ways. First, semi-structured interviews were made with different companies in the recreational sector (multiple case interviews). In a second moment, a single case-study was developed describing and analyzing the POLI-USP Learning Factory.

In the latter case, the boundaries are the studied Learning Factory. It is an example of a Learning Factory, a novel method for teaching Industry 4.0. In the context of this work, it is studied in depth and compared to the literature and the Italian recreational boating sector. The objective is to understand "*Which technologies are present in the POLI-USP Learning Factory and how do they compare to the identified gaps in the Italian recreational boating sector*".

The research was done by visiting the Factory and asking questions to Professor Eduardo Zancul and several other people directly involved in the project in order to get a detailed and objective description of the used 4.0 technologies and their interactions.

The boundaries for the semi-structured interviews are defined as the members (preferably in high hierarchical) of main representative players in the recreational boating sector companies (shipyards, suppliers and design studios). Each case is a company, and the problem to be discussed is to seek answer for the two research questions, with especial emphasis to the second, which is of explanatory nature.

An interview can be defined as "a conversation that has a structure and a purpose determined by the one party – the interviewer. It is a professional interaction, which goes beyond the spontaneous exchange of views as in everyday conversation, and becomes a careful questioning and listening approach with the purpose of obtaining thoroughly tested knowledge" (Kvale, 2007). Some of the main strengths of interviewing include high return rate, fewer incomplete answers, controlled answering order and flexibility. However, it is time-consuming and potentially biased if not conducted properly (Alshenqeeti, 2014).

Kvale (2007) proposes seven stages of an interview inquiry, which were followed to conduct the interviews:

1. **Thematizing**, in which the purpose of an investigation is formulated, including the *why* and the *what* of the investigation, which should be clarified before the question of *how* – method – is posed.
2. **Designing**, in which the design of the study has to be planned taking into consideration all seven stages of the investigation before interviewing.

3. **Interviewing**, conducting the interviews based on an interview guide and with a reflective approach to the knowledge sought and the interpersonal relation of the interview situation.
4. **Transcribing**, preparing the interview materials for analysis.
5. **Analyzing**, deciding on the basis of the purpose and topic of investigation and of the nature of the interview material which modes of analysis are appropriate
6. **Verifying**, ascertaining the validity, reliability and generalizability of the interview findings.
7. **Reporting**, communicating the findings of the study and the methods applied in a form that lives up to scientific criteria and results in a readable product.

3.2.3.1 Thematizing and Designing

Thematizing was done before the interview method is selected as derivation of the first literature review and the subsequent methods, which enabled the definition of the research questions.

In the **designing** phase, the structure of the interview and the respondents were defined. *Purpose sampling* used to select potential respondents. The companies were selected among those which, in the Survey's last question, confirmed their availability to participate in an interview to provide further explanation of their answers. The criteria of first selection were two-fold. First, based on the results of the Survey, it was concluded that the design studios were in a very early maturity stage, and thus there was little to explore in an interview. The second filter consisted of selecting shipyards and suppliers in a similar proportion and dividing into three groups from different maturity levels of implementation and knowledge based on their answers to the Question 3. In this question, respondents had to choose between five alternatives the one that best replies the question "Do you know the Industry 4.0 topic". These were:

1. I don't know it;
2. I read articles online;
3. I have participated in events related to the topic;
4. I am evaluating on doing something about the topic;
5. I am implementing or have already implemented solutions related to Industry 4.0.

Those which chose the first option were excluded due to their lack of knowledge on the topic, which is to be explored in the interview. The three groups were then formed:

- Those who chose alternatives 2 or 3, meaning they know the topic but are still at an early maturity stage;
- Those which chose alternative 4, meaning they are evaluating but have not yet implemented;
- Those which chose alternative 5, meaning they have implemented or are implementing 4.0 solutions and thus have the highest maturity level.

As opposed to one case study in high depth, it was opted to performed some of them with the players that had different characteristics, in order to enable both triangulation of the results and a higher variety of perspectives.

A total of six interviews were made, with three companies of the first group, two of the second and one of the third. The remaining companies, even after confirming their interest on the survey, were not successfully interviewed due to the respondent's unavailability, including two cases in which the respondents made an appointment but did not answer phone calls. Interviews were performed in a *semi-structured* format, which means that it contains an outline of the topics to be covered, with suggested standardized and open questions, rather than a fixed structured order (Kvale, 2007). The order and wording of the questions, as well as follow-up questions to further investigate an answer were subject to the interviewers' judgement. This outline, which was composed of nine main topics, is reported in the **APPENDIX C – Case Studies' Questions**.

3.2.3.2 Interviewing and Transcribing

Interviewing was made in Italian language through phone calls by the author and the research and its co-supervisor, Lucia Ramundo. The addition of a second, most experienced, interviewer was beneficial to the conduction of the interview, many times directing it to further detail points that could be explored and would have been missed if only one researcher was present.

In the first minutes, a *briefing* was always used to introduce the interview to the interviewee, explaining who the interviewers are and the objectives of the research, "setting the stage" before the actual questions are posed. In the end, the interview was followed by a *debriefing* in which the interviewers asked the interviewee if they wanted their information to be associated with their name and company, or if it should be kept it in private. Since not all respondents were able to provide an answer in time, their company and personal names are kept anonymous and they are identified by a standardized name.

Transcribing was done during the interviews and the text was immediately associated with the topics that should be covered, which evidenced when topics still had to be investigated, greatly increasing the comprehensiveness of the results.

3.2.3.3 Analyzing, Verifying and Reporting

Analyzing and verifying was done in association with the results obtained using the previously described methodologies. Flick (2009) proposes that a possible combination of qualitative and quantitative research is when the same people are interviewed and fill in a survey, meaning that sampling decisions are taken in two steps. The same people are thus included in both parts of the study, but at some point, it has to be decided which participants of the survey research are selected for the interviews. Finally, the answers in the interviews were analyzed and compared, an, for example, a typology was developed. This approach is summarized in the **Figure 5:**

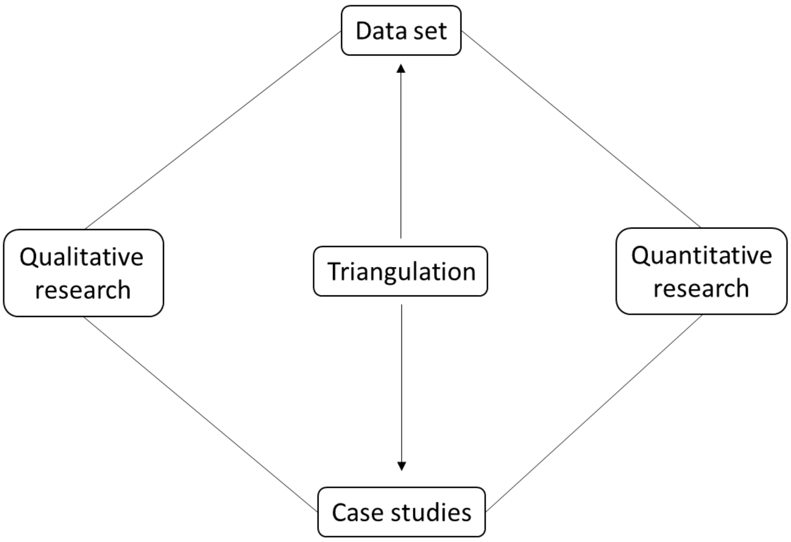

Figure 5: Levels of Triangulation of Qualitative and quantitative research. ***Adapted from Flick (2009)***

Since there are only few cases analyzed, their generalization capability if analyzed separately can be question. For this reason, the analysis of the answers is always performed by comparing it to the results obtained in the survey research, which has highest generalization capability, as suggested by Silverman & Marvasti (2008).

Finally, **reporting** was derived from the analysis and verification which was done by comparing the results between the different case studies and those achieved in the previous sections.

4 Industry 4.0 in the Maritime sector: A Bibliometric analysis

The data to perform the bibliometric analysis was gathered on the 15th June 2019, from the research platform *Scopus*. This platform was chosen because, among the available platforms, it contained the highest number of documents, by a great margin. This phenomenon was also present in the bibliometric analysis on Industry 4.0 performed by Muhuri et al. (2019). All the results presented refer to documents which include the terms in the keywords, thus not considering article titles or abstracts, which, after numerous attempts, have produced worse results.

A first search was made to understand the number of articles related to Industry 4.0, not focusing specifically on the maritime sector. The keywords used are presented on the **Table 4:**

Search Term (Group)	Number of articles in which the search term occurred on the keywords
“Industry 4.0”, “Industrie 4.0”	3373
“Advanced Manufacturing”	2458
Total[4]	**5785**

Table 4: Occurrences for different 4.0 groups of keywords. ***Source: Author’s elaboration.***

The evolution in the number of documents per year is exponential and is growing fast especially since 2014, which further confirms the recognized importance of Industry 4.0 in the scientific community.

4.1 Methodology

An effort was made to quantitatively map the research of the nautical sector through the lenses of Industry 4.0 and its technologies. The adopted approach was to iteratively determine a list of keywords by using the results from one search iteration to enhance and improve the search based on the achieved results. The methodology consists of three main phases:

1. **Selection of main keywords related to the nautical sector (Group 1):** in this phase, a variety of keywords was tested to define a group of terms that comprehended the greatest possible part of the documents related to the nautical market, with the least number of unrelated articles possible. The result is the **Keywords Group 1.** This was done by repeatedly iterating the following steps:

[4] Total value calculated by performing a search with the combined keywords of all lines, which solves the problem of counting twice the documents which are present in both lines.

   a. Starting with a with no terms in the group;
   b. Through brainstorming and manual research to evaluate the keywords used in the target documents, propose a new candidate term to be tested;
   c. Test the keyword by evaluating the results of a research containing only it;
   d. If the test result is positive, add it to the Keywords Group 1. If not, discard it;
   e. Repeat the process, starting from step **b**.
2. **Selection of main keywords related to Industry 4.0 (Group 2):** a similar process was adopted, but an extensive literature research (part of which is presented in the section "**Literature Review: Industry 4.0**") was necessary to propose the of keywords to be tested. The result is the **Keywords Group 2**;
3. **Combination of keywords and analysis of results:** by combining words from both groups, a bibliometric analysis was performed to analyze the documents published until the date in which the research was performed.

The results of the first two steps are presented in **Figure 6**:

Group 1

- Nautical
- Maritime
- Ship
- Boat
- Shipbuilding
- Shipyard

Group 2

- "Industry 4.0","Industrie 4.0", "Advanced Manufacturing"
- "Digital Twin", "Digital Simulation"
- "Augmented Reality", "Virtual Reality"
- "Smart sensor"
- "Big data"
- "IoT", "IIoT", "Internet of Things", "IoS", "Internet of Services"
- "Cloud Manufacturing", "Cloud Computing"
- M2M, "Machine-to-Machine"
- "Cyber-Physical System", CPS
- "Additive Manufacturing", "3D Printing", "3-D Printing", "Digital Manufacturing", "Rapid Prototyping"
- "Smart Manufacturing", "Smart Factory"
- "Smart Product", "Smart Boat", "Smart Ship"

Figure 6: Groups that contain the Maritime 4.0 keywords. ***Source: Author's elaboration.***

A first attempt of keywords in the *Group 2* included only the terms "Industry 4.0" and its German equivalent, which showed only 23 results when associated with all the keywords of the

Group 1. The addition of "Advanced Manufacturing" increased the results to 35, which is still too low to perform a bibliometric analysis. The inclusion of the individual components of the so-called fourth Industrial Revolution increased the amount of results to a reasonable number of 952 documents, which were then considered as a final version of this group to perform the analyses that follow. The combination of both groups produces a set of results which will be designated as "**Maritime 4.0**" for concision, since they are a combination of Maritime (*Group 1*) and Industry 4.0 (*Group 2*) keywords.

One of the challenges in finding the best words to include in *Group 2* was to decide which words better characterized the terms related to simulation in an Industry 4.0 context. As discussed in the previous sections, it can be argued that simulation is a concept that has been used for thousands of years by humans. From a mathematical and statistics perspective, the history of simulation can be divided into the pre-computer era (1777-1945), which started in the application of the Monte Carlo method in physical experiments, the formative period (1945-1970), in which the first Monte Carlo virtual simulations were performed and the expansion period (1970-1981), in which these models were enhanced (Goldsman, Nance, & Wilson, 2009). One of the candidate terms that was not included is "Computer Simulation", which produced over 5000 results. At first, the high number - five times greater than the sum of all others - was an indication that it was not focused enough on the 4.0 transformation. A deeper analysis considering its time-series evolution confirmed that in fact it was very different from all the other searches and it was consequently discarded.

4.2 Research Growth

The time series of the number of documents by year of the association of the two groups of keywords shows a growing trend. However, as can be seen in **Figure 7**, which compares the percentage of documents in the same period per year both in the general Industry 4.0 research and in the specific maritime context, the first is accelerating faster, especially in 2018:

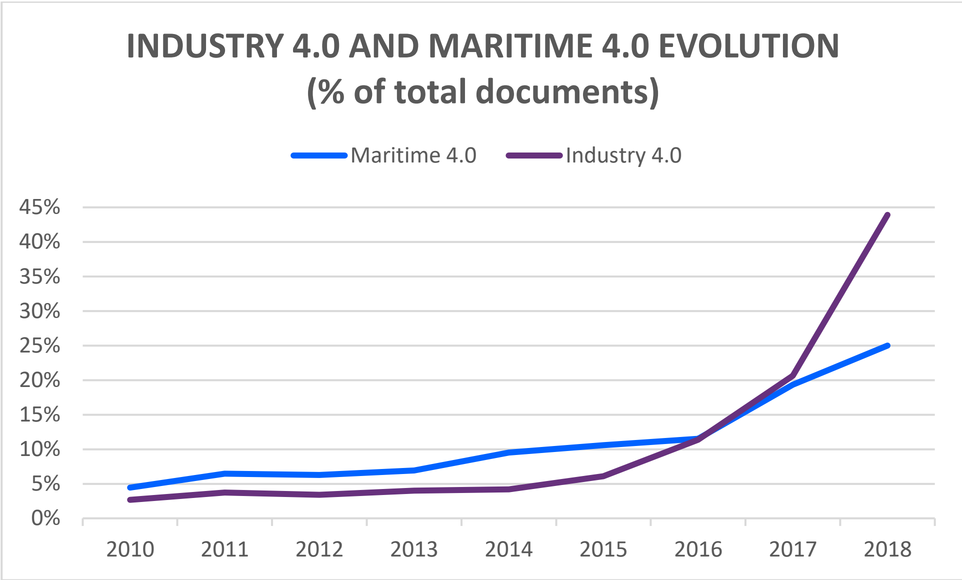

Figure 7: Comparison between Maritime 4.0 and Industry 4.0 evolution. ***Source: Author's elaboration.***

4.3 Country-wise Analysis

The vast majority of documents found in *Scopus* are classified according to the country (or countries) they are affiliated with. The 10 most productive countries in terms of number of documents were compared in number of documents and in total citation count. Documents may be associated with more than one country, and in this case, they are counted once for every country they belong to. The percentage is calculated over the total amount of only these players, using both criteria, and can be seen by comparing the bar size with the horizontal axis. The labels, on the other hand, show absolute values:

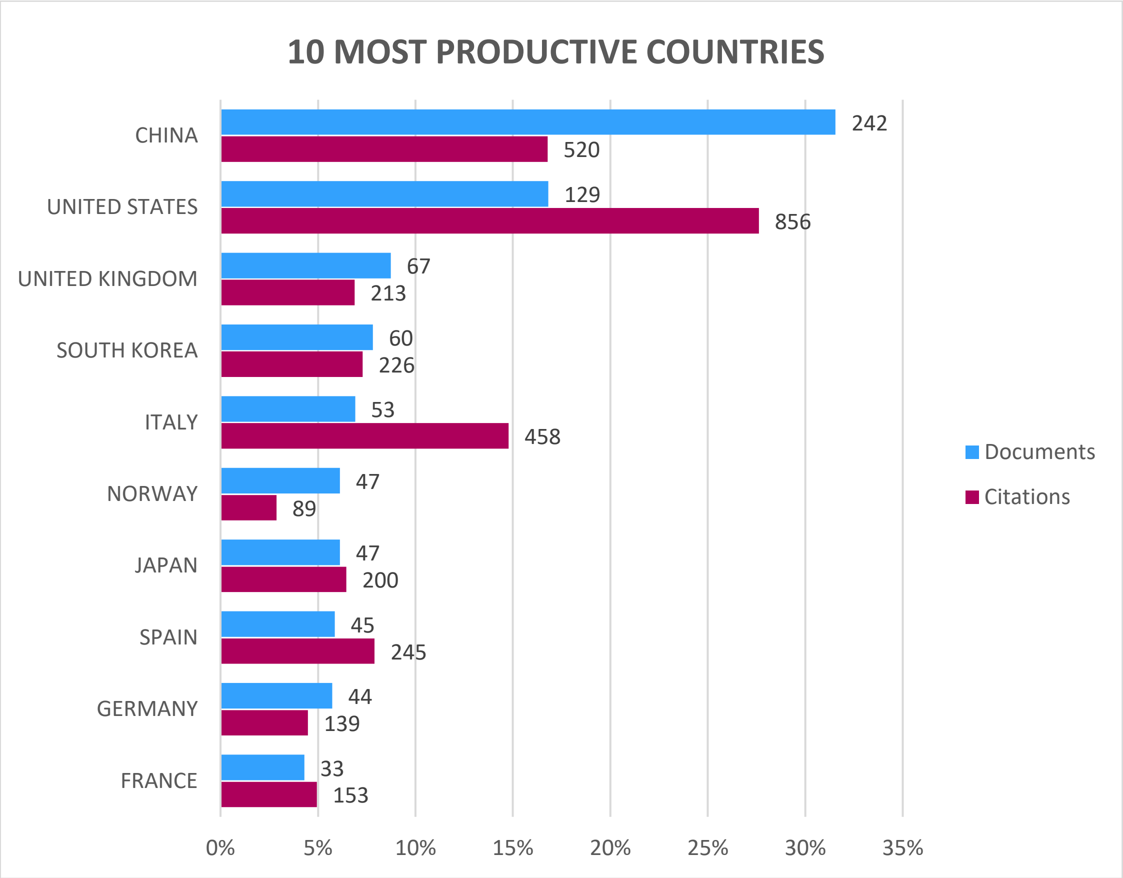

Figure 8: Most productive countries on Maritime 4.0. ***Source: Author's elaboration.***

China is the leading country when measured by number of documents (32%), which is almost two times the second player, the United States (17%). However, that is not the case when measured by total citation count, a proxy for the impact of the publications, in which the United States are the leading country (28%) and China is in the second position (17%). Italy is in the 5th position in number of documents (7%), while it is the third in citation count (15%).

4.4 Technology-wise analysis

The quantity of documents associated with each term is not evenly distributed, which is evidenced in the **Table 5**, showing how many results were found for the most important groups of keywords in *Group 2* when associated to the keywords of *Group 1*:

Search Term (Group 2)	Number of articles in which the search term occurred on the keywords
“Industry 4.0", "Industrie 4.0", "Advanced Manufacturing"	35
"Augmented Reality", "Virtual Reality"	427
"Big Data"	170
"IoT", "IIoT", "Internet of Things", "IoS", "Internet of Services"	117
"Additive Manufacturing", "3D Printing", "3-D Printing", "Digital Manufacturing", "Rapid Prototyping"	79
"Cyber-Physical System", CPS	66
"Cloud Manufacturing", “Cloud Computing”	62
"Digital Twin", "Digital Simulation"	29
"Smart Product", “Smart Boat”, “Smart Ship”	24
"Smart Sensor"	11
"Smart Manufacturing", "Smart Factory"	6
Total[5]	**952**

Table 5: Maritime 4.0 research results by technology. ***Source: Author’s elaboration.***

The low number of documents related to the broad “Industry 4.0” terms (34) when compared to total documents of specific technologies is an interesting result, evidencing that most of the research on the topic and in the nautical sector is not focused in a general vision of the transformation, but on individual applications. The few documents on “Smart Manufacturing” and “Smart Factory” also suggest that the general envisioned application of Industry 4.0 is not being studied very much by the scientific community.

The most researched groups are the ones containing “Augmented Reality” (427), “Big Data” (161) and “IoT” (117). At the same time, there are few documents about “Smart Manufacturing” (6) and “Smart Sensor” (11), which could have different reasons ranging from the simple low

[5] Total value does not count more than once documents which are presented in two different technological groups.

utilization of these keywords to a view of the sector in which these areas are considered less relevant.

Nevertheless, while observing the differences in the absolute number of documents is an important first step in trying to understand the volume of research that has been made, it is not enough to explain the phenomenon in a satisfactory way. A low value, for example, can have different meanings, such as that technology has been studied but is not considered relevant, or that it is still in an early mature stage but will be promising in the future.

For every technology, the number of documents was calculated for each year between 2010 and 2018 and those with at least 60 documents[6] in the period had their evolution presented in **Figure 9**:

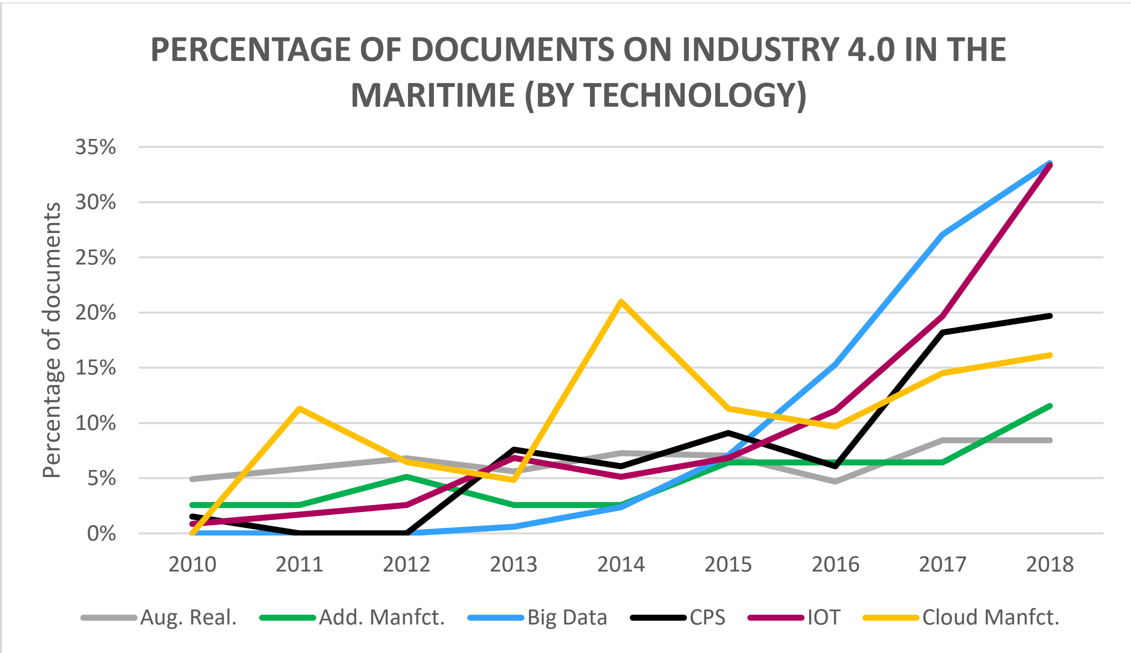

Figure 9: Evolution of documents by type of 4.0 technology. ***Source: Author's elaboration.***

The values in the chart represent the percentage of documents calculated for each technology as the number of documents in a year divided by the total number of documents presented in **Table 5**[7]. Therefore, these values only add up to 100% if all the documents were registered between 2010 and 2018, which did not happen for any of the technologies.

[6] Technologies with too few documents were not appropriate to be represented in the chart, since it considers their own percentage and thus the representation showed instability and was not insightful.
[7] The groups of technologies are still considered the same, although they will be called by just one of those technologies for concision.

Almost all technologies show a growing trend, which is consistent with the overall pattern of growth of the Maritime 4.0. The most accentuated growth curves are “Big Data” and “IoT”, while “Augmented Reality” is represented by a stable curve and “Additive Manufacturing” has a very low rate of growth. “CPS” and “Cloud Manufacturing” show intermediate growth patterns, the latter being more unstable, with high peaks in 2014 and 2011.

A growth index was calculated to each technology by subtracting the percentage in 2018 from the percentage in 2010[8], which was then compared to the absolute number of documents. The results are presented in the **Figure 10**:

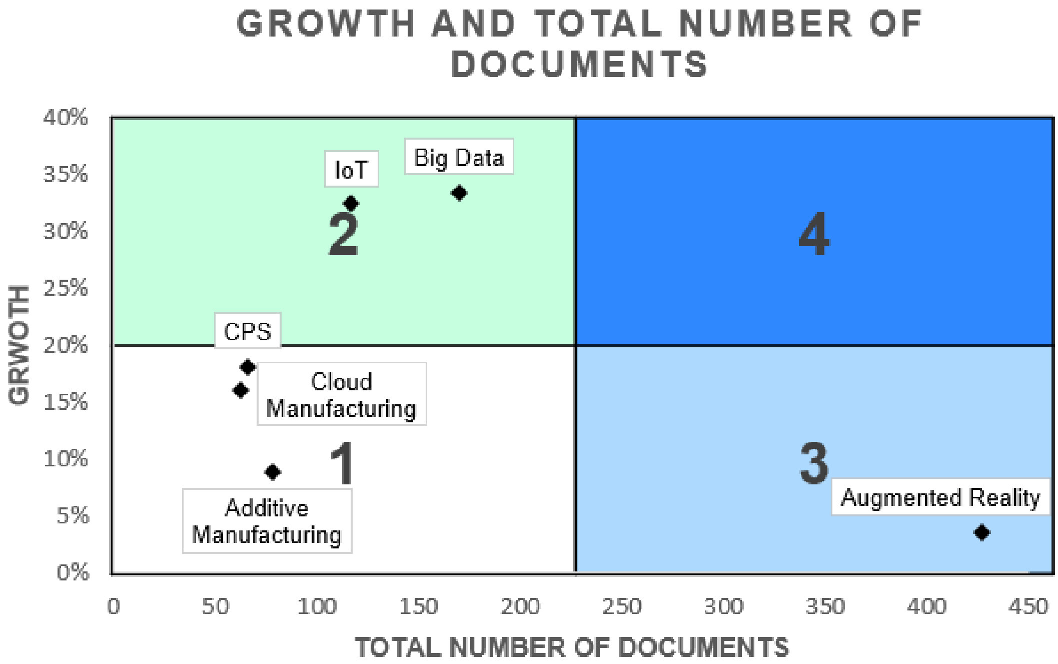

Figure 10: Growth and Total research framework. ***Source: Author’s elaboration.***

The chart was divided into four main areas, numbered from 1 to 4, which are associated with low and high values for both variables. The growth values are consistent with the previous analysis, and the technologies were divided into high (upper section) and low (lower section) growth rates. In the horizontal axis, the documents are divided into low (left) and high (right) number of documents.

