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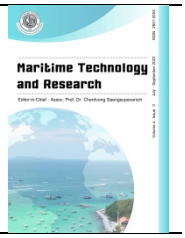

Research Article

The port of Gothenburg under the influence of the fourth stage of the industrial revolution: Implementing a wide portfolio of digital tools to optimize the conduct of operations

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Abstract

Taking advantage of the benefits associated with the fourth stage of the industrial revolution- quite often termed as the "era of digitalization" in the wider literature- has become a main priority for ports globally, as part of their further development. The implications of smart technologies on the sustainable development of these ports have not been adequately addressed by the existing literature, and it is exactly this gap that this study aims to fill. This paper aims to provide an overview of the innovative technologies adopted by a small number of smart ports around the world and highlight their links to sustainable development by employing an exploratory review of various sources. The design features of the smart ports identified by the existing literature have formed the basis for the development of a conceptual framework used in this paper for the analysis of the case of the Port of Gothenburg- the largest Scandinavian port, both in terms of number of visits and volume of cargo handled. The specific port is currently expanding its digital transformation by launching a platform during the second half of 2021 that will link digitally and coordinate the operations of all relevant stakeholders- shipping companies, freight forwarders, rail operators- in the port area. From the analysis, it becomes clear that the implementation of a wide portfolio of digital initiatives by the port under discussion has already resulted in the optimization of its operations and is strongly interrelated to its sustainable development. Important issues to be addressed in the near future that are identified by this research effort include necessary cultural adaptation and training activities to ensure the correct exploitation of these tools by the whole pool of the workforce.

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1. Introduction

The role of ports in global trade is essential, handling around 80 % of goods transferred all over the world, with rising demands on operational efficiency and productivity and, at the same time, sustainable development, to contribute to the goals of the United Nations 2030 Agenda for Sustainable Development. The challenge of conciliating these increasing demands is expected to rise in the years to come, given the predicted growth of container handling globally, and the diversified nature of global trade, with larger vessels and quicker transfers of goods along the supply chain (Johansson et al., 2021). A solution to these challenges can be provided by leveraging the benefits of digitalization in ports and the integration of innovative (digital) technologies. Given the increased digitalization of supply chains globally, ports need to preserve their role as "nodes" within these chains by transforming into "digital nodes". Furthermore, the fact that the shipping industry is constantly relying on timely and accurate data to feed its logistical plan should also be taken into account (Martjin et al., 2015). Both the wider maritime sector and ports are exploring paths to process the enormous volumes of data produced from a very extended pool of relevant sources (e.g., systems supporting the conduct of navigation and/or ship's machinery, marine fleet management systems, cargo handling management systems and related transactions, log books, etc.), and on a daily basis. The domain of "Big Data Analytics" examines large amounts of data to uncover hidden patterns, correlations, and other insights (i.e., market trends and customer preferences) that can help organizations make informed business decisions. It can be categorized as a special branch of the wider information technology (IT) domain, and its main aim is to discover correlations and interactions between different measurable or non-measurable parameters, in order to identify non-clearly defined standards and patterns (Goyal et al., 2020).

The port industry, because of its complex nature- which involves an extended number of actors/stakeholders- is often slower than others when it comes to adopting emergent technologies to expedite the shipping process. In this paper, the term "Smart Port" describes a port that uses automation and a certain number of nascent technologies with the aim to improve its overall performance. Indicative examples in this category include Artificial Intelligence (AI), Big Data (Analytics), Cloud Computing, and the Internet of Things (IoT), as well as Blockchain architecture to facilitate transactions (Dalaklis et al., 2020). Furthermore, under the term "autonomous vehicles and robotics" (hereafter, robotics), we refer to the use of a wide portfolio of advanced technology applications, not only within shipyards and ports, but also at sea or inland waterways, to serve very "niche" transport service needs (Johansson et al., 2021). On the other hand, although the port and shipping industries are often regarded as conservative and "resistant to change", many proactive and progressing ports around the world are already using certain very innovative technologies with very clear economic, operational, and environmental benefits and should, therefore, already be characterized as smart ports. Of course, there is always room for improvement. Following the example of other industrial sectors, the digitalization of port processes could lead to increased efficiency and productivity and a better management of resources, as it will enable the cooperation of all relevant stakeholders- i.e., shipping companies, freight forwarders, rail operators, etc.- in the port area (Acciaro et al., 2020). It is also useful to note that, according to Yang et al. (2018), the "cornerstone" of digitalization is the IoT, by considering that it enables the gathering of information from all industrial assets and, in this sense, smart ports are based on the IoT concept, as this technology offers the basis for bringing together all port stakeholders and operations that is a prerequisite for harmonized and optimized port activities.