[8] Other growth indexes were tested, but many – such as the yearly average growth rate – could not be applied due to the presence of null values in the first years for some technologies.

4.5 Topmost Keywords Cluster Analysis

In this section, another approach was adopted to gather insights on the Maritime 4.0 technologies. To visually present the topmost keywords used by authors in a co-word map with clustering, *VOSviewer* was used. A co-word map is a two-dimensional representation of a field in which strongly related terms are located close to each other and less strongly related terms are located further away from each other. It thus provides na overview of the structure of a field, in which different areas in a map correspond with different subfields or research areas (van Raan, 2014).

All keywords were analyzed (it was possible to select only the author or the indexed keywords), and their links strengths were calculated using the *Full Counting*[9] method. A total of 8531 different keywords were filtered to include only the 64 unique keywords which appeared at least 20 times. Among those, the 55 keywords with highest *Total Link Strength*[10] (between each of them and the other 54 keywords) were selected.

Some manual filtering was applied to remove duplicate terms (e.g. "three dimensional" and "three dimensional computer graphics", "IoT" and "Internet of Things" etc.) and words which are either not relevant or too generic. The excluded keywords by the latter criterion are shown:

Excluded Keywords		
ships	shipbuilding industry	algorithms
shipbuilding	ship simulators	data visualization
shipyards	internet	waterway transportation
automation	electric ship equipment	industry 4.0
visualization	ship propulsion	ship
computer software	marine engineering	virtual environments
mathematical models	optimization	

Table 6: Manually excluded keywords for technology clustering. *Source: author's elaboration. Source: Author's elaboration.*

[9] Full counting means that each co-occurence of keywords has the same weight, while fractionalized counting means that the weight is divided by the number of links. For example, using fractionalized counting, a keyword which co-occurs in a document with 5 others will establish 5 links of strength 1/5, and if there were more keywords the strength would be proportionally lower.

[10] When keywords co-occur in a document, each one of them establishes as link with the others. The sum of the total amount of links of a keyword multiplied by their weights gives the Total Link Strength.

The normalization mode selected for visualization is "Association strength". This means that, even though a term can only belong to one cluster, not all of them have the same level of "fit" to its category: the graphic visualization also creates a layout in which keywords tend to be closer to similar keywords. Consequently, terms in the border between clusters, even though assigned to one of them, tend to have a considerable similarity to the other. For better visualization, a minimum link strength of 2 is necessary for a link to be displayed as a curved line connecting two keywords.

In **Figure 11,** the terms found in the document's keywords are represented in a size proportional to their frequency. The most frequent term is "virtual reality", which has 376 occurrences 345 of *Total Link Strength*, while "big data" has values of 163 and 264, respectively. The terms are connected by lines which have width proportional to the co-occurrence of the keywords in terms. Based on the strength of co-occurrence of groups of words, three clusters were produced and represented in three different colors.

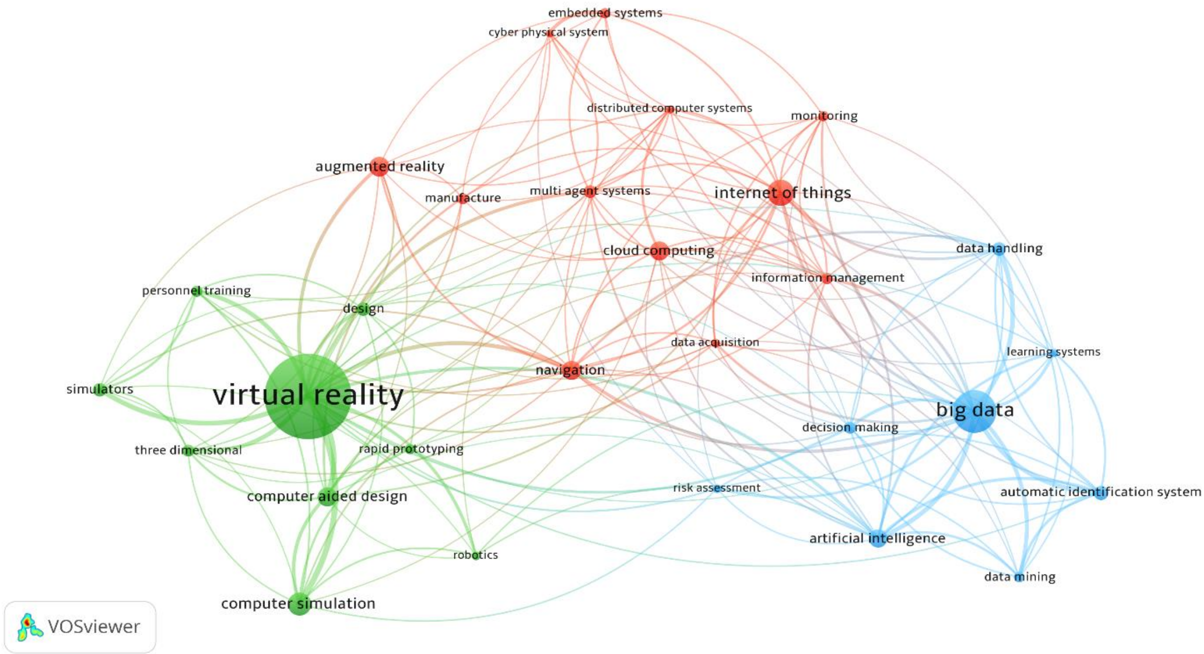

Figure 11: Keywords cluster analysis. ***Source: Author's elaboration.***

Clusters group similar terms, which can be insightful to better understand the relationship between technologies and for what purposes they are being applied. Three of them emerged by using the default value of 1 in the "Resolution" parameter, shown in different colors, which reflect the keywords that tend to appear together in documents and hence can be considered to have a stronger connection.

The green cluster contains 9 keywords associated with virtual reality, together with digital simulation and rapid manufacturing. This cluster can be interpreted as gathering the technologies related to the **digital representation** of assets and products. “Personnel training” and “simulators” suggest the use of virtual reality for training the operation of ships. “Computer simulation” can have various meanings, one of which is strongly correlated with the remaining keywords in the cluster, which indicate the usage of virtual reality in the design phase.

Classified in the blue cluster there are 8 keywords, mostly associated with Big Data and Artificial Intelligence. The most frequent words are related to **data collection and analysis.** Other keywords express possible applications such as using “data mining” to facilitate “decision making” and “risk assessment” processes and in developing “automatic detection systems” by using “learning systems”.

The red cluster has the largest number of keywords (12), and is the most heterogeneous, which reflects in the comparably higher distance between its own items. These include mainly IoT, Cyber-Physical Systems and Cloud Computing, which could be interpreted as the **interface between physical and digital** worlds in the manufacturing context.

5 The Italian recreational boating sector

5.1 Introduction

The nautical industry can be subdivided in five macro-sectors (**Figure 12**): transport, scrapping, port services, production and refitting shipyards and fishing (Carcano, 2010).

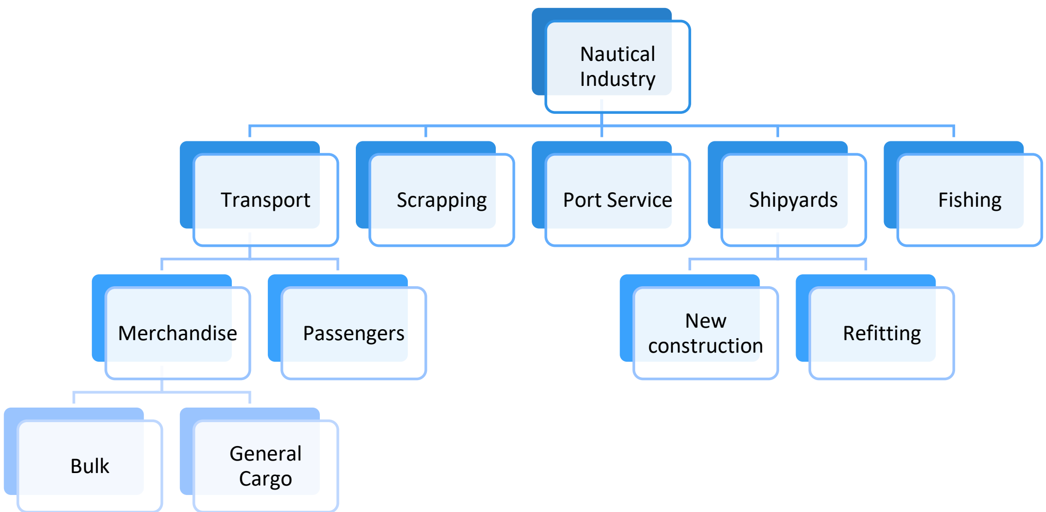

Figure 12: A general overview of the maritime industry. ***Source: Carcano (2010).***

The shipyards that construct new boats for the recreational boating market represent the main and most fundamental part of Italian production[11]. For this reason, this monography focuses on this sector, including its customers and suppliers. Recreational boats can be defined as "any kind of nautical construction independently of the kind of propulsion systems they have, intended for taking to the sea for racing and/or leisure purpose and not to earn money". These can be divided into the following categories (Carcano, 2010):

- **Ship**: any vessel with a hull more than 24 meters long;
- **Boat**: any vessel with a hull more than tel o less than 24 meters long;
- **Craft**: any recreational vessel with oars, or a hull equal to or less than ten meters long".

5.2 The Recreational Boating Sector

The global recreational boating sector generates over 45 billion revenue, of which over 20 billion (euros) is generated by shipbuilders (ICOMIA, 2017). It has presented steady growth rates starting from 2014, after a strong decline subsequent to the 2008 crisis.

In Italy and in this sector, combined sales of boats, engines and accessories to domestic and overseas markets of 3.9 billion euro in 2017, while boatbuilding alone accounted for almost 2.5 billion (ICOMIA, 2017). Italy produces 51% of all recreational boats worldwide and half of the global order for yachts and superyachts are given to Italian shipyards, a segment in which Italy is a global leader (CNA Nautica, 2018).

Italy is also the country with the highest total number of boat builders in the world - in 2017, they were 1200 out of 5824, which represents more than 20% of the global number of companies (ICOMIA, 2017). It is a global market leader and the sector is characterized by a majority of Small and Medium Enterprises (SMEs). These companies create products that are characterized by a high level of craftsmanship and whose demand is strongly seasonal in nature, the high season being between April and October (Carcano, 2010). The evolution of the Italian recreational boating industry turnover is shown in **Figure 13**:

[11] The bulding of new boats sector is almost 10 times bigger in terms of revenue than the refitting, repairing and renovation (UCINA Confindustra Nautica, 2017)

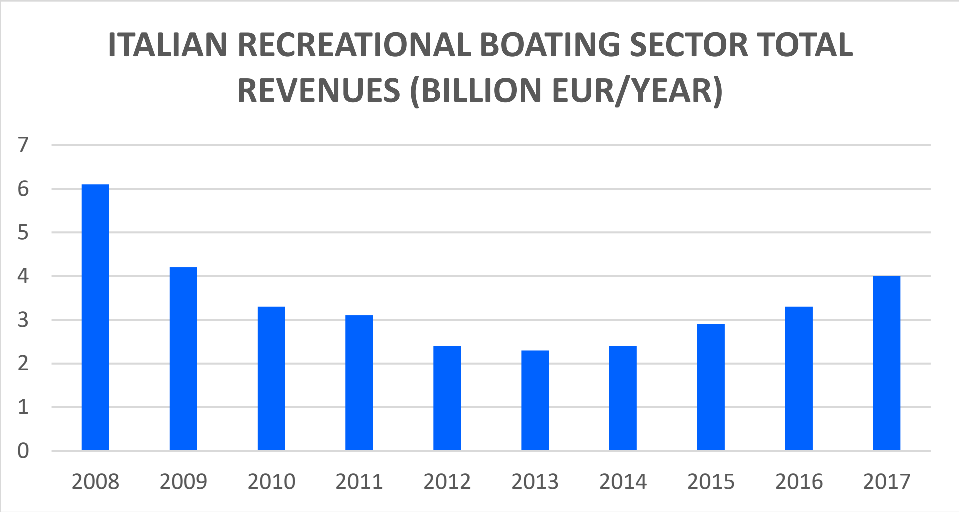

Figure 13: Evolution of market size. ***Adapted from CNA Nautica (2018).***

The recreational boating industry has five main components: suppliers, producers, customers, B2B services and B2C services, which are presented with their subdivisions in **Figure 14**:

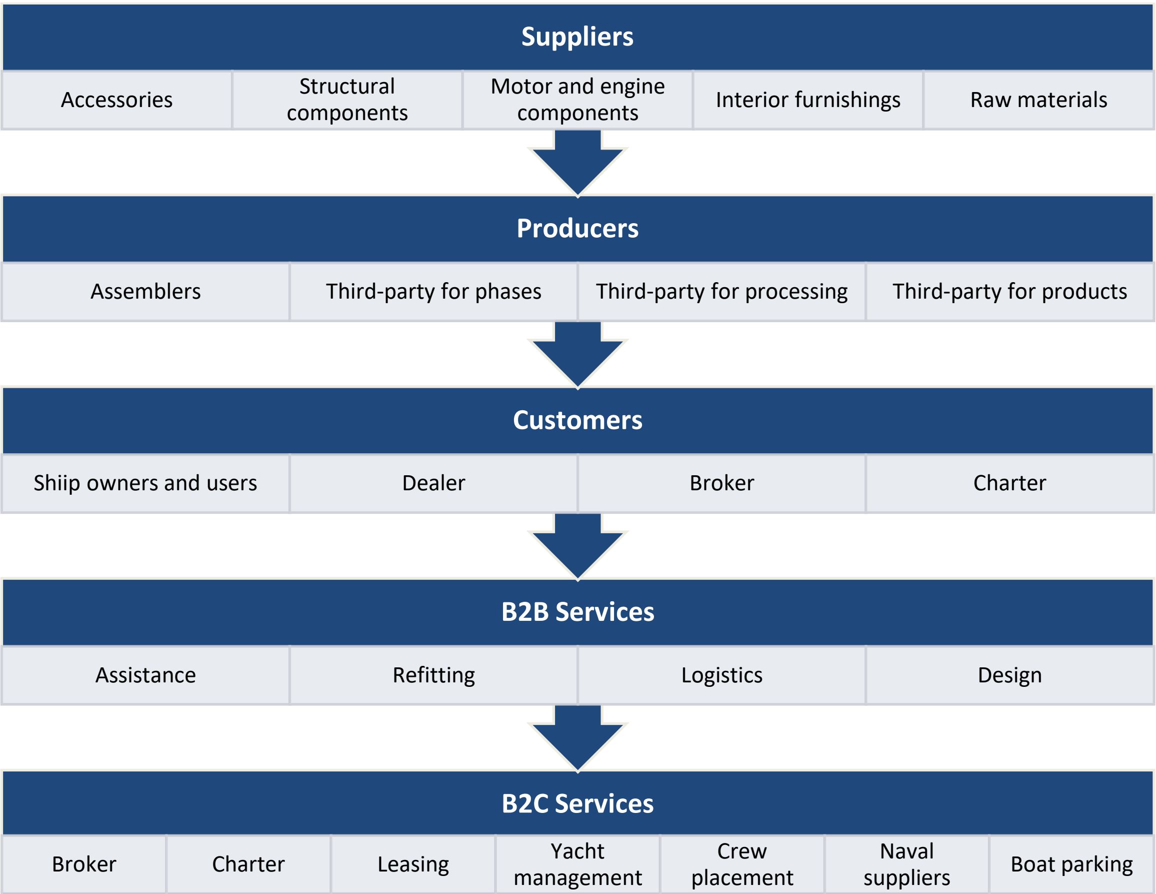

Figure 14: The main components of the recreational boating industry supply chain. ***Source: Author's elaboration.***

For the purpose of this work, three main players were considered: shipyards, suppliers, and design studios, the latter being included in “Design” under “B2B Services”.

5.2.1 Shipyards

Shipyards production is labor-intensive and typically is still very manual, with almost no automation. Shipyards are very heterogeneous and vary enormously in terms of their size, organizational structure, ownership, production typology and market target (Carcano, 2010). There are no completely vertically integrated shipyards anywhere in the world capable of building a boat from start to finish, including all the components and accessories it requires in order to function properly (Cazzaniga Francesetti, 2005).

Shipyards can be classified into three categories (Carcano, 2010):

- **Integrated shipyards** that conduct most of the production phases inside their own facilities. These are the leading companies in the Italian territory;
- **Assembly shipyards** that supervise the production process, conducting only the phases with greater added value within their own facilities. These are contractors who accept the order and then outsource the production completely to third parties;
- **Hybrid shipyards** that operate both as final shipyards and third-party producers.

The strengths of integrated shipyards, which are relatively free to decide their own strategies, having developed skills and competences within the diverse management areas, generally lie in the boat prototype, engineering and coordination of the production cycle (Carcano, 2010).

An analysis of this sector was performed by using the database AIDA (Aida, 2019), which aggregates detailed accounting information of a great number of Italian companies. Two main possible classifications were evaluated, according to their ATECO[12] code: (1) ATECO code 301, referring to companies associated with “Building of Ships and Boats”, and it sub-category (2) ATECO code 30120, which refers to “building of pleasure and sporting boats”, or the recreational boating sector. Information was gathered on 16th June.

A first methodological problem encountered was that the classification of companies according to their ATECO code is not perfect. Hence, examples were found of suppliers being classified inside the shipbuilding codes, or companies which should be in the subcategory 30120 but that

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[12] An Italian acronym to “Economic Activity”, it is a national identifier which classifies companies into different sectors.

belong to the complementary subcategory 30110, named “Building of ships and floating structures”. While the object of this analysis was the recreative boating sector, these two codes were used because they have complementary advantages and disadvantages: the analysis of the macro-category 301 tends to be more comprehensive by collecting all companies of the recreational boating sector, but also contains many companies which have a low (or null) part of their turnover coming from this type of activity. On the other hand, the analysis of the subcategory 30120 had a very high concentration of the target companies (high precision) but did not represent a considerable amount of them. This tradeoff is represented in **Figure 15** where all companies with the code 301 are represented.

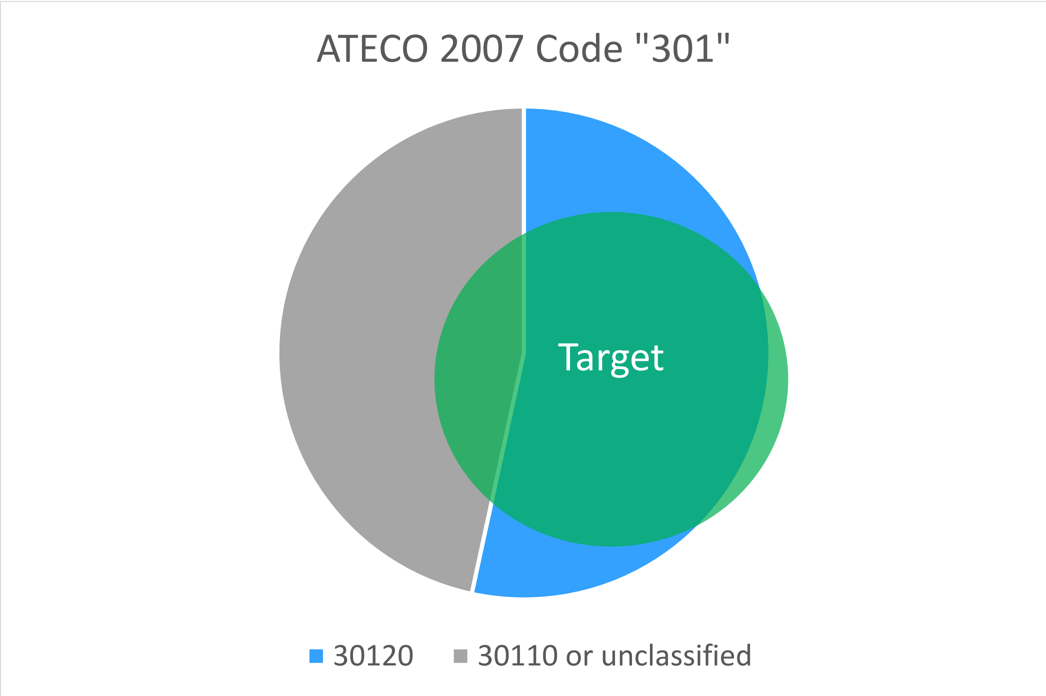

Figure 15: Companies with ATECO Code 301 and Italian target companies (green). ***Source: Author’s elaboration.***

The grey area represents the companies in the subcategory 30110 or not present in any subcategory, the blue area represents the companies with the code 30120, and the green circle represents the target of the analysis: companies belonging to the recreational boating sector.

A total of 2894 companies are classified within this category. However, an analysis of the data showed that it contained companies which should not be considered. Consequently, the adopted methodology was to use the 500 most important companies in terms of last available turnover classified with the 301 ATECO code and manually exclude companies with the following characteristics:

- Not shipyards
- Small or null percentage of revenues coming from the recreational boating sectors

Other two filter were applied to remove inactive companies (e.g. have been dissolved) (1) and (2) to remove companies with no information available on the revenue. After applying these filters to 500 companies, a total of 174 shipyards remained. The 10 main players in terms of revenues, as well as their Province, their revenues in the last available accounting year and the data in which the accounting year ends are presented in **Table 7**:

Company name	Province	Revenues (th EUR) of Last avail. year	Last Available date
AZIMUT - BENETTI S.P.A.	Lucca	667,421	31/08/2018
FERRETTI S.P.A.	Rimini	395,039	31/12/2017
SANLORENZO S.P.A. IN SIGLA SL S.P.A.	La Spezia	250,386	31/12/2017
INTERMARINE - S.P.A.	La Spezia	104,416	31/12/2017
OVERMARINE GROUP S.P.A.	Lucca	101,857	31/08/2017
C.R.N. S.P.A.	Rimini	73,133	31/12/2017
NUOVI CANTIERI APUANIA - S.P.A.	Massa-Carrara	65,888	31/12/2018
ABSOLUTE S.P.A.	Piacenza	60,861	31/08/2018
MONTE CARLO YACHTS S.P.A.	Torino	46,237	31/08/2018
BAGLIETTO S.P.A.	La Spezia	45,614	31/12/2017

Table 7: Ten shipyards with highest revenues. ***Source: author's elaboration.***

One methodological problem to perform further analysis was that not all companies' data were accounted in the same year. However, as it can be seen in the table, most data are from the last two years, so data was approximated as being from the same accounting year.

The total market size is around 2.9 billion euros, which suggests an adequate procedure when compared to the previous estimation of 2.5 billion euros by ICOMIA for 2017 and to the fact that revenues have been growing consistently in the past years.

To evaluate the market concentration, the Herfindahl index - a measure of the size of firms in relation to the industry – was calculated. It can assume values from 0 (extremely unconcentrated market, with a huge number of small firms) to 1.0 (pure monopolistic market). The resulting number is 0.09, which indicates very low concentration and thus high competitiveness. Among all 174 shipyards, only 8 are considered large enterprises, which means that about 95% of the companies are Small and Medium Enterprises (SMEs).

A brief financial analysis was performed to understand the evolution of the sector in the past 10 years. Average or median values were calculated for all companies depending on the case: average values tend to be less stable, but more interpretable than medians. Medians, on the other hand, are less affected by extreme outliers, which occur often in the case of financial indicators especially due to very low values of denominator.

The trend in the average and median EBITDA margin[13], which measures the operational capability of companies to make profit, is shown in **Figure 16:**

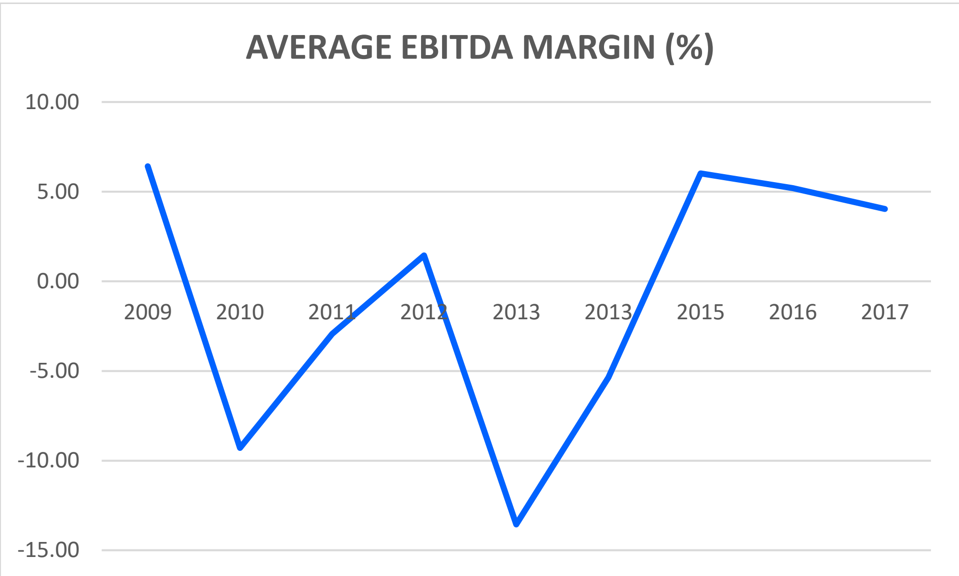

Figure 16: Average EBITDA Margin of analyzed shipyards. ***Source: Author's elaboration.***

The evolution in the EBITDA margin has a similar trend when compared to the previously shown total revenues of the recreational sector, presenting an approximately U-shaped curve with minimum in 2012-2013. The variation for average values, which range from -14% (2013)

[13] Calculated by dividing the Earning Before Interest, Taxes, Depreciation and Amortization (EBITDA) per revenues in a given year.

to over 10% (2018). The EBITDA margin shows that companies are achieving operational profitability levels similar to the pre-crisis level.

The net debt[14] of the companies was calculated and divided by their EBITDA[15], which measures the proportion of debt a company has when compared to its capabilities of generating operational profit. To reduce the impact of outliers, median results were calculated and are shown in **Figure 17:**

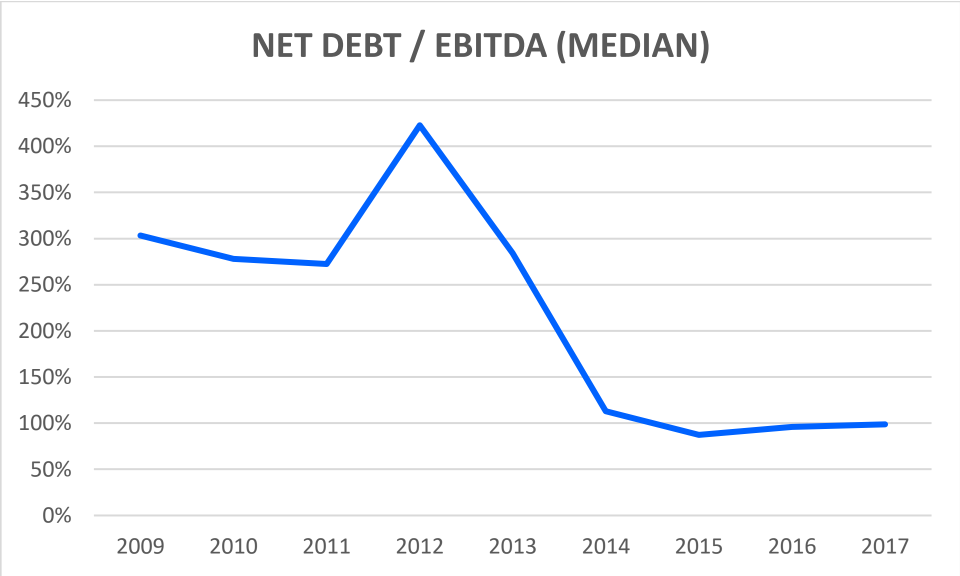

Figure 17: Median Net Debt / EBITDA of analyzed shipyards. ***Source: Author's elaboration.***

Higher values, such as the ones assumed in the same period when demand was lowest, indicate that companies are in worse financial conditions, meaning that they have little capabilities to invest. The situation has been improving in the past years, and companies have the lowest levels of debt of the historical series, meaning they have better financial possibilities to invest, for example, in their Industry 4.0 transformation.

5.2.2 Suppliers

Suppliers account for roughly 1.4 billion euros in revenues in Italy, which represents roughly 36% of the total revenues for the sector in Italy. Most of the suppliers for the Italian shipyards are also Italians - except for engines manufacturers – and are focused on the recreational boat sector. They are generally medium and small family-owned companies which often create long-term relationships with their clients – shipyards – that involve privileged collaboration, such as

[14] Calculated as the sum of bank loans (short and long term) minus cash.
[15] Only when it assumes positive values.

continuous exchange of information, leading to innovations in products and processes on the value chain. They frequently also supply after-sale services (Carcano, 2010).

In this section, an effort was made to map the suppliers in the Italian recreational boating sector, enabling better understanding of the value chain. The data was collected the 3rd June 2019 by integrating the most recent list of exhibitors of the three main events in the Industry, namely the METS Trade[16], the Seatec[17] and the Dusseldorf Boot[18]. A first filter was applied to remove duplicate values from companies which were present in more than one of those events. This filter had to be performed manually, since in most of the cases there were small differences in the registered names for the same companies in different equipment shows.

Companies were classified according to their ATECO 2007 code by individually and manually searching for their data in the AIDA database.

For all suppliers, two methods were used. The first, most natural way was using their names and province data to find their data directly on AIDA database. However, in many cases, small differences in spelling made this approach ineffective.

A second approach was to access their websites (usually listed in the website of the trade show) to discover their tax codes (IVA), and then perform a search based on that. Nevertheless, frequently, both approaches did not work, and some reasons include the lack of a company's website, or, as most common reason, the fact that both searches did not present any result in the database. In some few cases, the company was found, but some data was missing. In all cases, the data which was not found was labeled as "*n.a.*" (non-available).

After the classification, 245 companies (80%) were classified in 124 different ATECO codes, an average of approximately 2 companies per code. This illustrates the high level of diversification of suppliers, but also shows that this type of classification is not very effective to illustrate the number of companies on each category of suppliers. **Figure 18** shows that most codes (73, or 60%) have only one supplier associated with them, while the maximum number of suppliers that are associated with any code is 7:

[16] https://www.metstrade.com/exhibitors/exhibitors-met/
[17] http://sea-tec.it/exhibitors-list-2018/?lang=en
[18] https://www.boot.com/en/Exhibitors_Products/Exhibitiors_Products_2019

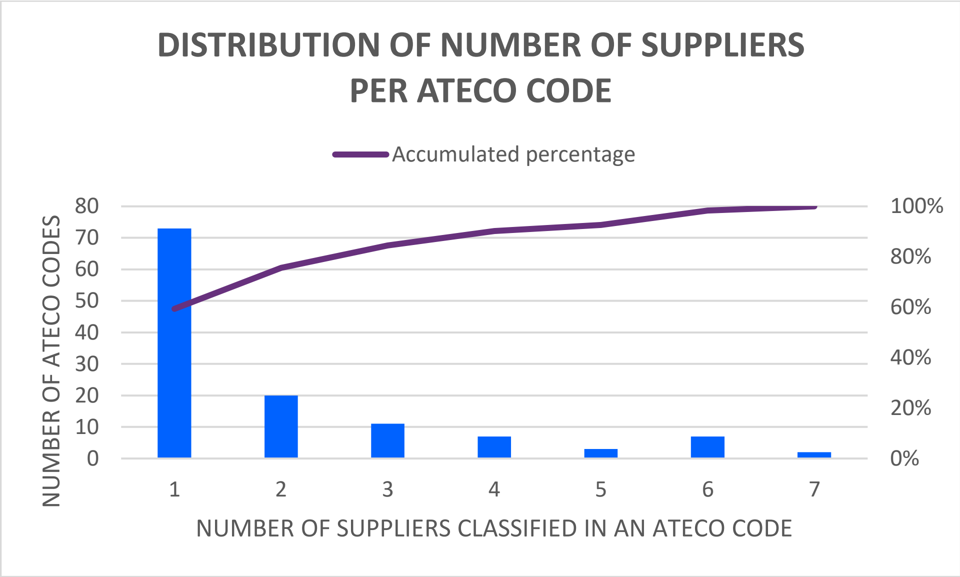

Figure 18: Number of ATECO Codes (vertical) which has a given number of suppliers classified with it. ***Source: Author's elaboration.***

There are many inherent problems with ATECO classification for the purpose of this analysis. One of them, also present in the case of shipyards is that there are too many categories, some which are in different hierarchical levels, which produces too few companies per categories and makes it hard to understand their relationships.

Moreover, since they are not specifically tailored to the maritime sector, it is often not clear how a code translates into certain products. One example is the code 205102, "manufacturing of explosive objects", which has two companies which manufacture "explosive objects". A further inspection shows that these companies manufacture safety equipment, some which explosive substances, such as hand flares.

Frequently the ATECO codes were also found insufficient to explain the company's products, which can be attributed to the fact that each company can only be associated with one code. For example, the codes starting with 46 (in which 33 companies are classified at different hierarchical levels) are associated with "wholesale trade", which could be contradictory to the fact that companies which only do distribution were previously excluded. However, these were carefully re-checked to make sure that, even though they were classified in this code, they were also involved with either design or production of their products, but for legal reasons chose distribution as the most appropriate category.

Finally, finding data for a company's ATECO code proved a very time-consuming process, in which data for 19% of companies was not available with the databased used. Data for companies' revenues was also collected and grouped into categories and results are shown in **Figure 19:**

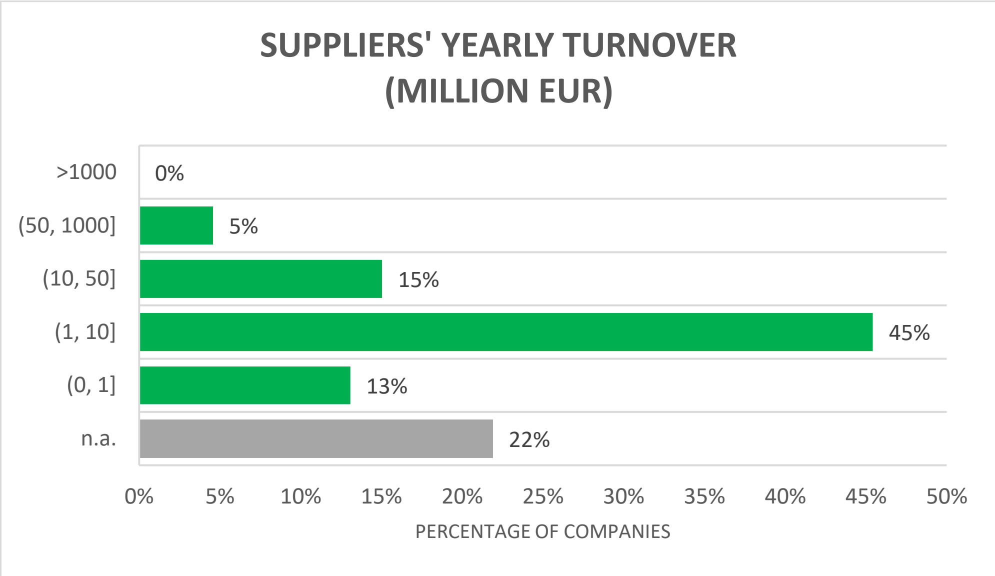

Figure 19: Suppliers' turnover distribution. ***Source: Author's elaboration.***

In many cases (22%) the information was not available, which happened most frequently with smaller companies, which means that the proportion of companies with low revenues can be substantially larger. Most companies evaluated have revenues between 1 and 10 million euros, which shows qualitatively that the suppliers are usually small companies in most cases there is little concentration. Similarly to the findings about shipyards, about 95% of the companies are SMEs.

Research was made to find a second classification methodology which solved these problems and allowed for better classification of companies. There is no established classification of suppliers according to the type of products offered in the literature on the recreational boating sector.

A classification proposed by Carcano (2010) divides them in 4 groups: accessories, strucutral components, engine components and furnishings. An attempt was made to adopt this classification, which proved unsatisfactory since it was not exhaustive enough to contain all types of products that the companies in the list offer. While the ATECO 2007 had too many codes, this classification had too few.

As an alternative, all 3 equipment shows have their own classifications, and among those the METS Trade proved the most exhaustive. Moreover, it is the most important trade fair of the sector and its categories are based on the ICOMIA (International Council of Marine Industry Associations) classification.

The classification consists originally of 37 categories of companies, and a great part of the companies which exhibit in the METS Trade were already classified, which increases the reliability of the classification process. For the companies that were not already grouped according to the adopted methodology, a manual classification was performed. This was a long process, which eventually proved consistent due to the detailed listing of products contained in each category.

Since the METS Trade exhibitors are not only suppliers, which are the object of analysis in this section, four categories were excluded as they are not considered to be suppliers: *Boats <3.2 length, Clothing and apparel, Magazines and websites* and *Maritime Goods* (boats measuring over 3.2m). Companies which are exclusively distributors (i.e. not involved in product design or manufacturing) were once again not considered.

A second filter was applied and the companies which did not fit into any of the new 33 categories were eliminated. Some types of companies which were frequently excluded were shipyards, communication and magazines, services (consulting, design studios), categories association, equipment distributors diving schools, brokers, ports and others. Companies were classified into all the categories they would fit in (often more than one per company) and were only excluded if in the end their products were not associated with the 33 considered categories.

This classification solved the problems associated with the ATECO 2007 codes. Since it has a much lower number of categories, the number of companies per category increased considerably, allowing for better interpretation. Moreover, these categories are always meaningful, since they were designed specifically for the recreational boating sector. Finally, companies could be classified in more than one category, which created the possibility of understanding their level of diversification and to better understand how many companies compete in each category.

The 306 companies were classified 664 times in the 33 categories, an average of 2.2 categories per company. To better understand this distribution and consequently the degree of specialization of companies, the **Figure 20** illustrates how many companies fall into each number of categories:

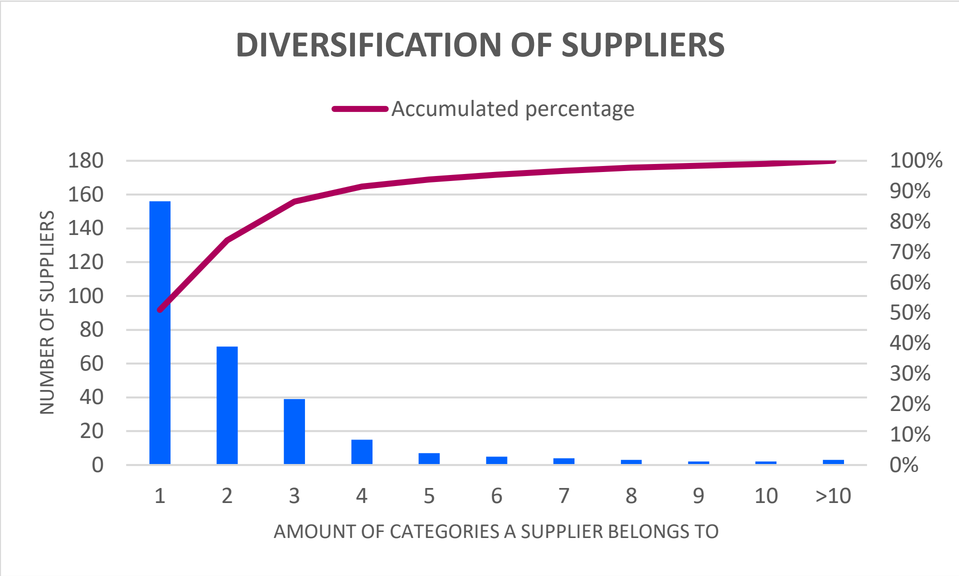

Figure 20: Distribution of suppliers by number of categories it belongs to. ***Source: Author's elaboration.***

The vast majority of companies are concentrated in producing in few areas. About 50% of the companies are classified in only one category, 23% in two and 13% in three, which adds up to 87% of the companies offering products which are classified into three or less categories. Thus, it is possible to say that the suppliers in the recreational boating sectors are mostly companies specialized in few types of products. However, this does not imply that most revenues come from small companies, since there are suppliers who offer products in almost all categories. Some companies have a wide range of products, with clients in different sectors (i.e. not exclusive for the recreational boating sector) and revenues of over 500 million euros but are classified into only a few categories.

In many cases, suppliers sell they products through a few wholesale distributors which were excluded from the list (since they were not involved in design or manufacturing) that distribute products of almost all categories. However, an analysis of all their websites have shown that most often they sell their products directly to shipyards. **Table 8** shows, for each category, the absolute and relative number of companies which manufactures this type of product, as well as the average revenues for the companies in each sector:

Category	Occurrences	Frequency	Average Turnover (million EUR / year)
Boatbuilding materials and equipment	65	21%	31.4
Interior furnishings	54	18%	12.8
Electrical	41	13%	18.0
Electronics	41	13%	7.3
Hardware	34	11%	8.5
Marina and yard equipment	31	10%	13.3
Anchoring and Docking Equipment	29	9%	5.4
Boat care, chemicals, coatings, maintenance	28	9%	37.8
Deck hardware rigging	26	8%	13.9
Hydraulic systems	26	8%	4.8
Steering and stability equipment	24	8%	7.2
Navigation	20	7%	3.0
Plumbing	19	6%	11.4
Lighting	18	6%	6.0
Cooling and exhaust systems	17	6%	42.7
Engines and motors	17	6%	29.9
Safety equipment	17	6%	5.4
Mounting equipment	16	5%	3.1
Boat covers and canvas	14	5%	5.6
Trailers (<4.0m) and transport	13	4%	22.0
Ventilation	13	4%	6.4
Aspiration and Ventilation	12	4%	19.7
Galley equipment appliances	12	4%	13.2
Insulation	12	4%	7.1
Stern gear and propellers	12	4%	4.9
Engine Management	10	3%	7.7
Fuel handling	10	3%	7.4
Transmissions and gears	10	3%	6.7
Seating	9	3%	3.0
Lubrication	5	2%	37.0
Soft goods	5	2%	2.2
Gas installations	3	1%	13.6
Starter systems and parts	1	0.3%	12.4

Table 8: Supplier categories' characteristics. ***Source: author's elaboration.***

5.2.3 Design Studios

An effort was made to try to map the design studios, similarly to what has been done to both shipyards and suppliers. However, no reliable, up-to-date and comprehensive list was available as a starting point and the most specific ATECO code was still too broad, since it also considered, for example, companies that offer Designing services for the fashion industry. As a result, only a brief qualitative description is provided.

The design studios are considered as a B2B service supplier and are a crucial part of the recreational boating industry. They play a similar role to architects in civil engineering, being responsible for the designing a product that will be further produced by the shipyards. In some cases, especially when there is less customization, the shipyards are also responsible for designing.

The designers can be classified in to three main categories: (1) naval engineers, (2) yacht design and (3) interior design. Each of these categories are associated with different opportunities when analyzed through the Industry 4.0 optics, especially in the transition to increase the connectivity of ships. A considerable change in design and boat's features can be expected in the future due to the adoption of 4.0 technologies, ultimately leading to the concept of a Smart Ship.

5.3 Piano Nazionale Impresa 4.0

The *Piano Nazionale Impresa 4.0* (PNI 4.0), translated freely as "National Plan Enterprise 4.0" is a strategic plan to support the Italian industrial sector in the adoption of 4.0 technologies. It has five main guidelines (Ministero dello Sviluppo Economico, 2016):

1. *To operate in a neutrally technological way;*
2. *To intervene with horizontal actions, not vertical or sector-specific*
3. *Act on enabling factors*
4. *Orient existing instruments to facilitate a technological leap and enhance productivity*
5. *Coordinate the main stakeholders without an interventionist approach*

It was first implemented as *Piano Nazionale Industria 4.0* (using "Industry 4.0" instead of "Enterprise 4.0") for the 2017-2020 period and has been renewed with the new name in 2018 and 2019, expanding its influence on sectors other than manufacturing. The aimed objectives are to increase flexibility, speed, productivity, quality and product competitivity and is inspired in similar programs in other countries, such as the "*Manufacturing USA*" (United States), the "*Industrie du Futur*" (France) and "*Industrie 4.0"* (Germany).

Two main benefits present in the 2018 version are depreciation benefits and tax credits for personnel training. The depreciation benefits apply to companies which invest in physical assets related to 4.0 technologies, grouped in 9 categories: Advanced Manufacturing (1), Additive Manufacturing (2), Augmented Reality (3), Simulation (4), Horizontal/Vertical Integration (5), Industrial Internet (6), Cloud (7), Cyber-Security (8) and Big Data and Analytics (9). The tax credits for personnel training have the objective of stimulating the enterprise's investment in training in the relevant topics associated with the necessary technologies in the technological digital transformation, called "enabling technologies".

6 Nautica 4.0 Survey

A survey consisting of 33 questions was performed to better understand the current state of the Industry 4.0 in the recreational boating sector in Italy. It was designed and applied with the digital platform Survey Monkey.

6.1 Methodology and Respondents

The target of the Survey were shipyards, suppliers and design studios, and respondents could select more than option to better describe their activities. A fourth open category, "others", was added to enable different players to answer the question.

To maximize the number of respondents, multiple approaches were adopted to increase convenience of the process of filling the survey. In the design phase, there was a great effort to minimize the time spent by respondents without loss of information, which was achieved through a high degree of customization: a respondent who said that did not know about a certain topic, for example, was not asked further information about it, while those who had higher levels of knowledge answered questions with increased depth. Consequently, it was possible to forbid respondents to manually skip questions, since only appropriate ones were asked, an approach that increased the interpretability of data.

Most of the answers were provided by companies which have a connection with the *Osservatori Digital Innovation* or with the category association *UCINA*, and some responses were collected in a computer provided during events organized by those organizations. Multiple efforts were made to increase the number of responses, which included phone calls in which questions were read to the respondent and registered digitally by an interviewer and sending thousands of e-mails found on databases with information about the companies.

During the collection process, often companies replied partially, realized that they would not have enough time to complete it, and then replied it again completely in another moment. These first partial answers were removed, as well as those who replied less than 20% of the Survey (considering only the questions they are supposed to answer due to customization). As a result, total of 47 answers were considered, of which 32 (68%) were complete. Incomplete respondents' responses were not excluded, since they are still valid for the questions to which they answered. Analysis were performed for each question according to their respondents.

One difficulty in obtaining answers (complete and partial) was the extreme low knowledge of the respondents on the topic, which often reported themselves as feeling intimidated to answer a survey about a topic they knew and did very little about. This fact, which happened most often with design studios, possibly creates a distortion between the results obtained and the reality of the Italian recreational boating sector, and thus results should be interpreted as possibly over-estimating the percentage of respondents who know and have taken actions related to implementation of Industry 4.0 technologies.

6.2 Structure

A flowchart presented in the **APPENDIX B – Survey Structure Flowchart** illustrates the logic used to decide which of the questions would be answer by every respondent. In the next sections, the results for some of these questions is shown and analyzed. Due to length constraints of this work, the analysis of many questions is omitted. All questions, however, are available in the **APPENDIX A – Survey Questions**, which enables the interested reader to fully understand the logic behind the questionnaire. An effort is also made to remind, for each question, the characteristics of its respondents, but the flowchart can be helpful to better understand the logic behind the Survey's structure and thus to interpret its results appropriately. Moreover, the number of respondents will always be declared to help the reader keep track of how many respondents were still active in a given answer (due to survey abandonment).

6.3 Analysis

An analysis is performed for the some of the answers provided for the 33 questions which compose the Survey.

6.3.1 General information

In the first questions, respondents had to answer some general, objective questions about them and the company. In some cases, incomplete answers were filled with data found in external sources, mainly the companies' websites and the AIDA database. The revenue distribution of the respondents is shown in **Figure 21:**

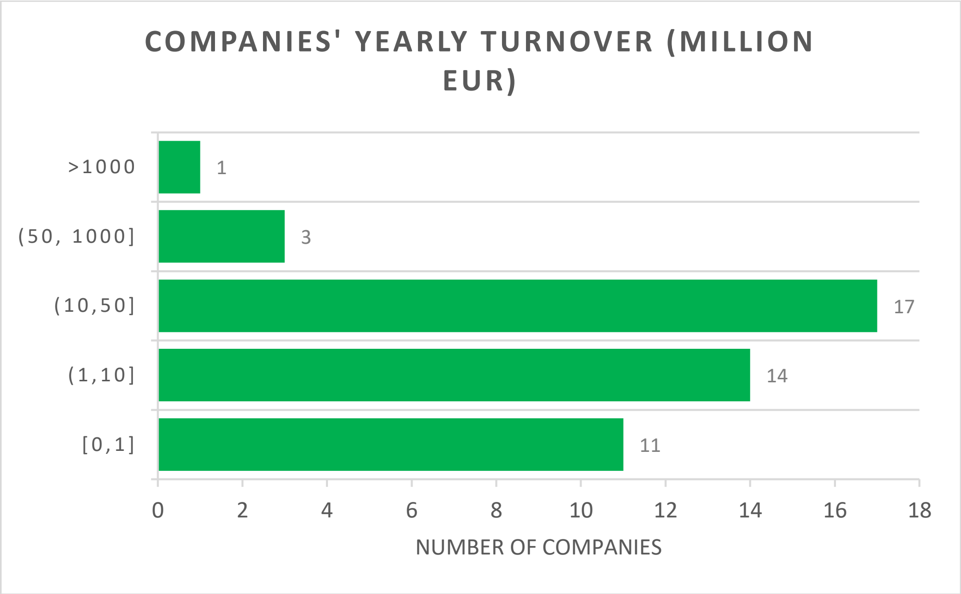

Figure 21: Respondents' yearly turnover. ***Source: Author's elaboration.***

Many companies have revenues below 1 million euros. These are most frequently design studios and suppliers of specific products. Most (91%) are small or medium enterprises (defined as less than 10 and 50 million euros of turnover, respectively). The sum of number of respondent's organizations equal 46 (and not 47) because information was not declared or found for UCINA (an industrial association)[19], which participated in the survey.

Respondents could openly write their role and functional area and were then manually classified into four C-level categories (Chief Executive Officer, Chief Communications Officer, Chief Operations Officer and Chief Innovation Officer) and "Others", which were mainly manager-level employees. The results are shown in **Figure 22**:

[19] Even though it is not a company, but an industrial association, the word "company" will be used to describe all respondents, since this is the only exception.

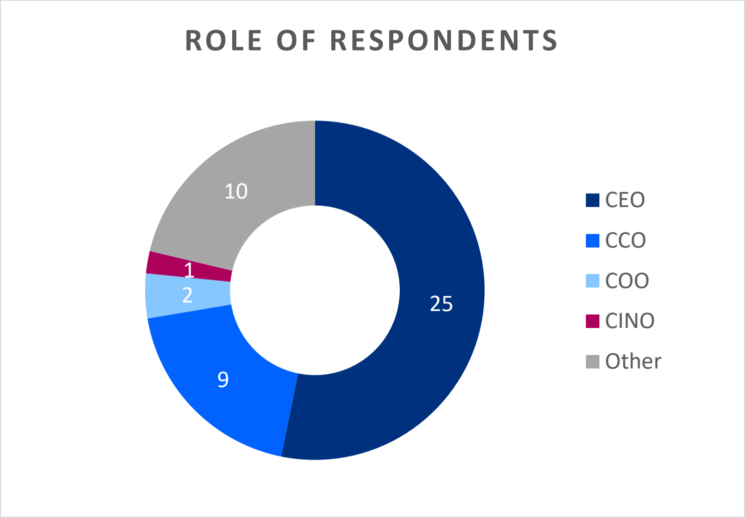

Figure 22: Respondents' roles in their companies. ***Source: Author's elaboration.***

These results indicate that answers will be provided by respondents in high hierarchical positions and thus are expected to be well-informed about the company's positioning in the topics on which questions were asked. This is also confirmed with a question of how long the respondent has worked in the sector and for that company, which has shown average values as high as 25 years depending on the type of the company.