This paper aims to provide an overview of the innovative technologies adopted by a small number of smart ports around the world and highlight their links to sustainable development by employing an exploratory review of various sources. The basic assumption lies in the fact that these new and innovative tools can help ports to improve their business model and, at the same time, contribute to the wider issue of sustainability. It is not a coincidence that the vast majority of smart ports identified in this study have also been proactive in the adoption of sustainability initiatives.

However, the implications of smart technologies on the sustainable development of ports have not been adequately addressed by the existing literature, and it is exactly this gap that this study aims to fill. The design features of the smart ports identified by the existing literature have formed the basis for the development of the conceptual framework used in this paper for the analysis of the case of the Port of Gothenburg- the largest Scandinavian port, both in terms of number of visits and volume of cargo handled. This port is currently expanding its digital transformation by launching an IT platform during the second half of 2021 that will link digitally and coordinate the operations of all relevant stakeholders within the port area (Christodoulou et al., 2021). The reason behind selecting this port is quite simple: this municipally-owned port is the largest one in all the Nordic countries, with over 11,000 ship visits per year from over 140 destinations worldwide. As the only Swedish port with the capacity to cope with the very large modern, ocean-going container ships, Gothenburg handles nearly 30 % of the country's foreign trade, comprising 39 million tons of freight per year (Port of Gothenburg, 2021). In any case, under the self-explanatory notion that the introduction of new technology applications is undoubtedly a catalyst of change, this paper is structured as follows: after this brief Introduction, Section 2 explains the notion of digitalization and the "fourth stage of the industrial revolution" (4IR), while Section 3 describes the related methodology of the current research effort. An overview of smart port solutions implemented around the globe is presented in Section 4, and the implications from the integration of smart technologies on the sustainable development of ports are analyzed in Section 5. The case of the Port of Gothenburg is examined in Section 6, by focusing on the applications and technologies implemented both at the Container Terminal and the Energy related sector of the port. Finally, discussions and conclusions drawn from our results are presented in Section 7.

2. Literature review

History clearly testifies that there is a dialectic relationship between humans and technology. It is indicative that, under the influence of the various stages of the "Industrial Revolution" (IR), the shipping industry has already benefitted via three main ways: (a) the introduction of steam power on merchant ships (mechanization); (b) an enlarged volume of goods to be traded and demand for raw materials, because of the increased factory production/output; and (c) certain metallurgical innovations that also improved shipbuilding techniques significantly (Duru, 2010). In retrospect, the first stage of the industrial revolution involved a change from agrarian societies to greater industrialization, as a result of the steam engine and other technological developments. The second technological stage (or second industrial revolution) was driven by electricity and involved very significant expansion of industrial production because of the introduction of the assembly line concept, as well as an extended number of related technological advances (spanning over the 18th and 19th centuries, with a spillover to the early 20th century). Subsequently, the third stage of the industrial revolution, sometimes referred to as the digital revolution, involved the development of computers and information technology (IT) (including the creation of the Internet) during the second half of the 20th century (Sanchez-Gonzalez et al., 2019).