Respondents could classify their company as any combination (containing at least one) of shipyard, supplier, design studio and "other". In few cases, respondents reported to belong to "Other" while they were, by our classification, considered suppliers, and these answers were manually edited. After few corrections, the Survey had 47 respondents, whose distribution is illustrated in **Figure 23:**

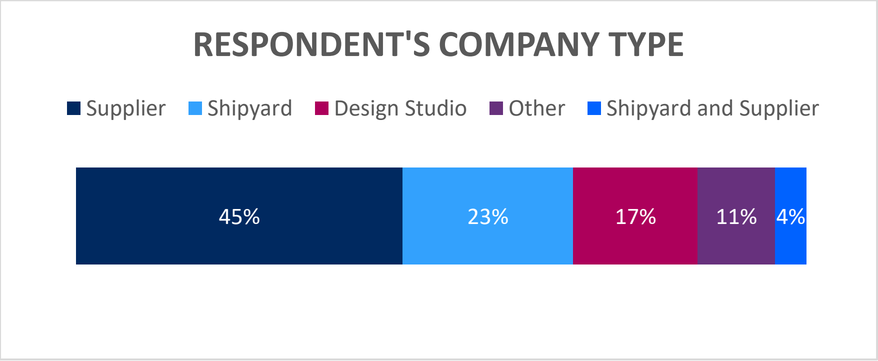

Figure 23: Respondents' company type. ***Source: Author's elaboration.***

Only the four first categories were considered when segmenting the results by type of company, which means that when the two respondents which belong both to the "Shipyard" and "Suppliers" category were counted in both segments.

6.3.2 Industry 4.0

In this section, questions were asked to try to understand the respondent's level of knowledge and usage of Industry 4.0.

6.3.2.1 Knowledge level on Industry 4.0

The third question aimed at understanding the knowledge level of the respondent's on Industry 4.0. Since they are mostly directors in their companies, this knowledge can be approximated as the knowledge on the company's strategic level on the topic. The 47 respondents were asked the question: "Do you know the Industry 4.0 topic?". As an answer, they could choose one among five different maturity levels, among which not knowing the topic (grey), intermediate levels (different tones of blue) and having already implemented solutions in their company. Overall results are shown (columns) in percentage and compared to benchmark values for the overall Italian industry[20]:

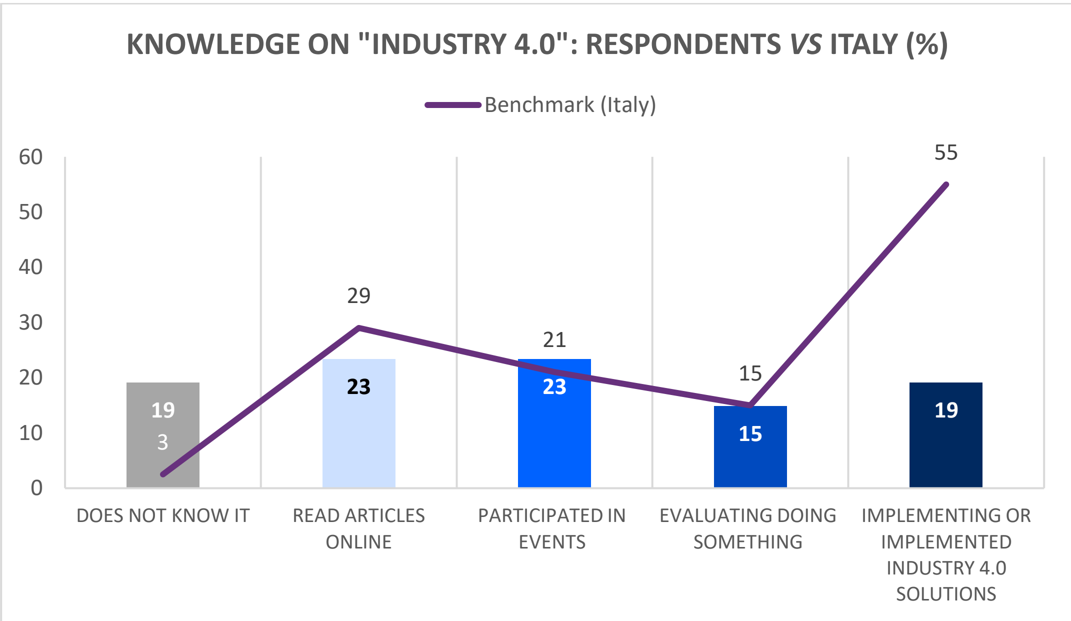

Figure 24: Knowledge and Implementation levels of Industry 4.0 (Respondent's and Italy). ***Source: Author's elaboration.***

[20] Data provided by the *Osservatori Digital Innovation* in a 2018 Survey with 236 Italian companies.

The results show that the survey's respondents have a lower knowledge on the topic (19%, when compared to 3%) and a much lower implementation rate (19%, when compared to 3%). Considering that a considerable number of potential respondents did not fill the survey because they considered to have an insufficient knowledge on the topic, the recreational boating sector is possibly even more immature than shown. The results were then segmented by type of respondent, which can be seen in **Figure 25:**

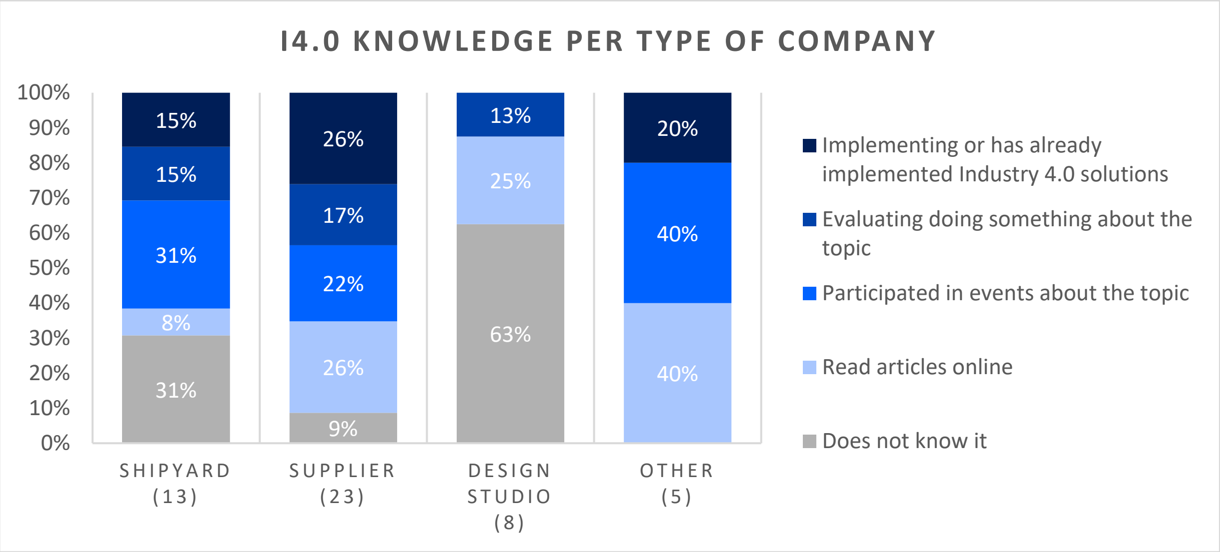

Figure 25: Knowledge and implementation level by type of company. *Source: Author's elaboration.*

Suppliers have the highest maturity level on the topic, which is indicated by highest levels of implementation (26%) and lowest levels of not knowing the topic (9%), but they are still much inferior to the overall Italian industry. Shipyards have a surprising high percentage of "Does not know it" (31%), which shows their high level of immaturity. Few suppliers (15%) have already implemented solutions on the topic. Design Studios have the lowest level of knowledge (63% have answered "Does not know it") and the lowest level of implementation, according to their evaluation.

6.3.2.2 4.0 Technologies

All respondents were then presented with a brief description of 7 main Industry 4.0 technologies[21] and 6 processes in which they could be applied. For each technology, they were

[21] In the Literature Review, 10 main Industry 4.0 concepts are discussed, but only 7 of which are specific groups of technologies which can be applied in manufacturing processes. "Smart Products" are the integration of 4.0 into a product, "Smart Sensor" is considered a prerequisite for other groups of technologies (such as Internet of Things) and "Smart Factory" is the manufacturing environment in which the 4.0 technologies are applied.

asked to declare either in which processes were used (a respondent could choose as many processes as wanted, including none or all) or to say that they did not know the technology.

This question was presented to all 44 respondents (even those who declared not to know the Industry 4.0 topic), since it is possible that a respondent does not know this term but has already implemented solutions related to it. This approach proved right, since for all technologies except "Cloud Computing and Manufacturing" (80%) the percentage of awareness is higher than the knowledge of the "Industry 4.0" concept (81%), which can be seen in **Figure 26**:

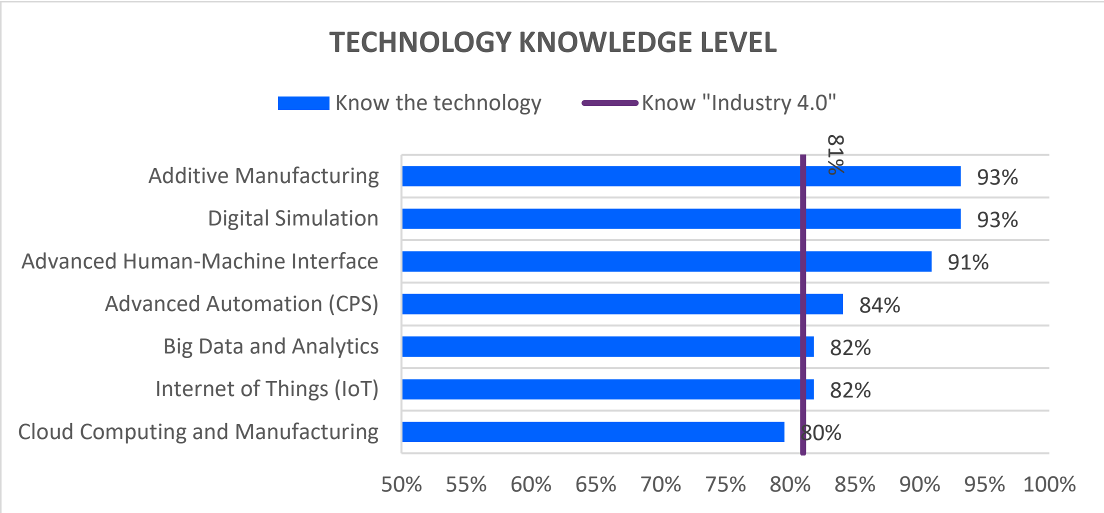

Figure 26: Knowledge level of each technology and of Industry 4.0. ***Source: Author's elaboration.***

Overall, the knowledge level of Additive Manufacturing and Digital Simulation is the highest, which can be attributed also to the fact that the Design Studios frequently use those technologies, many times not aware that they can be classified as part of Industry 4.0.

The results enabled not only to understand the knowledge level of each technology, but to understand the processes in which they are applied. These are presented in **Figure 27**, which shows the percentage of total respondents who have applications of each technology in each process, as well as average values for each technology and each process. For visualization purposes, technologies and processes were sorted in non-increasing order according to their average values:

		PROCESSES						
		Product development	Part manufacturing	Designer-Shipyard integration	Supplier-Shipyard Integration	Boat manufacturing	Communication with boat during navigation	Average
TECHNOLOGIES	Digital Simulation	55%	14%	14%	9%	14%	2%	**18%**
	Additive Manufacturing	32%	25%	7%	5%	7%	0%	**13%**
	Internet of Things (IoT)	18%	7%	11%	11%	7%	14%	**11%**
	Advanced Human-Machine Interface	18%	16%	11%	7%	7%	2%	**10%**
	Big Data and Analytics	16%	9%	0%	11%	2%	9%	**8%**
	Advanced Automation (CPS)	9%	18%	5%	5%	5%	2%	**7%**
	Cloud Computing/Manufacturing	14%	9%	9%	5%	2%	2%	**7%**
	Average	**23%**	**14%**	**8%**	**7%**	**6%**	**5%**	**11%**

Figure 27: Technologies and Processes Application Matrix. ***Source: Author's elaboration*.**

Digital Simulation is the oldest technology in the list, which justifies a higher average utilization (18%), which is most frequent in Product Development. More advanced applications, such as the use of Digital Simulation in manufacturing, value-chain integration and communication are still uncommon. Cloud technologies and Advanced Automation are the least used technologies (7%), which can be partially explained by the low general level of automation which characterizes the shipbuilding industry: companies usually produce customized products in lower scale, which makes automation more challenging.

Product development is the most common application of the 4.0 technologies, with an average value of 23%. The most used technologies, both in this process and in general, are Digital Simulation and Additive Manufacturing. In second place is Part Manufacturing, which leverages most frequently on Additive Manufacturing (25%) and Advanced Automation (18%). The four least mature applications have average values ranging from 5% (Communication with boat during navigation) and 8% (Designer-Shipyard integration).

6.3.2.3 Objectives and difficulties

All 43 respondents[22] were then shown Question 6, in which they asked to declare if their companies had 4.0 projects, and results are shown in **Figure 28:**

[22] Until this moment, 4 respondents had abandoned the survey.

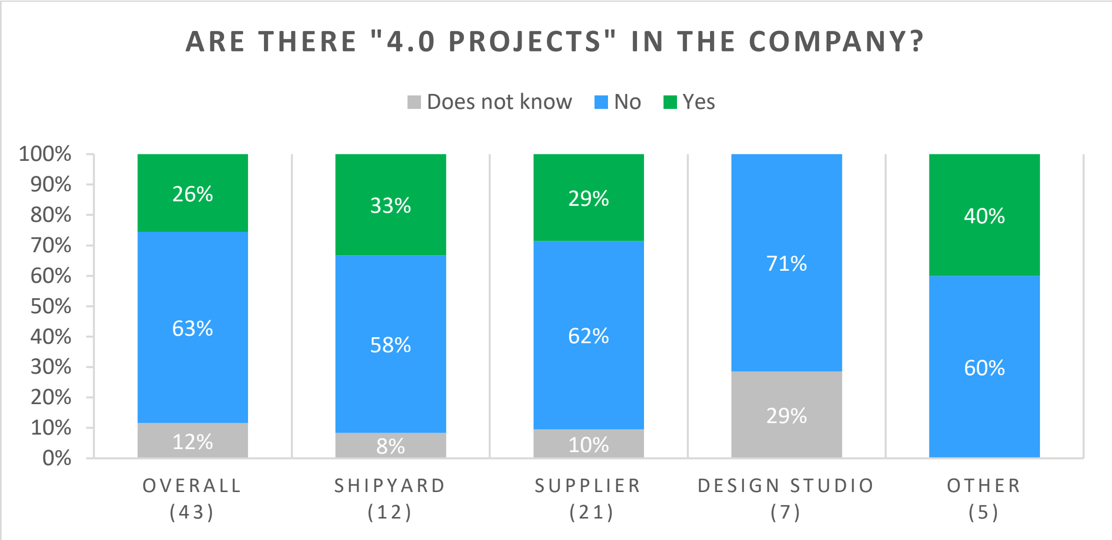

Figure 28: Existence of 4.0 Projects. ***Source: Author's elaboration.***

Overall results are similar to those of shipyards and suppliers, with around 26% of companies having Industry 4.0 projects. In the case of design studios, their low level of maturity when compared to the other segments is once again confirmed, since none of the companies have such types of projects. The 11 respondents who have replied positively to Question 6 were then presented with Question 7, in which they had to classify their motivations for developing such projects in 4 categories: high, medium, low and null. The results are shown in **Figure 29**:

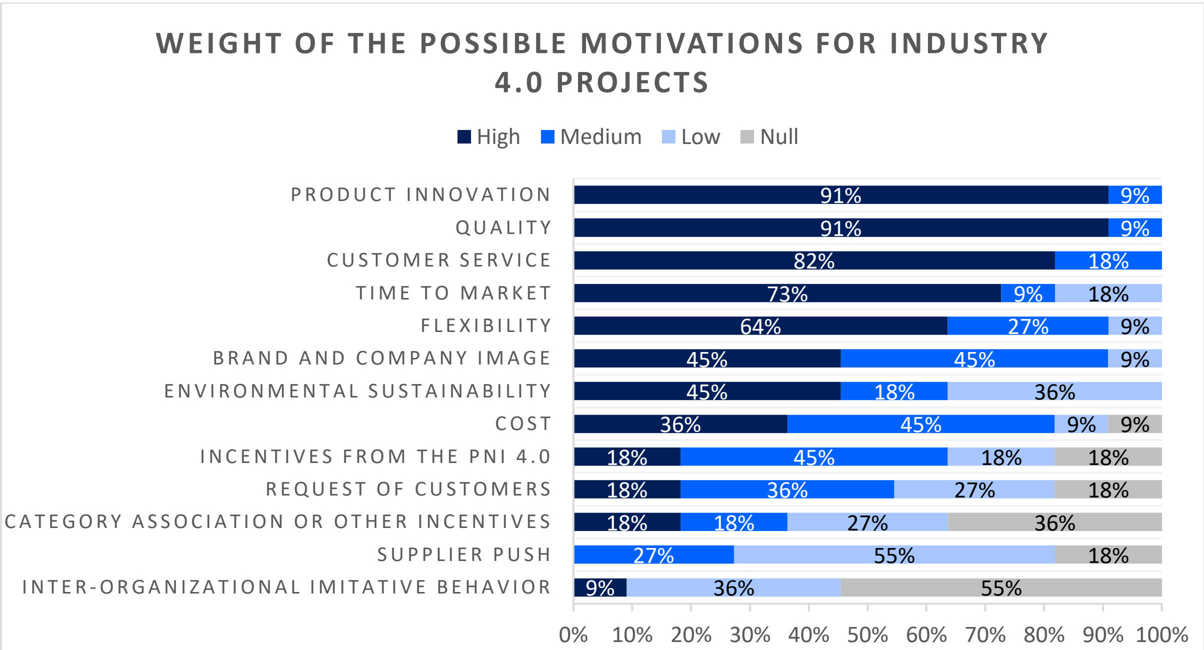

Figure 29: Weight of possible motivations for 4.0 projects. ***Source: Author's elaboration.***

The main motivations are focused on “Product Innovation”, “Quality” and “Customer Service”, a consistent result the high importance given to “Product Development” in previous questions. Interestingly, “Cost” is not among the most important motivations, and the “Incentives from the PNI 4.0” (which will be further discussed) have intermediate impact.

Another aspect of the analysis performed on the companies’ 4.0 projects was to try to identify who is responsible for guiding this transformation process. Question 8 was presented to the same group of respondents (which have 4.0 projects), asking who was responsible for directing the 4.0 transformation in the company. Respondents could choose 1 or 2 alternatives among those presented in **Figure 30**, besides two (“CIO” and “Others”) which were not chosen by any respondent. The percentages are relative to the total number of respondents and, as they could choose more than one alternative, they add up to more than 100%:

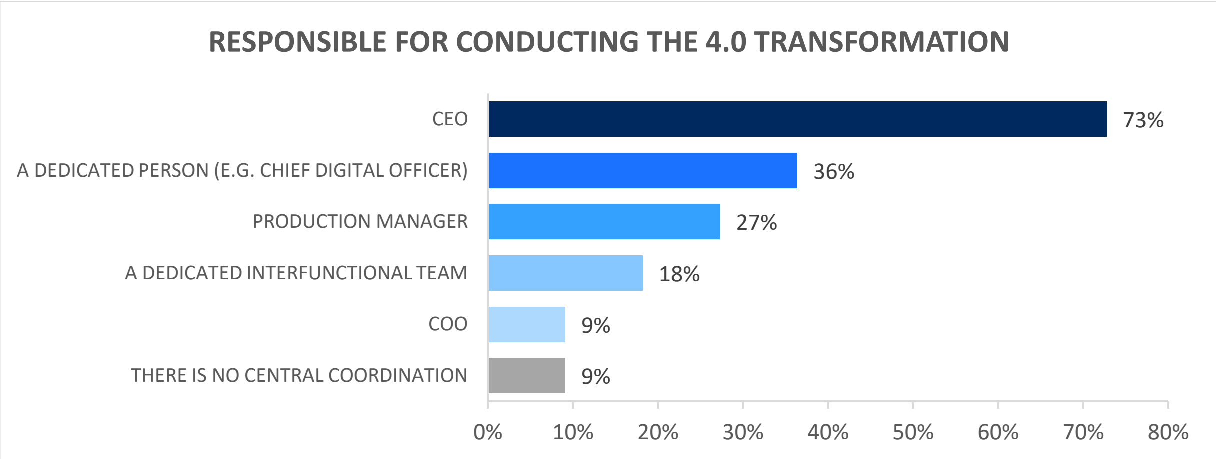

Figure 30: Coordinators of the 4.0 transformation. ***Source: Author’s elaboration.***

Results show that in most cases (73%) the 4.0 transformation is directed by the CEO. Considering that most survey’s respondents are either CEOs or are directly connected to them, this suggests a higher reliability of the results found. In few cases (9%) there is no central coordination.

All respondents were then presented to Question 9, in which they could choose between 1 and 3 alternatives that better describe their obstacles in “4.0 actions”. Results are shown in **Figure 31**:

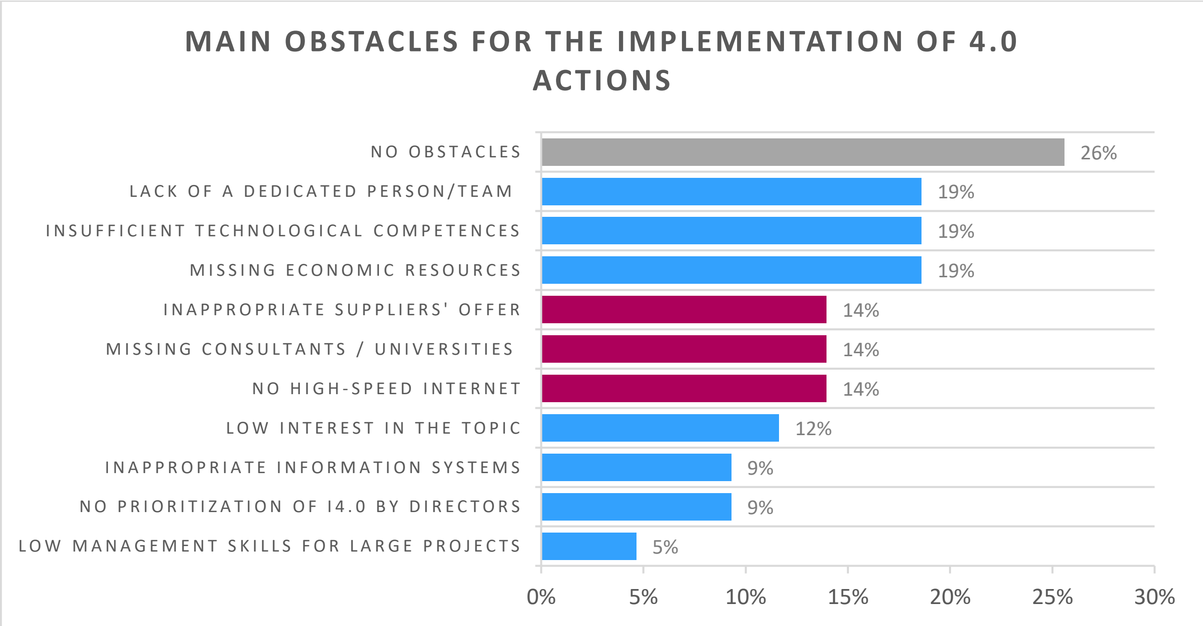

Figure 31: Main declared obstacles for the implementation of 4.0 technologies. *Source: Author's elaboration.*

About a quarter of respondents declared to be no obstacles in the implementation of these actions, which is consistent with the average results for the Italian Industry, in which 29% of the respondents in small and medium enterprises chose the same option[23]. The remaining respondents chose a great variety of them, which points to a variety of problems.

Some obstacles are related to company's human resources and organization, such as "Lack of a dedicated person/team" to guide the transformation (19%), "Insufficient technological competences" (19%)" and "Low management skills for large projects" (5%). Other internal obstacles are "Inappropriate information systems" (9%), which points to an internal technological obstacle, and "Missing economic resources" (19%). "No prioritization of I4.0" (9%) by directors is another internal obstacle at the strategic level.

In other cases, obstacles ae external (shown in purple), such as "Inappropriate suppliers' offer" (14%), "Missing consultants and Universities" (14%) and possibly[24] "No high-speed internet" (14%). Some of those obstacles are further analyzed. In Question 10, all respondents were asked to evaluate the suppliers' solutions.

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[23] Data provided by the *Osservatori Digital Innovation* in a 2018 Survey with 236 Italian companies.
[24] It is assumed that the companies which point "No high-speed internet" as an obstacle do not have it because it is not available in their area, and not due to their internal decision of not having it.

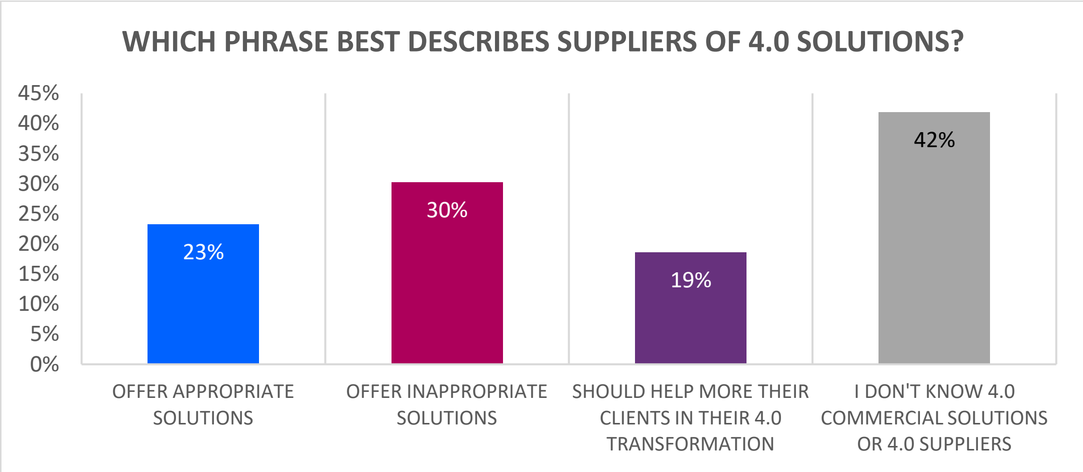

Figure 32: Respondents' opinion on suppliers of 4.0 solutions. ***Source: Author's elaboration.***

Respondents could to choose at least one alternative, which included the options of not knowing suppliers of 4.0 solutions[25] and not knowing 4.0 solutions. Answers for all 43 respondents are shown in **Figure 32**, and percentages are relative to the number of respondents.

Results illustrate that less than a quarter of respondents declared to know suppliers that have appropriate offers. However, this is partially due to lack of knowledge of those suppliers, which accounts for 42% of the answers. The reasons pointed by those who classified solutions as inappropriate are exposed in **Figure 33**. Percentages are relative to the total of answers "Offer inappropriate solutions" and since respondents could choose more than one reason, they do not add up to 100%:

Figure 33: Reasons for solutions' inappropriateness. ***Source: Author's elaboration.***

[25] These are not equivalent to the type of suppliers that answered the questions. Most of the participants of the survey are traditional suppliers, which means they also wera asked to evaluate possible suppliers of 4.0 solutions for their processes and products. An engine manufacturer, for example, can have as a supplier a company that provides sensors to equip that product the machines used to manufacture it.

These answers show that, in more than half of the cases, solutions are considered too complex for clients (54%) and in 23% of cases it is considered “Too innovative” when compared to their starting point. This data, together with the 19% of total respondents declaring that suppliers “Should help more their clients in their 4.0 transformation” and the 42% who do not know suppliers or solutions, shows that shipyards, suppliers, design studios and others are not prepared to adopt the solutions offered by their 4.0 suppliers.

6.3.3 Piano Nazionale Impresa 4.0

Almost 20% of the respondents have declared that “Missing economic resources” is an obstacle for the implementation of 4.0 actions. The PNI 4.0 is a possible help for that obstacle, since it creates financial benefits for companies that invest the 4.0 transformation. Respondents were presented with Questions 11 to 18 to understand their level of knowledge and adoption of the Italian government program.

In Question 11, all 43 respondents were asked to classify their maturity level with respect to the PNI 4.0 in one of 5 categories. Three of them were then grouped into the blue group on **Figure 34**, which also compares to overall results for the Italian Industry[26] (benchmark):

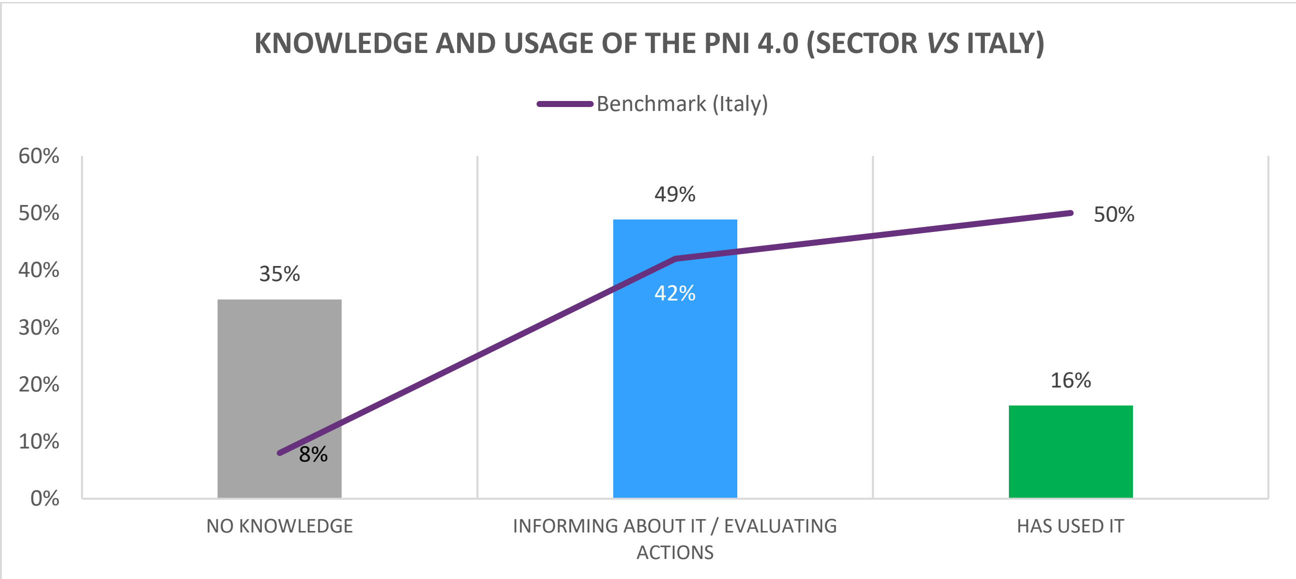

Figure 34: Knowledge and adoption of the Piano Nazionale Impresa 4.0. ***Source: Author’s elaboration.***

The percentage of respondents who replied that do not know the PNI 4.0 (35%) is more than four times the value for average Italian industries (8%), which shows that they are much less

[26] Data provided by the *Osservatori Digital Innovation* in a 2018 Survey with 236 Italian companies.

informed than the companies that replied to the overall survey. They also have much lower level of usage, of 16%, considerably lower than the overall values of 50%.

A more detailed version, in which the second category is as presented to respondents (divided into three sub-categories) and that segments results by type of company is presented in **Figure 35**:

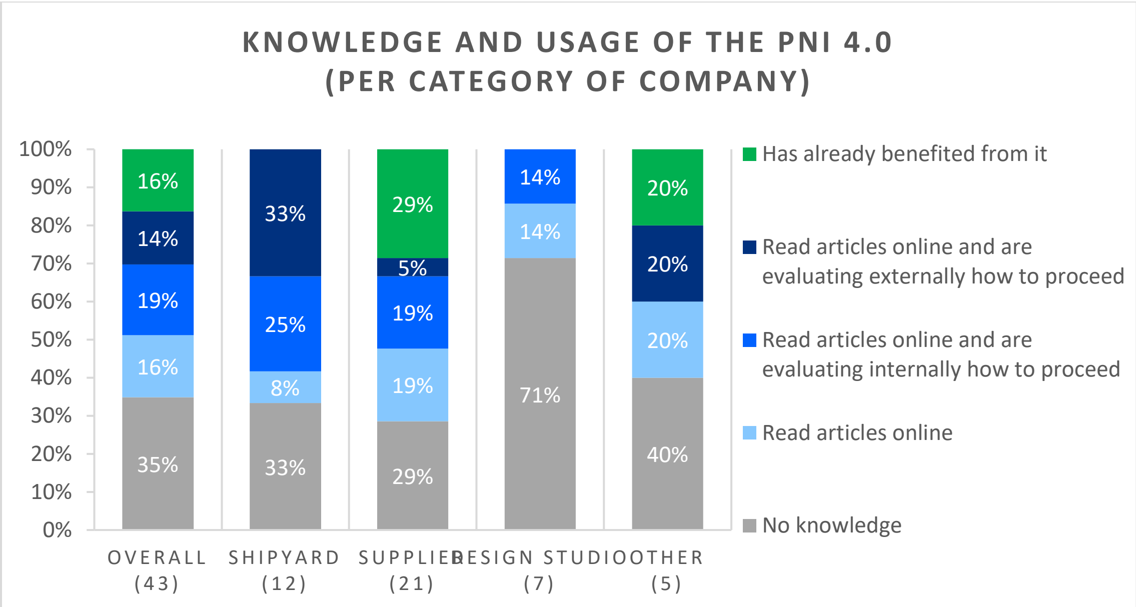

Figure 35: Knowledge and adoption of the PNI 4.0 (per type of company). ***Source: Author's elaboration.***

Suppliers are also in this case the most mature companies, presenting the highest level of "Has already benefited from it" (29%) and lowest level of "No knowledge" (29%), an opposite situation to the design studios, which have very high levels of the latter (71%) and no respondent which has benefited from it.

Even though Shipyards and Suppliers have a similar percentage of respondents which declared to have Industry 4.0 projects (**Figure 35**), respectively 33% and 29%, the first has null levels of usage of the PNI 4.0, but high levels of the intermediate categories, while the latter has a higher adoption of the national plan.

Later in the Survey, in Question 27 it was asked if the respondents knew which institution they should address to benefit from the tax credit incentives. As a result, less than half (44%) replied to know it. None of the design studios replied positively, which is another evidence of their lack of maturity in the topic.

6.3.4 Competences and New Personnel

In Question 28, respondents had to choose their preferred methods to prepare for 4.0 competences. Four alternatives were possible: “External courses”, “Internal courses”, “Activities other than courses” (e.g. training on the job and job rotation) and “No intention of training”.

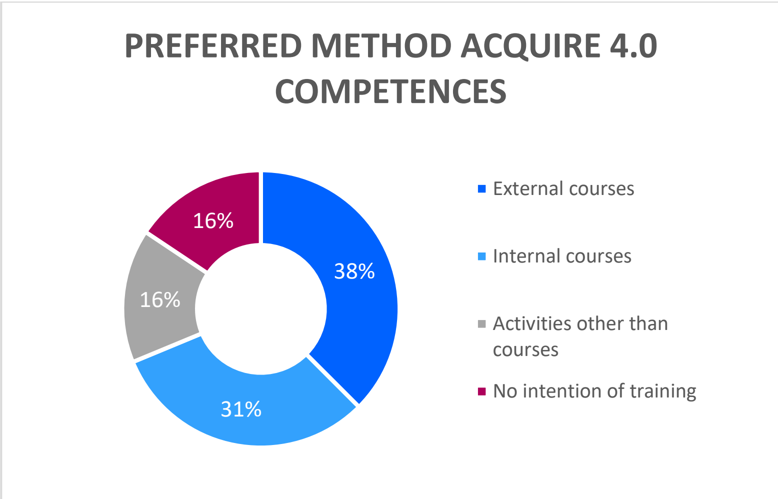

Figure 36: Chosen method for training on 4.0 competences. ***Source: Author’s elaboration.***

The proportion of internally and externally managed training is similar, and clearly most companies have the intention of performing some type of training for these competences (84%). The companies which replied to have intention to use externally managed courses were then presented with Question 29, in which they had to choose up to preferred 3 institutions to oversee it. Results are shown in **Figure 37**:

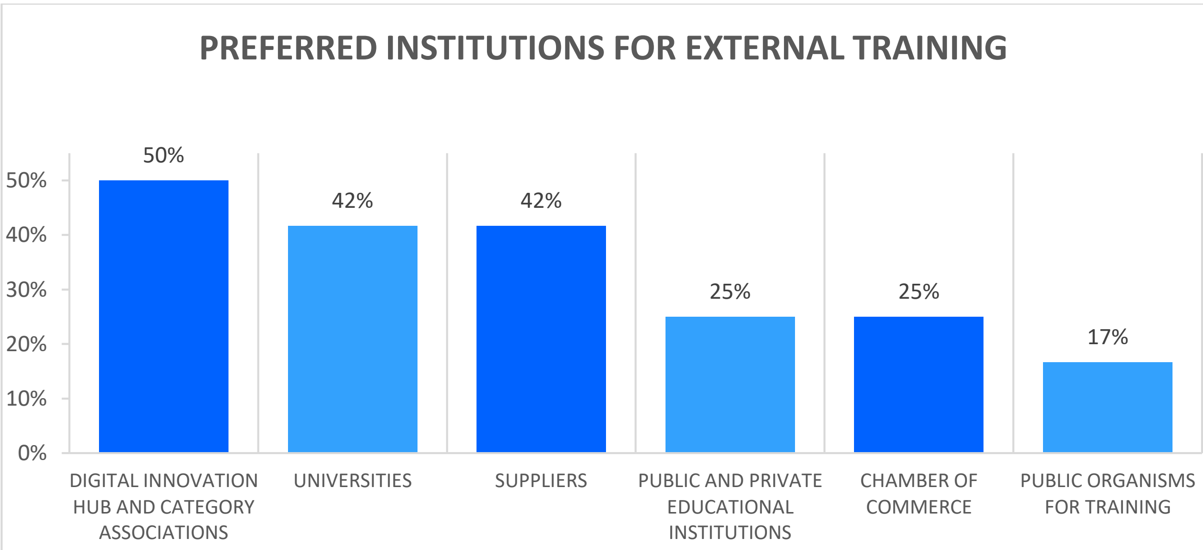

Figure 37: Chosen institutions for external training on 4.0 competences. ***Source: Author’s elaboration.***

Results show that many companies consider universities as a valuable institution to provide training on Industry 4.0, meaning that initiatives such as Learning factories could have high adoption rates. A final question was then posed to all respondents to verify their availability to participate in an in-depth interview. Ten respondents replied positively and eight left a phone number.

6.4 Main results

The Survey's results provide an overview of the Italian recreational boating sector through the lenses of the Industry 4.0 transformation. Three groups of respondents (shipyards, suppliers and design studios) were used as samples to understand the maturity level of their types of company in the topic. Some results were also compared to the overall Italian industry.

Overall, companies in the sector are immature in the topic, especially when compared to the overall Italian companies. About one fifth of them does not know the concept, when compared to 3% of Italian companies, and only a similar proportion is implementing or has implemented 4.0 projects, compared to 55% in the Italian average. The situation is not homogeneous in the different types of companies: in the case of design studios, over 60% does not know the topic and none has implemented such projects. Suppliers are the most mature, with 26% having implemented and only 9% declaring not to know it.

When confronted with the specific technologies, the most applied and used are "Digital Simulation" and "Additive Manufacturing", which are known by 93% of respondents, a higher value when compared to the average 81% that know the Industry 4.0 concept. About 55% and 32% of companies, respectively, use those two technologies in Product development, which is the most frequent application of 4.0 technologies. Thus, while companies may not know the topic, they more frequently use technologies which can be included in the 4.0 transformation, even though the applications are far more immature than the envisioned potential applications in a Smart Factory.

"Product Innovation", "Quality" and "Customer Service" are the most important motivations for companies to develop 4.0 projects. "Cost" has intermediate importance, as well as "Request of customers", which means that their main motivation is to provide superior value to their customers, exceeding their expectations rather than satisfying their stated, conscious needs.

"Missing economic resources" is only pointed by 19% of respondents as a relevant reason for not implementing 4.0 projects, which is coherent with the financial analysis of shipyards that showed that their financial situation has improved substantially when compared to the past five years. In most cases, obstacles are related to lack of knowledge and interest of the company, even if some external reasons such as lack of high-speed internet (14%) and missing consultants and universities (14%) to help in their transformations are still pointed by some companies.

The lack of interest in the topic is also clear by the fact that 42% of the respondents have declared not to know either commercial 4.0 solutions or suppliers of these solutions. Only 23% of them have declared that they know suppliers and that their solutions are appropriate, which frequently is due to their high innovation level or complexity for customers, meaning that customers are not ready to embrace the 4.0 transformation. About a fifth of respondents declared that suppliers should help more their clients in the 4.0 transformation.

The PNI 4.0 provides financial incentives for companies which invest in 4.0 technologies, but 35% of the respondents do not know it, compared to 8% of the average Italian companies. Once again, there is a higher maturity level for suppliers, followed by Shipyards and, with 71% declaring that they do not know the plan, design studios.

7 Case studies

Nine survey respondents that have indicated to be available in participating in an in-depth interview were contacted. Among those, six replied and were successfully interviewed in a phone call two weeks after the survey was closed. Design studios were not selected because none was available and had a minimum maturity level on Industry 4.0 required for further exploration of their knowledge and intentions of implementing 4.0 solutions.

7.1 Structure

The semi-structured interview followed general guidelines to cover the same areas of the survey, adding depth and providing a higher explanatory capability to the analysis of the previously gathered quantitative. Each respondent was classified according to its maturity level to Industry 4.0. Respondents were divided in three groups from different maturity levels of implementation and knowledge based on their answers to the Question 3, in which respondents had to choose between five alternatives the one that best replies the question “Do you know the Industry 4.0 topic”. These were:

1. I don’t know it;
2. I read articles online;
3. I have participated in events related to the topic;
4. I am evaluating on doing something about the topic;
5. I am implementing or have already implemented solutions related to Industry 4.0.

Respondents which chose the first option were not selected for interviewing. The three groups were then formed according to their maturity level and adaptations were made to the questions made to each group. For example, those which had implemented 4.0 projects were asked to describe them, while those which haven't were asked about which opportunities they envisioned if these projects were considered. Groups A, B and C are defined:

- **Group A:** respondents that have implemented or are implementing 4.0 solutions and so have the highest maturity level (alternative 5).
- **Group B:** respondents which are evaluating the possibility of investing on 4.0 technologies, but have not done it (alternative 4);
- **Group C:** respondents which know the topic but are still at an early maturity stage (alternatives 2 and 3);

Three companies from each group were selected initially, of which 5 suppliers and 3 shipyards. However, four of them were not successfully interviewed, including the three members of Group C (lowest maturity). The reasons for that were mainly the impossibility of contacting the companies: in some cases, phone calls and e-mails were never replied, while in orders the potential interviewees failed to present in the interview appointment. For this reason, the interviewees consisted finally of:

- **Group A:** two suppliers and one shipyard;
- **Group B:** one shipyard and one supplier;
- **Group C:** one supplier.

Respondents were identified according to their type of company (shipyard or supplier) and the group they belong to (A, B or C). If there are more than one company of the same type and group, they are indicated with a number for differentiation.

7.2 Interviews

The general structure of the interview consisted in 9 main topics to be covered. In each area, some possible questions are marked as an orientation in the moment of the interview, which does not mean that all questions were asked to all interviewees. However, all areas were covered for all interviewees. These areas, as well as the possible questions for each group, are available in the **APPENDIX C – Case Studies' Questions**.

7.2.1 Group A

Three companies from Group A (have implemented or are implementing 4.0 solutions) were interviewed. Main results are described and analyzed.

7.2.1.1 Shipyard A

This shipyard is a traditional player with over a hundred years of experience in producing custom and semi-custom boats using the Engineer to Order (ETO) production approach with low automation. Its brand is associated with a strong brand which is worldwide associated with high quality and speed, which, together with its unique customization and design competences, is a strong source of competitive advantage for the company. It currently produces superyachts, a growing market, some of which are speed boats, a market in decline especially due to environmental reasons, since customers are becoming increasingly aware of the higher emissions associated with more powerful engines. The company currently produces and delivers between 2 and 4 superyachts per year and has yearly revenues of around 20 million euros and 50 employees. It is supported by a great number of small suppliers, which account for around 250 people. The interviewee has been the CEO of the company for a few years.

When asked about 4.0 projects, two main projects were cited. The first one was internally developed with the help of a technical consultancy company and consists of a personalized ERP project-based software which is suited for their needs and is based on the agile methodology. It allows for integration of the product development with the production planning and control (which is customized for each project), coordinating the action of the different company’s functional units. This system integrates all their suppliers but is completely managed by the company: information is given to the company manually by request (sometimes via telephone). When asked about the specific 4.0 technologies, the respondent admitted that it contained very few of those, even though it was a step in the direction of implementing some of them. The second project is a CRM system based on Microsoft’s cloud platform, which is used to manage marketing, sales and customer service, making information more available for the relevant employees and stakeholders.

Later in the interview, the interviewee reported that they plan to increase the number of sensors in their boats to better monitor how their products have been used. They currently have included the cheapest solution of the kind, which gathers data to be transferred to the shipyard, including the environmental conditions and the ship operation by the crew. The main objective is to associate this data with their warranty policy, which does not cover damages caused by misuse or improper maintenance, for example.

It was discovered that the company has invested to create a new factory in which production could be much more controlled due to their improved infrastructure. Due to time constraints, this part was not explored in-depth, but it was reported that this project could enable the utilization of some 4.0 technologies, such as IoT, which would not be possible in their current installations. This project is still under development.

The main difficulties pointed by the respondent were in the process of managing the change, especially on what concerns the company's employees. Since it is a traditional sector and company, people were reported to be resistant to any changes in their way of doing their job. However, with time the results were convincing, and adoption of the new procedures increased.

No changes in organizational structure were performed or are intended to be performed. However, there is a plan to hire someone with the necessary competences to manage the CRM database, to operate in the back-office with the goal of increasing its automation and reduce the time needed to input new data, thus increasing its commercial impact.

The company's CEO was asked the reasons why the company decided to be the only responsible for managing its novel ERP system. As an answer, it was pointed the fact that their suppliers are considerably different from each other and many of them have very little technological maturity, so they decided that it would be more reliable – even if, from an automation point of view, a simpler solution that consumes more of the company's time – to centralize the project management in the company. In the other projects, there is no collaboration with other companies in the value chain.

The company did not perform any formal feasibility analysis in any of their projects. In the cases when an external consultancy company was hired, they followed their suggestions by simply analyzing the solutions which better fit their budget capabilities. For none of their projects they have used the PNI 4.0, but they are evaluating the possibility of using it.

The main benefits of their implementations were, in the first case, to better manage their projects. This is expressed in less waste due to problems of integration, such as wrong production of parts by their suppliers (e.g. different specification or quantity), or time needed to gather and manage the information about the project. All information about the project became more accessible and reliable, reducing costs and dramatically reducing errors in predicted project duration (i.e. less delays). The CRM project allows the marketing, sales and customer service areas to be more integrated, having easily accessible and up-to-date information on their customers which they can rely for better performing almost all their activities.

The company's respondent considers to be in a more advanced level when compared to their competitors. Still, during the interview, it was clear that the 4.0 phenomenon is not being understood as a revolution that will have a strategic impact. One example is that, after initially describing the project considered their main 4.0 implementation, when the respondent was asked which 4.0 technologies were being used, the answer was that there weren't any. During the interview, the interviewee reflected on the topic and started pointing out other initiatives that he thought could be considered as part of Industry 4.0

From a scientific point of view, the first implemented project is a pre-requisite for the implementation of 4.0 technologies, since it is basically associated with the generation, management and simple analysis of databases. However, none of the described 4.0 technologies were implemented, even in a low maturity stage. In the second project, the company uses a third-party cloud, which can be interpreted as Cloud Computing. It was clear from the interview that there is no planned vision or strategy which includes the 4.0 transformation, but rather the possibility of using some of its technologies when the company judges (in an unstructured process) that it is a satisfactory solution to a problem it constantly faces.

7.2.1.2 Supplier A.1

This family-owned supplier manufactures valves and hydraulic systems, which are sold mostly to Italian shipyards in the recreational boating sector in a Make to Order (MTO) production strategy. Their revenues are around 8 million euros per year, and there are around 30 employees. They consider to be in advance when compared to their competitors in terms of their 4.0 implementation. The interviewee is a manager responsible for quality, environment and security with over 20 years of experience in the sector working in this company. Their transformation is conducted mainly by their CEO and their production manager.

The respondent reported that the company invests a high percentage of its revenue in innovation (around 10%), which is focused both on production (mainly machines) and products (design phase). The survey results show that this company is implementing at least one 4.0 project, which the respondent was asked to further detail.

Their main project is still in implementation phase. It consists of a new vertical warehouse that is connected to their ERP. It contains "statistical and connection" instruments on the machines, which were not detailed by the respondent. The main objectives are to "improve internal and external logistics”. It was also briefly described that they constantly invested in “machines to increase productivity” as a 4.0 project. They also plan to have a Business Intelligence project, which is necessary for a certification in hydraulics.

The difficulties pointed were centered the integration of different software provided by many suppliers, which frequently are rigid and do not allow customization for each company’s reality. Suppliers of these technologies, it was reported, tend to offer a complete solution, and when a partial one is adopted from different suppliers, the coordination is difficult.

These projects are managed by external consultants, since there are no internal employees with the necessary skills to be in charge of this type of activity. They also have an IT person that visits the factory once a week to solve problems related to these initiatives, but it was said that there was no need for a full-time employee. The local category association had a small participation in their projects as a consultant.

Their clients are aware of their transformation but did not participate in the decision-making process or had to change their operations. It was reported, however, that the supply chain “could be” more integrated, but that it would need a stakeholder to coordinate the solutions. The national association (UCINA) did not participate in any of their projects.

There is no structured process to decide the implementation of the 4.0 projects, so not necessarily any feasibility indicator is calculated. These decisions are made by the technical department, and it was not clear which criteria are used to evaluate possible actions. There is no strategic vision of the 4.0 implementation: the respondent reported that it is very challenging for a small company to have a long-term plan. Their projects are planned, at maximum, over a one-year time horizon. Since they are small, they also have little influence over the legal decision-making process at national and European levels.

Their warehouse project is still not efficient, it was reported. Their main objectives are to reduce the times (to perform the logistics operations) and to better manage the space (thus a vertical warehouse). They have used between 100 and 300 thousand euros in depreciation incentives from the PNI 4.0, which have reduced the time horizon of their investments but not increased its total value.

During the interview, it was clear that there was not a clear understanding of the meaning of Industry 4.0. The respondent reported that he perceived it as “instruments that will help integrating the operational level with their information systems” and that it will help “to make production a bit smarter". The respondent in many cases also replied in a generical way, which did not enable an in-depth understanding of their initiatives. It was not possible to precisely identify which (if any) 4.0 technology is used.

7.2.1.3 Supplier A.2

This supplier is a family-owned business that produces hydraulic components for international cruiser and cruiser-racer boats. Most of these boats are used in racing competitions, which means that frequently their production is based on Engineering to Order approach, developing products together with the shipyards according to their unique specifications. In most cases, a solution that is developed for a client is only produced once, which makes a high automation level challenging due to low standardization of production processes.

This characteristic makes it a particular case in the recreational boating sector, since, for competitions, clients require the highest performing systems and are available for paying price premiums for it: indeed, they have reported to have almost no competitors, since they work in a niche market which require state-of-the-art technology. Their revenues are around 4 million euros per year, and they have around 20 employees. The interviewee is a partner that works at the C-Suite level that has worked for 17 years in this sector, all of those were in the company.

The company is, indeed, an outlier in the recreational boating sector. Connectivity between machines and a company central management software, as well as many other innovations that are not present in the other companies, have been used for at least 15 years. The parts in production have always been monitored, at first with pencil and paper, and nowadays with bar codes. A Computer Aided Manufacturing (CAM) is connected with the company's business management software, which helps production and product testing. Many of those projects are old and were implemented even before the interviewee worked for the company, for which they were not explored in further depth.

The company is actively looking to adopting 4.0 solutions. One of their projects involve the gradual substitution of their machines with new ones that include sensors that monitor their condition with the objective of performing predictive maintenance, which involves 4.0 technologies such as Big Data and Analytics. They are evaluating the possibility of incorporating a solution in which their supplier monitors their machines and automatically provides (predictive) maintenance. This solution was not adopted due to its high cost compared to the company's profit-generation capabilities. However, the interviewee considers that it would be a valuable acquisition for the company for reducing production downtimes and increasing the predictability of their product duration, which will be adopted if the prices are lower in the future.