Finally, the current fourth stage of the industrial revolution is considered as a "new era", rather than as a continuation of the third stage, because of fast and rapid developments and the disruptiveness of associated technologies. In other words, the term "fourth industrial revolution" describes the current and foreseeable environment in which disruptive technologies and trends are all changing the way humans live and work (World Maritime University, 2019). Indicative examples are Cloud Computing and the Internet of Things (IoT), Artificial Intelligence (AI) and Big Data Analytics, Robotics, Virtual and Augmented Reality (VR/AR), and/or Simulation applications. It is not a coincidence that terms like "age of boundless connectivity" and "intelligent automation" are often used to describe our future world. For example, a report under the title "Transport 2040: Automation, Technology, Employment - The Future of Work", which was quite recently launched by the World Maritime University (WMU), puts forward the notion of Dalaklis (2018):

"Technological progress and innovation have occurred throughout history and changed its course, for example the Industrial Revolution in the eighteenth and nineteenth centuries. Currently, we are about to embrace what is now termed the Fourth Industrial Revolution, which is characterized by the introduction of artificial intelligence, robotics, more and more interconnection, among other innovations". The contemporary world is very well interconnected through global trade; this, in turn, creates the need for the wider transportation industry striving to be more and more efficient. In any case, significant changes are becoming apparent in ports (as well as in the wider framework of port activities, to the extent that ports provide various services to very automated vessels equipped with numerous advanced technology applications). It is, therefore, argued that both the shipping and the port industries are under the influence of the so-called digitalization phenomenon (Sanchez-Gonzalez et al., 2019; World Maritime University, 2019; Dalaklis, 2018; Dalaklis et al., 2019). A summary of all the above developments is presented in **Figure 1**.