Another project is the installation of sensors in their project (IoT), which monitors the boat condition and transfers data to the supplier. This was enabled by the long-term relationship between the company and their clients, in which there is trust that the data will be used appropriately. Indeed, it is mainly applied to improve product design: boats are initially designed based on theoretical data and during test phase the sensors gather information necessary to improve the model and refine their products. In the case of competition boats, the sensors are removed for competition to reduce their weight. For leisure cruises, they are kept during usage to monitor the conditions of the boat and see how it is being operated, a condition that is established by contract with their customers, which reported to have benefits of increased safety during cruise usage.

This high-technology company has reported to have a strong interest in adopting cloud technologies, which the interviewee reported that would be “a dream come true”. However, they do not have access to high-speed internet, which is necessary to work in a compatible speed by implementing such technologies.

They are very interested in 3D printing technologies, specifically titanium and aluminum pieces made with additive manufacturing. However, they have reported the technology to be still too inefficient when compared to subtractive manufacturing, both in terms of costs and of time, especially due to the low precision of the current methods. The company has already identified how this technology, if improved, can help in their manufacturing process.in the future. 3D Printing in plastic is already used for few accessory parts of low importance for the company.

The respondent reported that they are internally developing a customized MES software for planning their production, in which the data on the state and times of parts in production is registered. The external market solutions were pointed as too standard and adapted for larger enterprises.

Feasibility analysis is not structured. The process for evaluating the implementation of technologies that are judged by directors as potentially interesting is facilitated by an external consultant, which helps to map the potential incentives the company may use. The company is, among the survey’s respondents, the one which has spent the most using depreciation incentives from the PNI 4.0, which account for approximately 10% of their revenues, while most of the companies did not reach the 1% threshold. Competences are not considered an obstacle for 4.0 implementation, which helps explaining why they do not know the tax credits for training.

The respondent reported that their procedure for evaluating new 4.0 solutions is less related to integrated projects than to specific, incremental solutions. They tend to prefer incorporating solutions from suppliers from which they have previously bought in order to reduce their total number of suppliers, which makes integration and maintenance easier. There is little supply chain integration between the company and its suppliers or customers.

Even though the interviewee reports the highest implementation level (by a great margin) when compared to the other interviewed companies, there is little knowledge of the technologies. It was reported, for example, that they often had difficulties replying surveys about Industry 4.0, because they did not know which of their implemented technologies could possibly be classified into the scientifically established and validated 4.0 technologies.

7.2.2 Group B

Two companies from Group B (that are evaluating implementing 4.0 solutions) were interviewed. Main results are described in the next two sub-sections.

7.2.2.1 Shipyard B

This shipyard is not rigorously part of the recreational boating sector, since it manufactures professional ships, in two sectors: military and commercial. However, its similarities and differences when compared to the shipyards of the main focus of this study are worth studying. Some similarities include the ship (medium and small) and company (medium) sizes, the customized production (ETO strategy) and common suppliers. The interviewee works as a business developer and has been worked both in the company and in the sector for 4 years.

Some important differences include their customer requirements and acquisition processes. In most cases their clients are corporations or governments, which means that there are more structured requirements to be followed and, in the second case, that they have to produce with the lowest cost that fulfills objective requirements (i.e. public tenders), instead of having a product differentiation strategy as commonly occurs in the B2C market for recreational boats. Their main competitive advantage is reported to be their accumulated experience in the sector of almost 100 years and their ability to provide an enhanced customization. Their yearly turnover is around 30 million euros and they are directly responsible for 70 employees. They have not implemented any 4.0 projects, thus the questions focused mostly on their intentions and on their obstacles, especially on the military sector, which accounts for most of its revenues.

The company is evaluating 4.0 solutions which are related to improving processes, rather than products. This is justified by the fact that their product innovation is exclusively derived from customer requirements, and their customers do not have declared intention of improving their boats with the 4.0 technologies. They do not have strong relationship with their suppliers (almost all Italian), which are mostly selected according to the cost of their products, occasionally performing quality controls. This could also be a reason why they do not intend to use these technologies to improve their supply chain processes, since when questioned about collaboration with stakeholders, the respondent declared that they just follow their clients demands, not considering possible integration with suppliers.

For confidentiality reasons, the respondent preferred not to disclose in detail the technologies they have selected, even though they have said that there is already a list of those in a structured "technology intelligence" process which involves the company's strategic level.

The main processes they want to improve are product design, mainly by having a database to organize information about their experience on previous projects, and production, in which they want to use simulation to model the production to try to increase "efficiency" (e.g. changing factory layout). The technologies to be used are mainly simulation "and related technologies", but the respondent did not want to detail them.

The main difficulties pointed are "to bring innovations in a traditional business", since people are used to do things in a certain method and are resistant to change. These difficulties appear in any innovation the company tries to implement.

The company works with a consultancy company that takes care of the operative part of decision-making (e.g. set up meetings, find suppliers), but the intelligence and the decisions of technical and strategic aspects is made internally.

When asked about competences and hiring new personnel, the respondent declared that they have not yet evaluated the need of them, but if they realize that new competences are needed, their first approach is to try to train their employees. If necessary, new personnel can be hired.

The interviewee replied in a general way when questioned about the expected benefits, declaring that they aim to "reduce time and increase profit margin", as well as "to promote innovation" in order to not "lag behind" their competitors. When asked about more details of, for example, how to increase their profit margins (e.g. higher prices, lower costs), the respondent was not able to clearly specify the business justification which would lead to it, pointing generically to “higher efficiency and reduced times”. The company has identified competitors and companies from the recreational boating sectors which have implemented solutions that, in his vision, can be interpreted as 4.0.

They do not have a structured process to evaluate the possible benefits of the technologies or a feasibility analysis. However, it was reported that this analysis could be done by creating performance indicators for each technological solution and for each project. In some types of innovation, such a change in a broad process (e.g. product design), the respondent declare that such analysis would be too complex. As well as in the other cases, there is not a coherent strategy for the 4.0 implementation, but rather the possibility of achieving incremental benefits with partial solutions.

7.2.2.2 Supplier B

The last interviewed company is a supplier of innovative materials, with focus on sustainable solutions. They develop solutions internally, which includes, for example, recyclable fibers. They sell their products either separately or bundled with available sustainable solutions produced by other companies in a complete and integrated solution. Their clients are not limited to the recreational boating sector: some examples include the automotive, building engineering and aerospace. The collaboration with their clients (i.e. shipyards and other suppliers) is part of their business model, in which products are developed in projects together with their clients, called “partners”. They are a niche company, that existed for less than 10 years and generates less than a million euros in yearly revenue. Their projects are often supported by governmental incentives related to environmental sustainability. The interviewee is the company’s CEO and co-founder.

The company is evaluating implementing 4.0 solutions. One of the reported technologies is additive manufacturing (3D Printing), in an effort to increase modularization of components. However, this niche company has very little capacity of investing and is highly dependent on their customer’s demand. Their intentions of applying 4.0 technologies are limited to customer-driven requirements for their materials. They have, however, already used the tax credits for training and for research and development, in technologies which include additive manufacturing, IoT and Human-Machine Interface, with focus on innovative production techniques.

Their business model is, thus, based on collaboration with their clients and on internal development of novel materials. The main difficulties reported are related to their customers, which, according to the respondent, are not interested in innovations, especially when they are associated with sustainability.

Their maturity stage on 4.0 technologies is the lowest among the interviewed companies. For this reason, the interviewee had not reflected about how they would proceed in terms of feasibility analysis or evaluation of possible benefits of 4.0 technologies.

The company does not have and does not plan to have any significant collaboration with companies other than their customers. They also reported that there are no organizational changes in plan for the adoption of 4.0 technologies.

7.2.3 Group C

One company in Group C was interviewed using the following outline: A summary of the interview is described in the next sub-section.

7.2.3.1 Supplier C

This company provides waste management services for the nautical and others. They have a 'mobile demolition site', in which waste is brought (collected from their customers) and processed using backhoes waste shredders and an aspiration system to remove the resulting powder particles from the air. The waste is mostly not recycled, which is seen as an opportunity by the company leveraging on increasing sustainability concerns. In the recreational boating sector, their main activities are dismantling boats and demolishing them, as well as molds used in their manufacturing processes. Demolition is performed when there are governmental incentives and waste management is considered a problem in the maritime sector, since many boats are abandoned in ports. The interviewee has worked for about 10 years in the company and 15 years in the recreational boating sector and currently has a C-level position.

There was no clear understanding of what is Industry 4.0 and its associated technologies. The main obstacles pointed for not having evaluated the introduction of 4.0 solutions was "time and knowledge on the topic". Competences, however, were not considered an important obstacle by the interviewee, which after reflecting admitted that there little has been investigated – especially by the strategic management – on the possibilities enabled by Industry 4.0.

The interviewee was stimulated with some of the technologies that compose the Industry 4.0 transformation. One of the mentioned technologies is Additive Manufacturing, which they have evaluated on using for recycling, but the technology was not technically adapted due to engineering requirements. The interviewee's company also has implemented sensors in their industrial trash bins (an IoT initiative), which help monitoring their demanufacturing and demolishing processes, with positive results in terms of process planning and monitoring. In the survey, however, the interviewee failed to identify “IoT” and “Additive Manufacturing” as known technologies.

There are also plans of using position sensors to help monitoring waste collection, but this idea is still immature. This company, even though classified in Group C based on the survey answers, has presented only marginally lower knowledge and implementation levels when compared to companies of Group B.

The interviewee declared that the company did not use the PNI 4.0 because, even though they knew its existence, they have not identified their IoT as being potentially eligible for using these incentives, since there was not a clear idea of the concept and the technologies which consist Industry 4.0. When confronted with the possibility of using it in next projects, the respondent declared to be interested in investigating new opportunities. The interviewee also declared to have not looked for external personnel, suppliers of 4.0 technologies or external institutions (such as consulting companies) that could help them in the implementation of 4.0 technologies.

7.3 Main results

All respondents are SMEs with different implementation and knowledge level of Industry 4.0 and its associated technologies, ranging from those which are evaluating those solutions to companies that have already implemented. They work by producing customized products, most often adopting an Engineer to Order approach. The interviewees are company members, usually at the strategic hierarchical level, which are responsible for the evaluation of 4.0 projects. They have different level of knowledge and implementation: three have declared to have 4.0 projects, while two are still evaluating and one declared not to have them.

The recreational boating sector is composed mainly by traditional companies, which have in some cases existed continuously for more than 100 years. While this can be a source of competitive advantage, respondents often reported that it is an obstacle in the implementation of innovations that change their employees work, which includes the incorporation of 4.0 technologies.

The respondents, even those with highest implementation level, struggled to name the 4.0 technologies they have used. As a standard procedure, an open question was always asked to specify which 4.0 technologies are or will be implemented in their 4.0 projects. Respondents faced difficulties in naming them, and for which they were stimulated with a brief list of the technologies that the interviewers judged most likely to be implemented, as well as an informal explanation of them. After this, two different results were achieved: either the respondent realized that they did not have any of those technologies or they managed to associate and explain at least how one of those is used. This suggests that the survey results that measure the implementation level of Industry 4.0 in the recreational boating sector (19%) can be over-estimated due to the little knowledge of what are the constituting technologies of the fourth industrial revolution. The overall statistics for the same question in Italy are around 55%, which strongly indicates that this sector is in a preliminary stage, even when compared to the already immature Italian companies.

None of the respondents manage to clearly define the 4.0 transformation. Although there are few applicable maturity models to the case of SMEs, since most assume that these companies have an appropriate organizational culture and the required skills towards Industry 4.0, as well as proposing categories which are too advanced for them (Mittal, Khan, Romero, & Wuest, 2018), one of them was applied. This maturity model evaluates the (existence of a) strategic view of the 4.0 transformation, when applied to respondents, classifies them in the lowest maturity stage, defined as “Initial”, a category in which “it doesn’t exist a company specific industry 4.0 vision” (Ganzarain & Errasti, 2016).

This result is consistent with the results found in the literature, which says that SMEs “view Industry 4.0 as an evolutionary sum of adaptions in production, supply chain connectivity and digitization, rather than an outright Industrial Revolution” (Müller, Buliga, & Voigt, 2018).

Results found both in the survey and in the interviews, when contrasted to the literature review performed in the first step on the Industry 4.0, showed that reality in this sector is very far from the envisioned Smart Manufacturing, with connected supply chains. Indeed, some researchers conclude that academic investigation into Industry 4.0 extensively focuses on large enterprises and only marginally on SMEs (Müller et al., 2018), which have their unique characteristics. The technologies which can be adopted in a least expensive and least revolutionary way (such as traditional simulation and consolidated 3D Printing of some types of plastic) are the most exploited in these companies, while those allowing profound business transformations (such as CPS, Big Data) are still neglected by them. This was also a conclusion in other studies on SMEs (Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2018).

Some explanations in the literature for the lower capacity of adopting Industry 4.0 in SMEs include the fact that they are more specific (less product variety), so tend to have a deficit in cross-disciplinary networking opportunities and a result, they are not able to update themselves with the on-going, cutting-edge research (Mittal et al., 2018). Many SMEs face primary obstacles, such as lack of high-speed internet connection or database that organizes the company's "3.0" information. Results found in other studies point that SMEs have, in general, lower ICT utilization, mainly due to lack of proper knowledge, education and skilled owner-managers and employers within the enterprise (Arendt, 2008). These companies also often lack the resources to look at new avenues outside of their competencies. In most cases, they are not "early adopters," mainly because of the fear of investing in the wrong technologies or adopting inapt practices (Mittal et al., 2018). This is likely to affect the implementation of 4.0 technologies and is consistent with the results found in this study.

Even companies which have declared to be implementing 4.0 solutions still do not have many of the necessary basic resources, such as established ERP software, with which many of these technologies can be appropriately integrated. This is also consistent with the literature, which suggests that small and medium enterprises have much lower adoption rates of ERP systems (Buonanno et al., 2005).

Companies declared projects in three main areas: product development, manufacturing processes and supply chain. However, only a few of those can be rigorously considered as part of Industry 4.0.

The transformations in supply chain and logistics are limited inside the boundaries of companies, even in the most advanced cases. A possible reason is the market characteristics: companies are heterogeneous in terms of their digital capabilities, are small (difficult to establish standards) and have to interact with many others (a result obtained in the previous sections). There are no companies with bargaining power high enough to provide standardization in "inter-company information transfer to trigger challenges in value creation" (Müller et al., 2018). Considering the market characteristics as fixed in the medium term, this is an opportunity for category associations or the government to stimulate higher integration.

Formal organizational procedures can be challenging for SMEs, possibly because they have flexible structure and do not have the resources to create a dedicated area for innovation projects. An example is the fact that there is little to inexistent formal feasibility analysis and most frequently respondents were not able to clearly express the (expected) benefits with the 4.0 transformation. On the other hand, they try to outsource the most they can: in the most advanced cases, companies tend to use consultancy companies to get the necessary skills. This solution is potentially more efficient than hiring full-time employees responsible for IT.

External companies are also used to support the respondents' companies with the identification of possible governmental incentives, including the *Piano Nazionale Impresa 4.0* (PNI 4.0), which means that they often companies possess superficial knowledge on the available governmental incentives: none of the respondents has shown a clear and detailed knowledge of the plan. This can be explanation for the results obtained in the survey in which in some cases companies replied not to know the PNI 4.0, but later declared to already have used some type of incentive (e.g. depreciation or tax credits).

The general procedure for innovations started usually from the company's desire to innovate (which can come from internal initiatives, from 4.0 suppliers offering their solutions, including IT consultancy companies), which then started looking to quantify the necessary investments, considering possible governmental incentives. Results thus suggest that governmental incentives are not the initial driver for implementation of 4.0 (or possibly all innovative) projects in the sector, which requires further research to possibly be generalized to small and medium enterprises in other sectors. These are confirmed by the previously obtained results in the survey, which rank "incentives from the PNI 4.0" in 9th position among 13 possible motivations for the implementation of these projects.

Table 9 summarizes the results found in the interviews:

Analyzed dimension	Overall results
Companies sizes	Small and medium
Production approach	Mainly ETO and ATO
Vision on Industry 4.0	No strategic vision, but a pragmatic implementation of specific technologies. There is not a clear understanding of 4.0 and companies are often not able to associate their implementations with 4.0 technologies
Implementation level	Often still implementing pre-requisites for 4.0 technologies, such as ERP or CRM information systems
Innovation areas	Product design, Manufacturing and Supply Chain
Boundaries of 4.0 initiatives	Limited to inside the companies
Procedures for designing innovative projects	Internal identification of opportunities followed by external consultancy institutions to help materialize them. There are no structured processes of feasibility analysis or benefits evaluation
PNI 4.0	Failing to identify their projects as part of Industry 4.0 has led companies to not use the benefit when they could have done it. PNI 4.0 is seen as a way to decrease the costs of projects, rather than a driver to promote knowledge on Industry 4.0
Main challenges	Missing knowledge on Industry 4.0 by directors (evaluation of projects) and change management (implementation of innovative projects)

Table 9: Summary of case studies' results. ***Source: Author's elaboration.***

8 POLI-USP Learning Factory

All previous results demonstrate that the knowledge and implementation of Industry 4.0 in the Italian recreational sector is very low, and this may be a common finding in different industries, especially when composed by Small and Medium Enterprises. The Italian government's effort to stimulate the implementation of Industry 4.0 with financial incentives may not provide the desired results, since in most cases companies are not aware of the competitive advantages that Industry 4.0 can provide. One possible path to provide training for non-researchers and illustrate in an easily understandable way the concept and applications of Industry 4.0 is trough Learning factories.

8.1 Learning factories: concept and objectives

Many engineering universities are aware of the importance of the 4.0 transformation. The combination of this fact with the low knowledge of the topic in many companies — such as the ones composing the Italian recreational boating sector — represents an opportunity for these institutions to address this gap through education and collaboration with companies and policymakers.

In this context, new learning approaches, such as learning factories, are needed to allow training in realistic manufacturing environments, modernize the learning process and leverage industrial practice through the adoption of new manufacturing knowledge (Abele et al., 2017).

Learning factories can be defined as a "learning environment specified by:

- **Processes** that are authentic, include multiple stations, and comprise technical as well as organizational aspects,
- a **setting** that is changeable and resembles a real value chain
- a physical **product** being manufactured, and
- a **didactical concept** that comprises formal, informal and non-formal learning, enabled by own actions of the trainees in an on-site learning approach.

Depending on the **purpose** of the Learning Factory, learning takes place through teaching, training or research. Consequently, learning outcomes may be competency development or innovation. An operating model ensuring the sustained operation in the Learning Factory is desirable" (Abele, 2016).

Processes inside learning factories are based on real industrial sites, thus only minor abstractions are needed to understand its components and general objective (Abele et al., 2015). **Figure 38** shows how learning factories are able, through abstraction and resolution, to overcome barriers of will, skill and knowledge to the solution of real factories' problems.

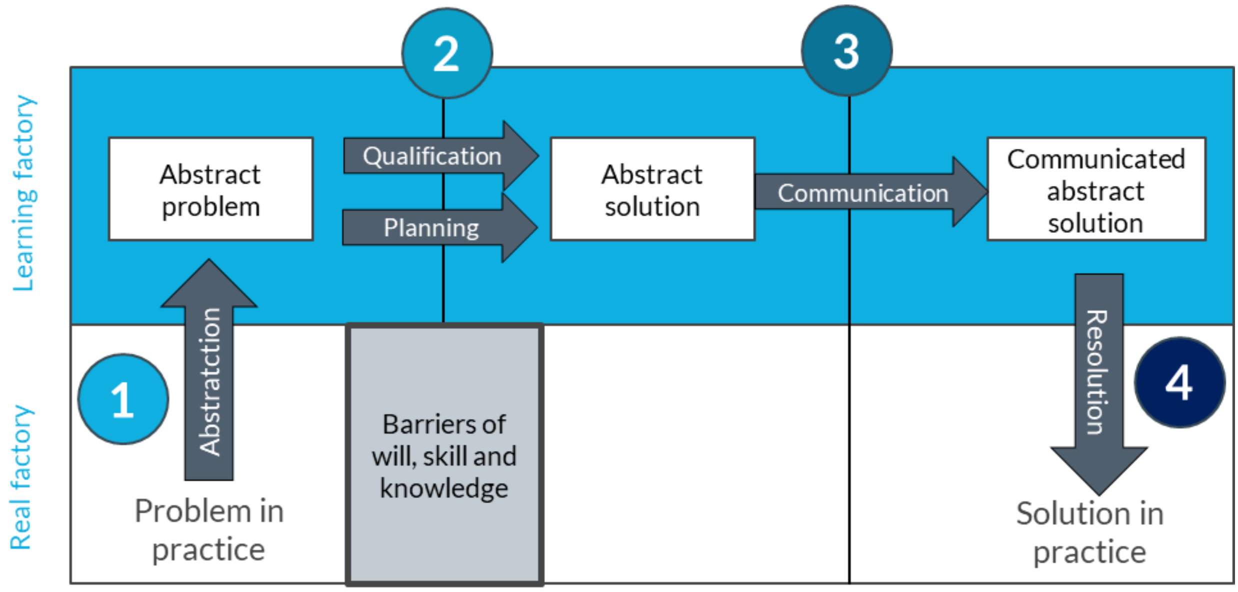

Figure 38: Learning factories value to the solution of real factory problems. ***Source: Abele et al. (2017).***

8.2 The "Fábrica do Futuro" network

A recently-built Learning Factory at Universidade de São Paulo's engineering school (POLI-USP) called "Fábrica do Futuro" is the object of study of the following sections. Its objectives can be grouped into three main areas:

1. **Didactics** based on contextualized projects for undergraduate and post-graduate students, as well as professional training;
2. Multidisciplinary **research** of 4.0 technologies in an environment of application and testing;
3. **R&D** environment for collaborating companies, which can test and develop their technologies in the factories' demonstrators.

The factory is part of a modelled supply chain, which is composed of three sites, as shown in. The object of this study is the POLI-USP site, which assemblies the skateboard and produces part of the optional components on 3D printers. The CITI-POLI-USP supplies the electronics for the Connectivity Box, while the Insper site, located in another university (Insper) in São Paulo produces the trucks and ships them using smart logistics. The three sites, as well as their connection, is shown in **Figure 39:**

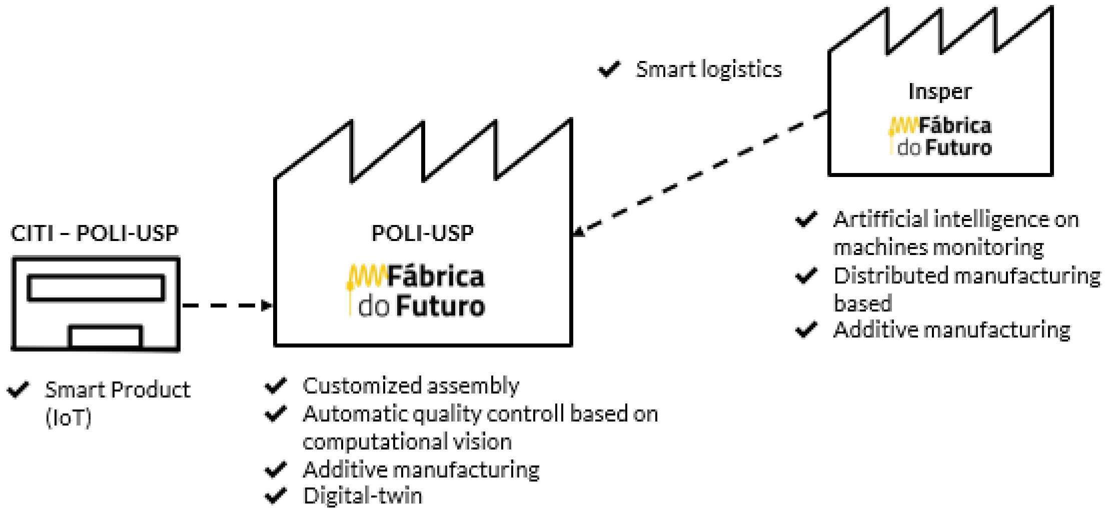

Figure 39: POLI-USP Learning Factory supply chain. ***Source: Fábrica do Futuro (2019).***

The operation model of the studied Learning Factory consists of six dimensions, for which there are associated features, as shown in **Table 10**:

Dimensions	**Theoretical features** (Abele et al., 2017)	**POLI-USP Learning Factory** (F. Leal, Zancul, & Fleury, 2019)
Purpose	Teaching and/or training and/or research	Demonstrate and disseminate technologies of Industry 4.0 to academy and industry
Setting	Changeable + real or virtual	Physical
Didactics	Concept-based + formal and informal learning + own actions of trainees	i. Final projects from undergraduates; ii. Projects from graduates and post-graduates; iii. Undergraduate disciplines; iv. Short courses.
Process	Actions of trainees + on-site or remote learning	Skateboard assembly, including four technology demonstrators
Product	Authentic + multi-stage + technical and organizational	Skateboard
Operating Model	Sustainable plan allows the ongoing operation	i. Testbed for teachers, students, and researchers; ii. Training for companies and executives

Table 10: Dimensions and features of the Learning Factory. ***Sources: Abele et al. (2017), F.Leal, Zancul & Fleury (2019).***

The purpose of this Learning Factory is to demonstrate and disseminate technologies of Industry 4.0 to academy (including students) and industry (especially SMEs, which are most of the collaborating companies). The deriving operating model consists of (i) work as testbed for teachers, students and researchers and (ii) training for companies.

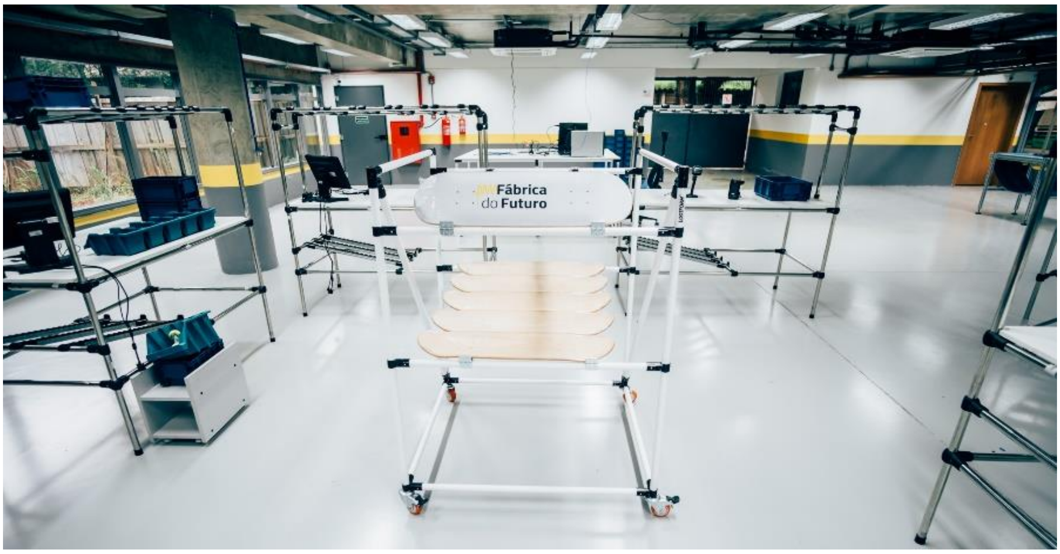

Figure 40: Learning Factory physical location. ***Source: Fábrica do Futuro (2019).***

Due to budget and space constraints, the Process, Setting and Product dimensions were limited for the initial version of the factory but can be later expanded. The setting is physical and there is no fixed layout, allowing flexibility for further expansion and for different uses. The product is a skateboard, which was chosen due to a number of characteristics, such as the simplicity of assembly and possibility of demonstrating customization in the processes and final product. It is produced using the ATO approach, which is similar to most shipyards in the Italian recreational boating sector.

The skateboard has two optional features. The first one is a Rail Guard, which is produced in the factory's 3D printers. The second one is a Connectivity Box, which can be attached to the product to collect information such as total distance and instant and average speeds. A smartphone application can show this information to the customer. Other customization options include the possibility of choosing the wheels colors and defining, from 0 to 10, the torque applied to the truck, which impacts the skateboard's maneuverability.

Didactics refers to available opportunities of research, mainly thesis for undergraduates and research projects of graduates and post-graduates' students, which will be demanded by the partner companies. Teachers from undergraduate courses can also use the space to complement the theoretical concepts given in class with experimental assignments. Courses will also be offered to companies and executives regarding basic concepts of Industry 4.0 and the enabling technologies, some of them demonstrated in the Learning Factory, followed by workshops in which the attendants are incited to reflect on what technologies could be applied to their companies and industry, as well as creating roadmaps for implementation (F. Leal et al., 2019). These activities are similar to many of the events organized by *Osservatorio Digital Innovation*, in Italy, in the context of the Nautica 4.0 project, in which managers of relevant companies were brought together to discuss opportunities of Industry 4.0 in the sector.

8.3 Assembly process, demonstrators and technologies

The factory contains eight technology demonstrators, summarized in **Table 11** and further explained in their context below:

Demonstrator	Operation description
D1: Customized assembly to order based on individual product requests	On a tablet, the customer accesses a website and select the personalization of the skateboard (ERP interface). Possible personalization: 4 options of color for the front and back wheels (both front wheels same color and both back wheels same color); Torque application (range from 1 to 10); Connectivity box (include or do not include); Rails (include or do not include)
D2: Automatic quality control based on computational vision and machine learning	A camera identifies the colors of the wheels, using computer vision and machine learning, and communicates to the MES if are correct or not.
D3: Individual parts tracking	Tag applied to the skateboard carrying the information regarding the product customization and owner.
D4: Distributed manufacturing based on additive manufacturing.	Connectivity Box and Rails are produced through additive manufacturing.
D5: Low-scale manufacturing based on additive manufacturing	The additive manufacturing process enables production in low scale, reducing the production of stocks and thus following lean production principles
D6: Machines monitoring and artificial intelligence for predictive maintenance	3D Printers are monitored and controlled via software, which shows its current status. The application of artificial intelligence (under development) will enable predictive maintenance actions.
D7: Digital twin in the product lifecycle	The Connectivity Box generates a Digital twin of the product, which can be monitored by the customer and the company
D8: Connected product to support additional services in product lifecycle	The incorporation of the Connectivity Box transforms the skateboard in a Smart Product, thus enabling the monitoring of its lifecycle and the offer of additional services.

Table 11: Demonstrators and their descriptions. ***Adapted from F. Leal et al (2019).***

The assembly process starts by receiving two main inputs:

1. The customers desired configuration of the skateboard (wheel colors, optional features and torque), which is obtained through a web interface, which is part of the factory's ERP (**Demonstrator 1**) and transmits the information to the MES (**Figure 41**);
2. The parts to be assembled (shape, wheels, trucks and other small parts), which may or may not contain parts produced in the factory's 3D Printers (**Demonstrators 4 and 5)** in a parallel process (**Figure 42**).

Figure 41: Customization page of ERP interface. ***Source: Author's elaboration.***

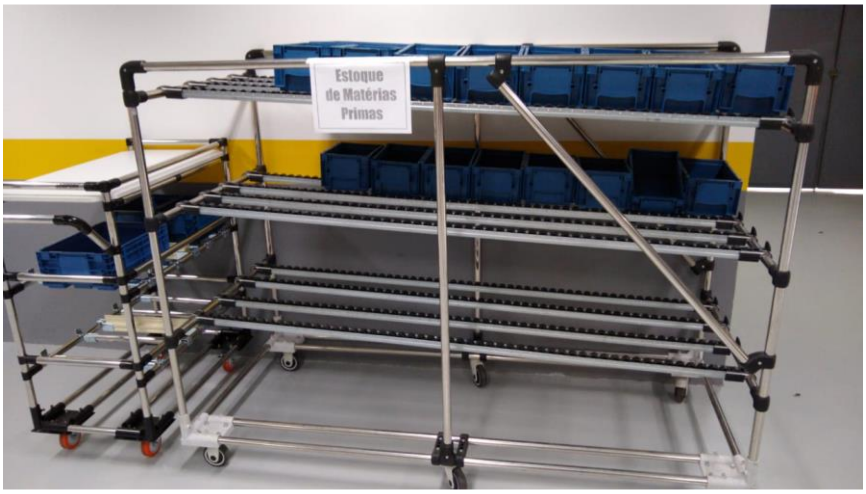

Figure 42: Inventories of parts to be assembled. ***Source: Author's elaboration.***

The assembly process is then divided in four workstations. On the first workstation, trucks are assembled to the shape and a tag is applied to the skateboard. This tag carries all the information of the product assembly and customizations, as well as its owner. Its purpose is to be an identifier of the product, collecting and feeding information to the MES (**Demonstrator 3**).

Figure 43: First workstation. ***Source: Author's elaboration.***

On the second workstation, the wheels are assembled according to the color configuration specified by the order (customers can choose any combination of four of the available wheel colors). This process is aided by a quality check, in which a camera collects information from each wheel's color, processes it and compares to the order. The result of this control is displayed in real time to the operator (wrong colors are marked with a red square) and transmitted automatically to the MES, providing automated quality control though computational vision (**Demonstrator 2**).

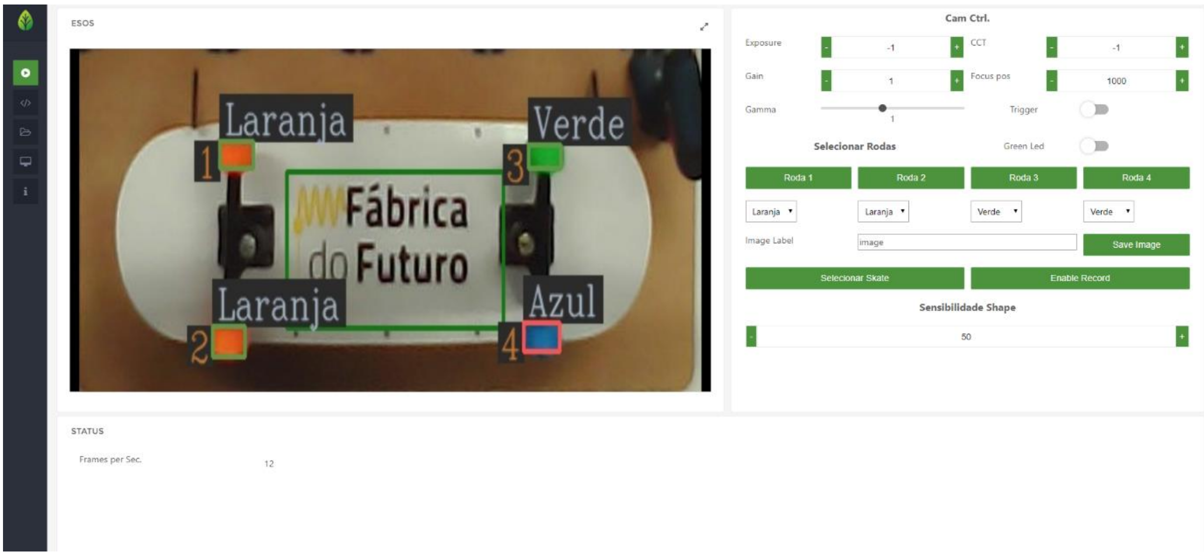

Figure 44: Automated quality control at Workstation 2, spotting a blue wheel where the operator should have assembled a green one. ***Source: Author's elaboration.***

The third workstation contains a machine that applies the desired torque to the truck (**Demonstrator 1**). On the fourth workstation the optional components (rails and Connectivity Box) are assembled if requested on the order (**Demonstrator 4**). The assembled products are then kept in a (daily) stock of orders.

The parallel production of rails and the plastic container for the Connectivity Box (**Demonstrator 5**) is performed in two 3D Printers that are operated and monitored through a dedicated software**.** This software will be improved to use artificial intelligence for performing predictive maintenance (**Demonstrator 6**).

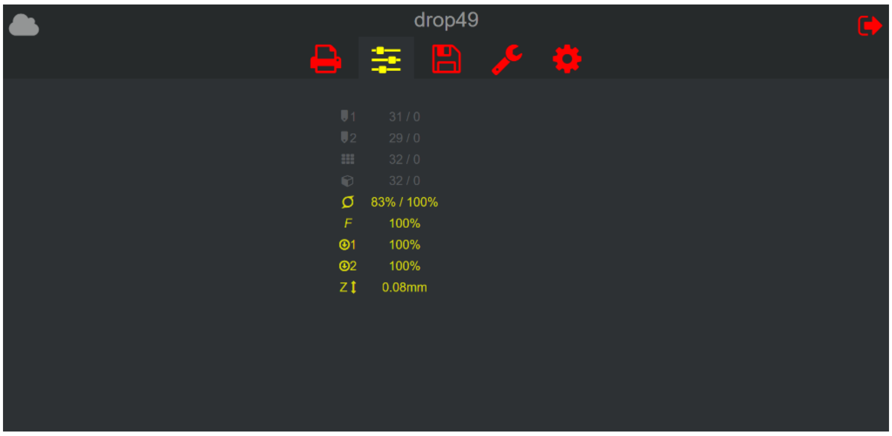

Figure 45: Variables which explain the operating conditions of 3D Printing for monitoring. ***Source: Author's elaboration.***

The skateboard with a Connectivity Box has two different sensors. The first one points to one wheel and measures its rotations, enabling the calculation of speed and thus monitoring its usage and performance. The second uses a gyroscope to generate a 3D visualization (Digital Twin) of the current position of the skateboard and can be used both by customers (e.g. to view the skateboard movement while a trick is being performed) and the company (**Demonstrator 7**). Both sensors enable the company to gather information about the product usage and offer additional services during the product lifecycle, such as insurance or advertisement to buy a new skateboard (**Demonstrator 8**).

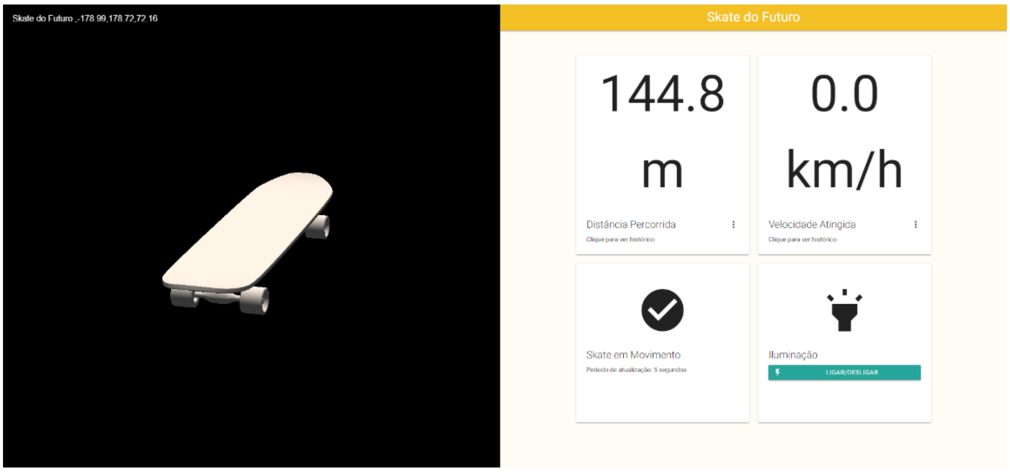

Figure 46: Skateboard Digital Twin (left) and speed monitoring (right). ***Source: Author's elaboration.***

Each of the eight demonstrators can be associated with one or more of the seven identified technology groups that describe Industry 4.0.

The customized assembly to order based on individual product requests **(D1)** is done through the ERP system and directly correlated with the lean structure of the factory, which enables the production in an assembly-to-order approach. The ERP runs and stores product data in the university's cloud server, called "interNuvem". The assembly process is supported by all technologies which are present in at least one demonstrator.

The automatic quality control based on computational vision and machine learning (**D2**) is based on artificial intelligence (Big Data and Analytics) to illustrate the possibilities of Advanced Manufacturing, in which quality control can be automated. The computer used by operators shows the information which is produced both by the MES software (called PPI Multitask), which has the product information to be checked (e.g. the correct set of wheel colors) and the camera software, which compares the wheel colors chosen by the customers with the ones assembled and sends a message back to the MES. If the set of colors is correct, this assembly step is done, and the product can be moved to the next step. The MES also runs at interNuvem, while the camera software runs in another cloud.

The individual parts tracking (**D3**), which is done through the insertion of a RFID tag (also produced in the factory), is an example of IoT. If scaled, it can potentially generate a lot of data, which can be analyzed and processed to better understand and improve the assembly process (Big Data and Analytics). Data is also stored and processed in the university's cloud.

The distributed manufacturing (**D4**) based on Additive Manufacturing relies on the incorporation of sensors to the machines (IoT), which can be controlled and communicate with each other autonomously (Advanced Manufacturing). Low-scale manufacturing (**D5**) refers to the possibilities enabled by the characteristics of Additive Manufacturing. The 3D Printers can be monitored through a software, which collects real-time data (IoT, Big Data) that can be processed (Analytics) for predictive maintenance (**D6**). All information storage and processing necessary to provide integration between systems is done through interNuvem.

The generation of a Digital Twin for the product lifecycle (**D7**) and the transformation of the skateboard in a Smart Product (**D8**) are consequences of the incorporation of sensors associated with IoT. The analysis of the great amount of data generated in the sensor represents an opportunity for the company in terms of Big Data and Analytics. The data for generating the Digital Twin is stored and processed at locally (to ensure low latency), while the server responsible for monitoring movement and the database to store data are hosted at an external cloud.

The results of this analysis are summarized in **Table 12**:

Technology	D1	D2	D3	D4	D5	D6	D7	D8	Total
Simulation modelling and Digital twin	X						X	X	**3**
Additive manufacturing	X			X	X	X			**4**
Internet of Things and Internet of Services	X		X	X		X	X	X	**6**
Advanced Human-Machine Interface									**0**
Big Data and Analytics	X	X	X			X	X	X	**6**
Advanced Manufacturing (CPS)	X	X		X		X			**4**
Cloud Computing and Cloud Manufacturing	X	X	X	X	X	X	X	X	**8**

Table 12: Association of the demonstrators with the 4.0 technologies. ***Source: Author's elaboration.***

The most common application of Industry 4.0 is the usage of Cloud technologies, which is explained by the fact that all demonstrators collect and use data which is at least partially processed and stored in cloud.

The second most common application is related to the group of Big Data and Analytics, which is present in six demonstrators. It comprises both demonstrators that generate a great amount of data, those which use algorithms trained with previously generated data (i.e. machine learning) and those which can potentially do both. The generation of this data is tightly associated with the Internet of Things, in which sensors are added to the skateboard, and is present in more than half of the demonstrators.

Half of the demonstrators can be associated with Additive Manufacturing or Advanced Manufacturing. However, the latter case shows a lower maturity when compared to the envisioned environments of decentralized control and autonomous machine operation in the Smart Factory also known as Cyber-Physical Systems.

Digital twin is associated with three demonstrators and consists of the generation of a digital model of the skateboard. This model is still at early levels, since it is does not comprise other physical assets in the factory, which could enable a digital simulation of the whole factory operation. Advanced Human-Machine Interface (Virtual and Augmented reality) are not present in the Learning Factory.

8.4 Learning Factory and the Italian recreational boating sector

A comparison between the results found in the survey, which focuses on the recreational boating sector applications, the previous results of the bibliometric analysis, which measures the research in the maritime and the applications in the Learning Factory is shown in **Table 13**. For visualization and summarization purposes, quantitative data was converted into quantitative.

In knowledge level, values above 90% were considered “High”, values below 81% (the average knowledge level of Industry 4.0, or the benchmark) were considered “Low” and the intermediate values were transformed in “Medium”. For application level, average values in the application matrix which includes the processes were considered, and values between 9% and 12% were considered “Medium”, while the upper and lower values were transformed in “High” and “Low”. In the total research, values between 60 and 100 documents were translated as “Medium”, while lower values than 60 became “Low” and those higher than 100 were transformed in “High” or “Very High” (in the latter case, if above 400).

Research growth was considered "High" if their growth in number of documents (as proposed in Section 4.4) is above 20% and "Low" if below 10%, while "Medium" in the other cases. Research growth was not calculated when total research is "Low" due to an insufficient number of documents. On the Future Factory, there are 8 demonstrators, thus the presence was classified as "Very High" if equal or above 7, "High" if equal to 6, "Medium-High" if equal to 5, "Medium" if equal to 4 and "Medium-low" equal to 3 and "Low" if below 3. Null values are also possible if they are not present.

	Italian recreational boating sector (Survey)		*Bibliometric Analysis*		*Learning Factory*
Technology / Concept	**Sector Knowledge level**	**Sector Application Level**	**Total Research**	**Research Growth**	**Learning Factory Presence**
Simulation modelling and Digital twin	High	High	Low	-	Medium-Low
Additive manufacturing	High	High	Medium	Low	Medium
Internet of Things and Internet of Services	Medium	Medium	Medium	High	High
Advanced Human-Machine Interface	High	Medium	Very High	Low	Null
Big Data and Analytics	Medium	Low	High	High	High
Advanced Automation (CPS)	Medium	Low	Medium	Medium	Medium
Cloud Computing and Cloud Manufacturing	Low	Low	Medium	Medium	Very high

Table 13: Survey results, maritime research and applications in the Learning Factory. ***Source: Author's elaboration.***

In the next sub-sections, results are further described for each technology.

8.4.1 Simulation modelling and Digital twin

Simulation modelling is a traditional engineering tool, which explains its high knowledge and application level in the Italian recreational boating sector. It was grouped in the literature on

Industry 4.0 with Digital Twin, since it is a specific type of simulation which can be used for product development and monitoring. Even though this grouping is logically correct, open answers in the survey and the case studies show that high knowledge and application of the technique in the Italian recreational boating sector is almost exclusively not related to Digital Twin, but to computer simulation techniques used to evaluate product and parts (in the case of suppliers) performance. Thus, even though the group scores high in the survey, it is not necessarily correlated with the trends of the fourth industrial revolution. Total research on its maritime applications in the context of Industry 4.0 is also low, which suggests either that it is not studied or that these technologies are studied without a focus on specific sectors.

In the Learning Factory the opposite situation happens, and the applications consist completely on the use of Digital Twin. Since the research shows that companies in the Italian recreational boating sector have little knowledge on Industry 4.0, which is one of the reasons why they have low implementation levels, initiatives such as the Learning Factory could contribute to the adoption of 4.0 simulation applications such as the Digital Twin.

8.4.2 Additive Manufacturing and Digital Manufacturing

Additive manufacturing is the second most used 4.0 technology in the Italian recreational boating sector, and knowledge about it is as widespread as for simulation. Applications, however, are mostly limited to 3D Printers used to produce non-essential and standard parts in the factory. This contrasts with the Digital Manufacturing concept in which Additive Manufacturing relates to of Industry 4.0 by enabling higher flexibility and customization, as well as parts being produced outside of factories and closer to final customers. Most expected innovations expected by interviewees were associated with the possibilities of using Additive Manufacturing to produce materials that could not be done with the technique (e.g. metal components) and not to their impacts on the supply chain.

Even though the Learning Factory’s main process is assembly of the skateboard, Additive manufacturing has a considerable importance. The usage of 3D Printers has the main benefit of enabling the production in low-scale, reducing the need for inventories. Other benefits such as the customization of parts and the production outside of factories are not explored. In the first case, the parts produced are not customizable, but future developments could enable, for example, customers to choose the color of the plastic to be produced. In the second case, future initiatives could model a different supply chain in which 3D Printers are outside the factory and the parts produced through Additive Manufacturing are assembled, for example, by the final customers. The demonstration of all potential applications of Additive Manufacturing in Digital

Manufacturing in the Learning Factory, besides increasing awareness of the technology, can make companies which already use it - such as some of the companies in the Italian recreational boating sector - better understand its possible advantages and increase utilization.

8.4.3 Internet of Things and Internet of Services

Survey results show intermediate knowledge and utilization of IoT. It is interesting to note that, differently from the two previously described technologies, the applications of the technology are not very concentrated in Product Development. Interviewed companies revealed projects to add sensors to their products to monitor their performance and behavior, while applications in the production processes are less common. It should also be noticed, however, that the case studies have shown that many respondents are not able to correctly identify their IoT applications, which may result in an underestimation of the technology's utilization.

In the Learning Factory, the application of IoT is widespread, which is aligned with the high levels of past and growth of research in the maritime. The applications are balanced between monitoring the skateboard during and after assembly, as well as providing connectivity between the 3D Printers and monitoring their status. These applications have implications on production efficiency, product development and enables the offer of personalized additional services (e.g. insurance) through the collection and analysis of data on product usage.

8.4.4 Advanced Human-Machine Interface

Virtual reality is the most common keyword found in the bibliometric research, which makes this group of technologies the most researched. However, most of the research was done in the past, and growth is very low. The keywords cluster analysis helps understanding these applications, suggesting that the most common applications are related to prototyping and personnel training (e.g. simulators for training ship navigation).

Knowledge on the topic in the Italian recreational boating sector is high and implementation level is medium. The implementation is also not concentrated in Product development, while there is a considerable percentage related to Part manufacturing. Since none of the interviewees had such applications, more research is needed to better understand how Advanced Human-Machine Interfaces are being applied in the sector. The Learning Factory does not have any demonstrators using the technologies of this group.

8.4.5 Big Data and Analytics

In the Italian recreational boating sector, there are few applications of Big Data and Analytics, distributed along the different processes in a similar way to IoT, which suggests an intersection of applications. This is coherent with the idea that IoT sensors may be used to generate high amounts of data, which can be analyzed both by humans and by algorithms, which can automatically provide responses.

This fact contrasts with the considerable and fast-growing number of research documents on the possible applications of this group of technologies, which fully comprises one of the three clusters found in the bibliometric analysis. Interestingly, even though there is a high correlation between IoT and Big Data, the first is in a different cluster and associates more strongly with terms such as cloud computing and monitoring.

The Learning Factory is aligned with the importance given by the literature, and Big Data and Analytics are commonly used in the Learning Factory at both the process (e.g. automatic quality control by using analytics and monitoring of 3D Printers) and product levels (data on product usage generated by the IoT). Such demonstrations, as well as the ones described previously in the IoT sub-section, could illustrate possible applications and generate insights on possible applications in industries such as the Italian recreational boating sector.

8.4.6 Advanced Automation (Cyber-Physical Systems)

Advanced Automation is among the two least used technologies in the Italian recreational boating sector, being however the only in which the most common application is not in Product development, but Part manufacturing. These results may be partially explained by the low level of automation in the companies.

However, the Learning Factory has applications on the automatic quality control and in the autonomous exchange of information of the 3D Printers. These demonstrations show that even producing in low scale and using the ATO production approach, 4.0 technologies such as the Cyber-Physical Systems can bring advantages such as improvements in quality control and automation of small tasks, which can be applied to companies at a similar maturity stage to the ones in the Italian recreational boating sector.

8.4.7 Cloud Computing and Cloud Manufacturing

Cloud applications are the least known and used in the Italian recreational boating sector. In the case studies, the only disclosed application was a CRM system, which provides information about customer that can be used for Product development. The concentration of the few applications in Product development suggests that this may not be the only case, meaning that Cloud applications in production processes are even less common. This may be attributed to the low usage of Big Data, which requires high computing processing levels that are only available to small companies through cloud services. The cluster analysis classifies cloud computing in the same cluster as IoT and Cyber-Physical Systems.

The POLI-USP Learning Factory uses Cloud Computing at least partially in all of its demonstrators, using different Cloud servers to store and process data. However, the application of Cloud Manufacturing envisioned by the literature — in which distributed resources are aggregated and represented as cloud services and managed in a centralized way and clients can use the cloud services according to their requirements — is not present. Still, companies in the Italian recreational boating sector could learn from the applications in the Learning Factory to substitute their local data storage and analysis (many times done manually in applications that are not well-suited for Big Data, such as Excel) with Cloud Computing.

9 Discussion and conclusions

9.1 Conclusions

The Italian recreational boating sector consists mostly of Small and Medium Enterprises (SMEs), which have a low knowledge level of Industry 4.0, even when compared to average Italian companies. Companies in the sector can be divided in those which are concerned with pragmatic challenges and others which are still trying to understand how to take advantage of the phenomenon. A strategic vision of Industry 4.0 as an industrial revolution was not found even in the most mature companies. This result is aligned with the bibliometric analysis, which also shows that general terms (such as Industry 4.0) and more advanced applications (e.g. Smart Factory) have not been studied in the maritime context by the scientific community.

Three main typologies of companies were studied in depth: shipyards, suppliers and design studios. While results are categorical in pointing that overall companies are still in preliminary stages in knowledge and implementation of Industry 4.0, observations differed considerably according to the type of company. Suppliers had the highest participation in the survey and the highest knowledge and maturity level. Design studios performed worst, with lowest participation, implementation and knowledge level. No design studio was interested in collaborating with interviews, so these were performed only with shipyards and suppliers.

One possible explanation for the low implementation and knowledge is associated with the market characteristics. Some studies propose that this is a common trait in Small and Medium

Enterprises, which are neglected by most of the literature and should require special attention given their characteristics and economic importance (Müller et al., 2018). Findings corroborate the research that states that manufacturing SMEs in many cases do not have accurate, real-time and consistent information about their own shop-floor resources (Zhang, Lee, & Taylor, 2014). This makes it difficult for companies to evaluate their manufacturing performance (Shin, Woo, & Rachuri, 2014) and create a demand for Industry 4.0. Literature also confirms that usually SMEs are less prepared for Industry 4.0, having implemented less solutions and thus are in higher of becoming victims of the transformation (Sommer, 2015), (Vrchota, Volek, & Novotná, 2019). SMEs often lack resources to invest in research and development activities, have difficulties managing complex computer solutions and lack experts that are not devoted solely to the production process (Mittal et al., 2018), (Moeuf et al., 2018).

A preliminary financial analysis of shipyards has shown that their profitability is rising, and their debt rates are at historically low levels, which suggest they are potentially able to invest in Industry 4.0. In Italy, the government also has a program to financially support companies which invest in Industry 4.0. However, more often than not, there is not enough knowledge on the topic to understand the opportunities of the 4.0 transformation. Only 19% of the respondents have declared to know the concept of Industry 4.0.

In this context, the POLI-USP Learning factory is an initiative to provide teaching, research and R&D on Industry 4.0, stimulating companies to embrace the fourth industrial revolution. It is part of a modelled supply chain, which is composed of three integrated sites, and uses demonstrators to illustrate many possible applications of 4.0 technologies.

At the POLI-USP site, the focus of this work, a skateboard is assembled, and plastic parts are produced using 3D Printers in an ATO approach, also common in the shipyards of the Italian recreational boating sector. Among the seven groups of 4.0 technologies identified in the literature review, six are present in the factory. In all cases, the implementation and knowledge of companies in the Italian recreational boating sector were compared to the applications demonstrated in the factory, as well as the degree of importance given to the technologies in the research on Industry 4.0 in the maritime context. Possible new applications which could be applied for companies in a similar maturity state were proposed, showing that such initiatives may address the gap of knowledge that is possibly the most important obstacle to the implementation of Industry 4.0 in SMEs.

9.2 Contributions, limitations and future research

This work describes the situation of the Italian recreational boating sector with respect to Industry 4.0 and its related technologies through quantitative and qualitative approaches. Possible reasons that justify the current state were also proposed, which helps policy makers and business executives to understand the situation and thus take better informed action.

Some inherent limitations of each methodological steps were balanced by adopting a mixed methods approach. Still, survey results have to be confronted with other studies that rely on larger samples, since it is common to survey studies that the nature of the sample and perceptual nature of certain measures suggest that results are not necessarily generalizable. The survey's results can possibly be biased, for example, to show more mature results than the reality, since the companies which are less interested in the topic also tend to be less collaborative with the research. This can be also balanced by possible advanced companies which do not want to share information regarded as competitive advantages. In the semi-structured interviews, only one person for each company was talked, which tends to produce a single-informant bias. Future studies could try to understand companies in higher depth, comparing multiple perspectives to better understand the mechanisms that explain the knowledge and adoption levels.

One possible approach to increase knowledge of Industry 4.0, the Learning Factory, was studied in depth to understand how it could help companies in the sector to incorporate the 4.0 technologies. These results may be generalized to other sectors composed mainly by SMEs, which have found to be understudied in the literature of Industry 4.0.

Among the main limitations of this research is the fact that it studies in depth one sector and one Learning Factory. Future research should analyze both other sectors and other Learning Factories in order to understand the validity of these findings if Learning Factories are to be recommended as general approach to promote the 4.0 transformation. Another possible path is to study specific cases of companies which had contact with Learning Factories (e.g. as a controlled environment for R&D or by hiring students that were taught in this environment) and understand its impact in the degree of innovation.

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APPENDIX

APPENDIX A – Survey Questions

Q1: We kindly require some preliminary information:

a. Name and surname: __________________
b. E-mail: __________________
c. Company name: __________________
d. Role and functional area: __________________
e. Yearly 2018 revenues (million euro): __________________
f. Number of employees: __________________
g. For how long have you been working in this company? __________________
h. For how long have you been working in this sector? __________________

Q2: Your company is a…

a) Design studio
b) Shipyard
c) Supplier
d) Other (please specify): __________________

Q3: Do you know the Industry 4.0 topic?

a) I don't know
b) I read articles online
c) I have participated on external events on the topic
d) I am evaluating the possibility of doing something about the topic
e) I am implementing / have already implemented 4.0 solutions

Q4: How do you see the position of your company (in Italy) compared to the general situation of the recreational boating sector?

a) We are aligned to the best practices of our sector

b) We are advanced when compared to the developments in our sector
c) We are in delay when compared to the developments in our sector
d) I am not able to define our position

Q5: The main innovative technologies in Industry 4.0 include:

- *Internet of Things (IoT): connectivity, equipment of sensors in machines, logistical assets, RFId, NFC, M2M, Bluetooth low Energy etc.*
- *Big Data and Analytics: Predictive Analytics, Failure pattern recognition, Supply Chain Analytics (e.g. predictive maintenance) etc.*
- *Simulation: CFD, finite elements simulation, Digital Simulation etc.*
- *Cloud Computing and Cloud Manufacturing: Cloud Computing, Fog Computing, Cloud Manufacturing, Resources virtualizations, platforms and online software etc.*
- *Advanced Human-Machine Interface: Advanced Human-Machine Interface (HMI), Touch display, 3D Scanner, Augmented Reality, Electronical manuals etc.*
- *Advanced automation: Cyber-Physical systems, cognitive and collaborative robots, drones etc.*
- *Additive Manufacturing: Additive Manufacturing, 3D Printing, Rapid Prototyping.*

In which processes of your company (in Italy) are these enabling technologies used? Please select the application of a technology for each process (for every line, select one or more alternatives):

	Product development	Part manufacturing	Designer-Shipyard integration	Supplier-Shipyard integration	Boat manufacturing	Communication with boat during navigation	I don't know this technology	I know it but has no application
Internet of Things	☐	☐	☐	☐	☐	☐	☐	☐
Big Data and Analytics	☐	☐	☐	☐	☐	☐	☐	☐
Simulation	☐	☐	☐	☐	☐	☐	☐	☐
Cloud Computing and Manufacturing	☐	☐	☐	☐	☐	☐	☐	☐
Advanced HMI	☐	☐	☐	☐	☐	☐	☐	☐
Advanced Automation	☐	☐	☐	☐	☐	☐	☐	☐
Additive Manufacturing	☐	☐	☐	☐	☐	☐	☐	☐

Table 14: Representation of survey question 5. ***Source: Author's elaboration***

Q6: Are there Industry 4.0 projects in your company?

a) Yes
b) No
c) I don't know

Q7: What is the weight of the possible motivations for Industry 4.0 projects in your company?

	High	Medium	Low	Null
Inter-organizational imitative behavior	○	○	○	○
Supplier push	○	○	○	○
Category association and Access to other incentives	○	○	○	○
Request of customers	○	○	○	○
Incentives from the Piano Nazionale Impresa 4.0	○	○	○	○
Cost	○	○	○	○
Environmental sustainability	○	○	○	○
Brand and Company image	○	○	○	○
Flexibility	○	○	○	○
Time to Market	○	○	○	○
Customer Service	○	○	○	○
Quality	○	○	○	○
Product Innovation	○	○	○	○

Table 15: Representation of survey question 7. ***Source: Author's elaboration***

Q8: Who conducts the 4.0 transformation in your company? (Select at maximum two alternatives)

a) CEO (Chief Executive Officer)
b) CIO (Chief Information Officer or IT responsible)
c) COO (Chief Operations Officers or director of operations)
d) Production Director or responsible
e) A dedicated person (e.g. Chief Digital Officer, Industry 4.0 manager)
f) A dedicated team with people from different functional units
g) No particular person: initiatives are not coordinated in a centralized way
h) Other

Q9: What are the main obstacles in the implementation of 4.0 actions? (Select at most three alternatives)

a) Lack of interest
b) No obstacles found so far

c) Direction does not consider it important enough
d) Lack of economic resources
e) Missing technological competences
f) Missing appropriate information systems
g) Missing high speed internet
h) No dedicated person/team in charge of the topic
i) Lack of management skills for large projects (Project Management, Change management)
j) Missing consultants, universities and competence centers to support the transformation
k) Suppliers do not offer appropriate solutions

Q10: Which of the following alternatives best describe the suppliers of 4.0 technologies? (Select at least one alternative)

a) Offer appropriate solutions to our reality
b) Offer solutions that are too expensive
c) Offer solutions that are too complex
d) Offer solutions that are too innovative when compared to our starting point
e) Should help companies more in their transformation process
f) I don't know suppliers of 4.0 technologies
g) I don't know commercial 4.0 solutions

Q11: What is your knowledge level of the *Piano Nazionale Impresa 4.0*?

a) I don't know it
b) I read articles online about it
c) I read articles online about it and we are evaluating internally how to proceed
d) I read articles online about it and we are consulting external experts because we want to use it
e) We have already used it

Q12: Have you used the incentives on the *Piano Nazionale Impresa 4.0* to renew assets of your company (e.g. super-depreciation and hyper-depreciation)?

a) Yes
b) No, but we intend to do it
c) No and we do not intend to do it

Q13: How much have you invested using the super-depreciation and hyper-depreciation incentives?

a) Less than 50.000 euros
b) 50.000-100.000 euros
c) 100.000-300.000 euros
d) 300.000-500.000 euros
e) 1.000.000-3.000.000 euros
f) More than 3.000.000 euros

Q14: The investments that you have done using depreciation incentives…

a) Would have been done equally without the *Piano Nazionale Impresa 4.0*
b) Would have been done in the same period, but in lower value
c) Would have been done in a more distributed way over time, but in same value
d) Would have been done in lower value and more distributed over time
e) Would not have been done without the *Piano Nazionale Impresa 4.0*
f) I don't know

Q15: With respect to the tax credit incentives for 4.0 training…

a) We have used it
b) We have decided not to use it
c) We are evaluating, but have not yet decided what to do
d) I don't know this type of incentive

Q16: Why are you still not sure about using the tax cred incentives for 4.0, or have decided not to use it?

a) Missing of implementing decree
b) Difficulties in agreeing on collective training contracts

c) High bureaucracy costs
d) Not aligned with the company's needs
e) Not interested in investing in training/education
f) The covered incentive areas are not interesting
g) Company's financial situation
h) Other

Q17: In which technologies (lines) and areas (columns) listed in the tax credit incentives have you performed training?

	Production techniques and technologies	Sales and Marketing	Informatics
Internet of Things (IoT) and of Machines	☐	☐	☐
Big Data and Analytics	☐	☐	☐
Cloud/Fog Computing	☐	☐	☐
Virtual/Augmented Reality	☐	☐	☐
Advanced and Collaborative robotics	☐	☐	☐
Additive Manufacturing	☐	☐	☐
Simulation and Cyber-Physical Systems	☐	☐	☐
Human-Machine Interface	☒	☐	☐
Rapid Prototyping	☐	☐	☐
Cyber-Security	☐	☐	☐

Table 16: Representation of survey question 16. ***Source: Author's elaboration***

Q18: How did you come to know the tax credit incentives for 4.0 training? (Select at most three alternatives)

a) Government
b) Media
c) Academical Partnerships
d) Tax advisor
e) Word of mouth
f) Digital Innovation Hub/Category Association

g) Chamber of commerce
h) Labor union
i) Consultancy and Training companies
j) Suppliers
k) Others

Q19: How is the functional department "Human Resources" involved in the development and implementation of the 4.0 strategy?

a) Company has no HR
b) No participation
c) Full and active involvement
d) Participation on the projects related to HR
e) Based on single requests for specific actions
f) Other

Q20: Has the company evaluated or does it plan to identify the necessary competences for Industry 4.0?

a) Yes, the evaluation has been concluded
b) Yes, the evaluation is in progress
c) No, but it will be done
d) No and it will not be done

Q21: What are the main reasons for not evaluating the 4.0 competences in your company?

a) Other competences have higher priority
b) Company has never thought about it
c) Insufficient Industry 4.0 knowledge
d) Company will not have Industry 4.0 projects
e) We already have all the competences
f) Other (specify): ________________________

Q22: In which hierarchical levels (rows) and areas (column) the company has evaluated or plans to evaluate the 4.0 competences?

	Production	Maintenance	Supply Chain	Design and Engineering	Sales and Marketing	IT	Human Resources
Manager and Project Leader	☐	☐	☐	☐	☐	☐	☐
Entrepreneur and Top Management	☐	☐	☐	☐	☐	☐	☐
Operational workers and technicians	☐	☐	☐	☐	☐	☐	☐

Table 17: Representation of survey question 22. ***Source: Author's elaboration***

Q23: Has the company developed a formal plan for developing 4.0 competences?

a) Yes
b) No
c) I don't know

Q24: How much do you plan to spend in training on 4.0 competences?

a) I don't know
b) Nothing
c) 0-10.000 euros
d) 10.000-50.000 euros
e) 50.000-100.000 euros
f) 100.000-300.000 euros
g) More than 300.000 euros

Q25: What is the importance level of each of those competences in your company?

	Very high	High	Medium	Low	Null
Lean Manufacturing application for Industry 4.0	○	○	○	○	○
Organization, work and Human-Machine Relationship in Industry 4.0	○	○	○	○	○
Big Data Management and Analytics	○	○	○	○	○
Digital Supply Chain Management	○	○	○	○	○
Cyber-security	○	○	○	○	○
Implementation of Digital Architecture for Industry 4.0	○	○	○	○	○
Strategy and Business Model innovation for Industry 4.0	○	○	○	○	○
Predictive Maintenance	○	○	○	○	○
Process/Product Simulation	○	○	○	○	○
Product-service integrated design	○	○	○	○	○

Table 18: Representation of survey question 25. ***Source: Author's elaboration***

Q26: For each competence, is the current level of development in the company sufficient?

	Yes	No, but it is implementing training programs	No, but it will do training in the next 18 months	No, but it will hire/collaborate with other institutions in the next 18 months	No and nothing will be done in the next 18 months	Not enough knowledge to answer
Lean Manufacturing application for Industry 4.0	○	○	○	○	○	○
Organization, work and Human-Machine Relationship in Industry 4.0	○	○	○	○	○	○
Big Data Management and Analytics	○	○	○	○	○	○
Digital Supply Chain Management	○	○	○	○	○	○
Cyber-security	○	○	○	○	○	○
Implementation of Digital Architecture for Industry 4.0	○	○	○	○	○	○
Strategy and Business Model innovation for Industry 4.0	○	○	○	○	○	○
Predictive Maintenance	○	○	○	○	○	○
Process/Product Simulation	○	○	○	○	○	○
Product-service integrated design	○	○	○	○	○	○

Table 19: Representation of survey question 26. ***Source: Author's elaboration***

Q27: Do you know which entity should be contacted to take advantage of the tax credits for training?

a) Yes
b) No

Q28: How do you intend to provide training for the Industry 4.0 competences?

a) External courses
b) Internal courses
c) Activities other than courses
d) No intention of training

Q29: For the externally managed courses, which entities do you plan to collaborate with? (Select at most three alternatives)

a) Digital Innovation Hub, entrepreneurial associations and category associations
b) Universities
c) Suppliers
d) Public and Private Educational Institutions
e) Chamber of Commerce
f) Public organisms for training
g) Labor unions
h) Other institutions (specify): ____________________

Q30: Has your company adopted innovative training approaches supported by digital technologies (e.g. e-learning, mobile learning, serious games, virtual and augmented reality)?

a) Yes (specify): ____________________
b) No, but plans to do it
c) No and does not plan to do it
d) Does not know

Q31: Has your company developed a plan to select and hire new personnel for acquiring the necessary 4.0 competences?

a) Yes
b) No
c) I don’t know

Q32: Which channels are you using to find new personnel to acquire the necessary 4.0 competences?

a) Relationship with Schools and Universities
b) Web advertisement
c) Word of Mouth
d) Labor agencies

e) Headhunting Companies
f) Other (specify): ___________________

Q33: Would you be available to further contribute with the research in a short phone interview?

a) Yes
b) No

If yes, please leave a phone number to be contacted: ______________________

APPENDIX B – Survey Structure Flowchart

Each number in the flowchart represents the question with the same index. Mandatory questions for all respondents are marked in blue, while questions that may or may not be answered depending on the path have a white background. Black arrows show a mandatory path, while grey arrows have a condition to be followed: each answer is followed either by one black arrow or by two or more grey arrows. In the first case, all respondents must follow it, while in the latter, the decision of which path to take is made according to the condition labeling the arrow.

Question were associated with groups, which correspond to sections of the survey:

- **Grey**: contains Questions 1 and 2, which correspond to general information about the companies and respondents, such as revenues, type of respondent and type of company;
- **Blue:** contains questions 3 to 10, and is about Industry 4.0 knowledge, technologies, objectives in the adoption and difficulties;
- **Black:** question 11, about knowledge of the Italian National Industry 4.0 plan (PNI 4.0). It is a very important question to determine how many questions the respondent will be presented, since one who replies "I don't know" will skip to question 19.
- **Yellow**: questions 12-14 about the depreciation incentives inside the PNI 4.0;
- **Red:** questions 15-18 about tax credits for training of the PNI 4.0;
- **Green:** questions 19-32 about competences, human resources and new personnel;
- **Question 33:** a question which aims to know the availability and interest in participating in the semi-structured interviews.

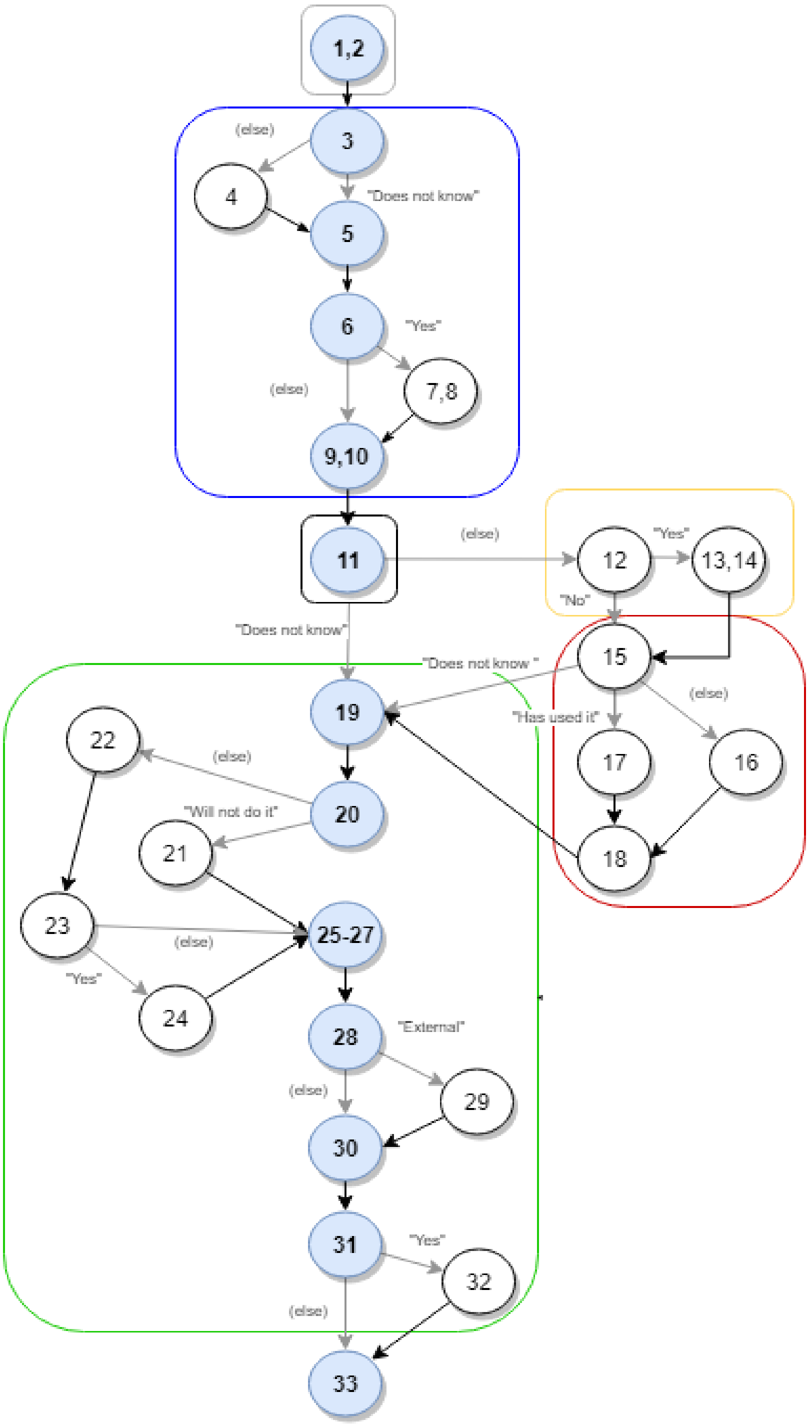

Figure 47: Survey structure flowchart. ***Source: Author's elaboration***

APPENDIX C – Case Studies' Questions

Group A

Group A ("Has implemented or is implementing")	
Objective	**Possible questions**
Company Introduction	Company's core activities; in which levels the company is structured and where are the main production and design locations; competitive advantage;
Introduction on 4.0 projects	Brief description of the 4.0 projects that were implemented or are being implemented (e.g. in which processes and areas, in which phase of the lifecycle they are); objectives of the 4.0 projects when compared to the strategy; have these projects been included in a long-term plan? If yes, which departments and hierarchical levels were involved and are responsible for it? Has the PNI 4.0 been used? Why?
4.0 Technologies	Which of the 4.0 technologies were introduced or are being introduced in the previously indicated processes?
Obstacles and difficulties	Which difficulties have been found in the design and execution phases of the project? What has been done to face these obstacles?
Organization and competences	Was it necessary to change the organizational structure and the coordination mechanisms to develop 4.0 projects? If yes, which? Which competences (internal and external) were necessary for these projects during and after implementation?
New personnel	Do you plan to, or have you already hired new personnel for the development of the 4.0 projects? If yes, for which positions and for which competences were they hired?
Collaboration	Have you collaborated with other supply chain stakeholders (e.g. clients, suppliers, OEM, influencers, category associations, consultants) to develop the 4.0 projects? If not, why? If yes, with who, which are the most important collaborations and why?
Feasibility analysis	For the previously mentioned project, has any feasibility analysis been performed? If yes, which? Have you identified any indicators (e.g. ROI)? If yes, which?
Benefits	Was it possible to identify improvements and benefits from the 4.0 project? Did you estimate the objectives to be achieved (qualitative and quantitative)? How do they compare to the achieved results?

Table 20: Group A questions. ***Source: Author's elaboration***

Group B

Group B ("Evaluating")	
Objective	**Possible questions**
Company Introduction	Company's core activities; in which levels the company is structured and where are the main production and design locations; competitive advantage;
Introduction on 4.0 projects	Brief description of the 4.0 projects that are being evaluated (e.g. in which processes and areas, in which phase of the lifecycle they are); objectives of the 4.0 projects when compared to the strategy; will these projects be included in a long-term plan? If yes, which departments and hierarchical levels will be involved and responsible for it? Are there intentions of using the PNI 4.0? Why?
4.0 Technologies	Which of the 4.0 technologies will be introduced in the previously indicated processes and projects?
Obstacles and difficulties	Which difficulties have been found in the design phase of the project? What is being or has been done to face these obstacles?
Organization and competences	Have you identified possible changes in the organizational structure and the coordination mechanisms that will be necessary to develop 4.0 projects? If yes, which? Which competences (internal and external) will be necessary for these projects during and after design and implementation?
New personnel	Do you plan to, or have you already hired new personnel for the development of the 4.0 projects? If yes, for which positions and for which competences will they be hired?
Collaboration	Do you intend to collaborate with other supply chain stakeholders (e.g. clients, suppliers, OEM, influencers, category associations, consultants) to develop the 4.0 projects? If not, why? If yes, with who, which will be the most important collaborations and why?
Feasibility analysis	For the previously mentioned project, has any feasibility analysis been performed? If yes, which? If no, will it be done? Have you identified any indicators (e.g. ROI)? If yes, which?
Benefits	Have you identified potential improvements and benefits from the 4.0 project(s) you are evaluating? Did you estimate the objectives to be achieved (qualitative and quantitative)?

Table 21: Group B questions. ***Source: Author's elaboration***

Group C

Group C ("No implementation of 4.0 solutions")	
Objective	**Possible questions**
Company Introduction	Company's core activities; in which levels the company is structured and where are the main production and design locations; competitive advantage;
Introduction on 4.0 projects	Which are the main opportunities of the 4.0 transformation for the company?
4.0 Technologies	Which of the 4.0 technologies could be introduced in your company? Why?
Obstacles and difficulties	What are the main reasons why you have not implemented or intend not to implement 4.0 solutions?
Organization and competences	Could the fact that you are not evaluating the possibilities of developing Industry 4.0 projects be related to the lack of competences or the need to perform structural changes in the company? If yes, which and how do you plan to proceed?
New personnel	Do you think it would be necessary to hire new personnel for possible Industry 4.0 projects
Collaboration	Could a possible collaboration with other supply chain stakeholders (e.g. clients, suppliers, OEM, influencers, category associations, consultants) enable the company to evaluate 4.0 projects? If not, why? If yes, with who, which will be the most important collaborations and why?
Feasibility analysis	In the evaluation of innovative projects, do you usually perform a feasibility analysis? If yes, would this procedure be valid in a Industry 4.0 project? If not, how would it have to be adapted? Would also the indicators (if present) need to be adapted?
Benefits	Do you think of evaluating Industry 4.0 projects to obtain possible improvement and benefits in the next 12 months? Which benefits could be the most important?

Table 22: Group C questions. ***Source: Author's elaboration***