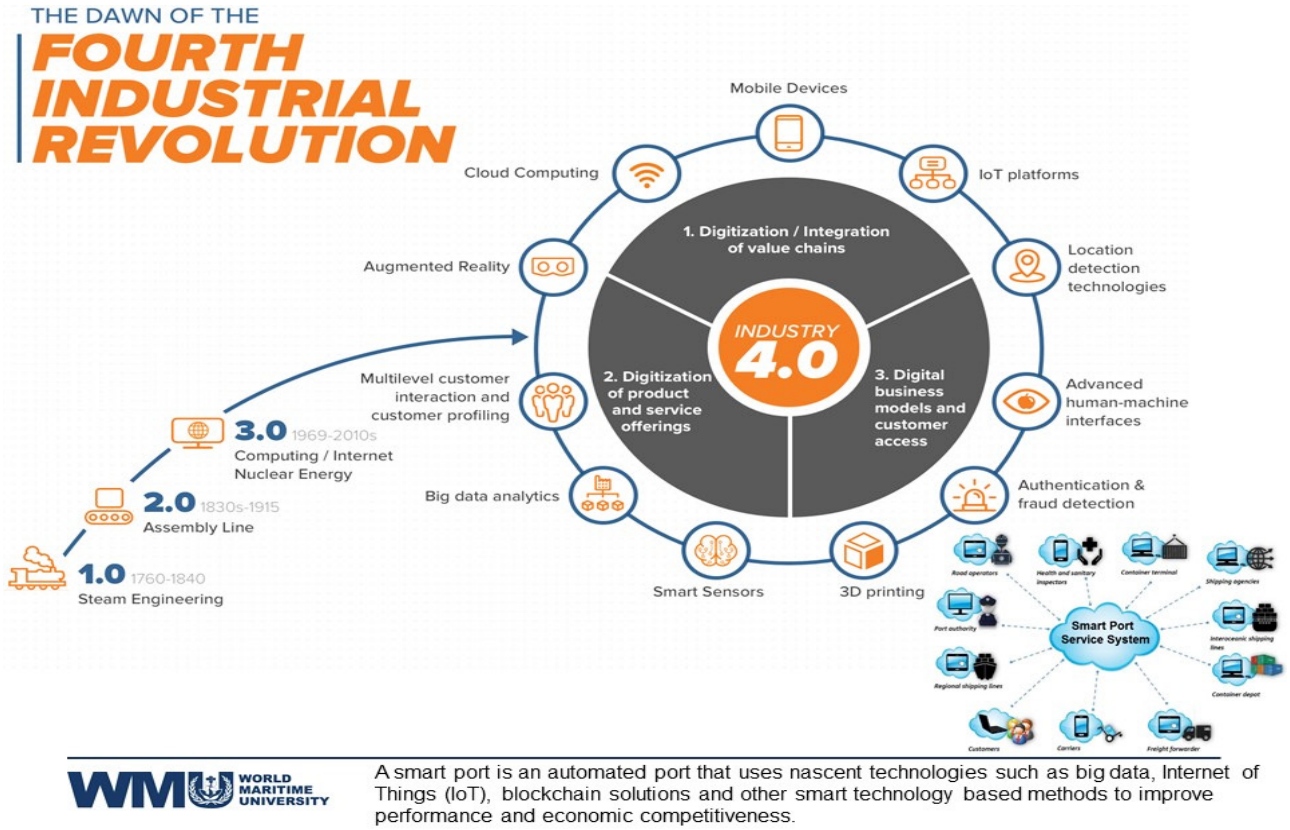

Figure 1 Stages of the Industrial Revolution and Technology Applications related to "Digitalization" (Dalaklis et al., 2019).

Nowadays, competition in the port sector is heavily related to the issues of port connectivity and automation, by considering that digitalization is clearly picking up pace. Digitalization and digital transformation, also designated as "industry 4.0", are more than just innovative technologies. They involve the creation of new business models, using and analyzing data in a scientific manner to optimize decision making and improving the relationships with customers on the basis of the analysis' results. Because all the previously mentioned terms are often used interchangeably in the wider literature, before moving to the next section, it is necessary to establish a clear framework of the definitions that will be used in this paper. The first term under discussion is "digital data", most commonly referred to as data. It is a self-explanatory fact that this term has a ubiquitous influence

in the contemporary information-intensive age; vast quantities of data are created every second, if not every micro-second (Duru, 2010). The dynamic benefits of data-acquisition and subsequent usage has led end-users to the general understanding that data has an unfeigned nexus with decision-making processes, especially ones that concern business-as-usual. Over the years, the term data has found itself being defined in myriad ways. It is further observed that each individual definition of data can be characterized as being "discipline oriented". Whether in natural science, economy, or law, scholars have put forth respective definitions from the prism, and to this extent, the term data has interacted with the subject matter of respective disciplines (Johansson et al., 2021; Zins, 2021). The quintessential definition of data, however, is found in the common lexicon, i.e., Cambridge English Dictionary (CED) (Cambridge English Dictionary, 2021): "information, especially facts or numbers, collected to be examined and considered and used to help decision-making, or information in an electronic form that can be stored and used by a computer".

Additionally, it is necessary to highlight that "digitalization" is often misinterpreted and misapplied to "digitization". Despite the fact that these two terms are highly specialized and fundamentally different, they are often indistinguishably used, broadly defined, and inconsistently applied (Sanchez-Gonzalez et al., 2019; Medium, 2021). Several definitions of digitalization have been proposed. From an academic perspective, science and technology scholars like Brennen and Kriess define digitalization through digital communication and digital media's impact on contemporary social life (Culturedigitally, 2021). The Oxford English Dictionary (OED) traces the first uses of the terms "digitization" and "digitalization" in conjunction with computers to the mid-1950s (Cambridge English Dictionary, 2021). In the OED, digitization refers to "the action or process of digitizing; the conversion of analogue data (esp. in later use images, video, and text) into digital form." Digitalization, by contrast, refers to "the adoption or increase in use of digital or computer technology by an organization, industry, country, etc." By embracing this distinction, in this paper, we will approach and define digitization as the material process of converting individual analogue streams of information into digital bits. On the other hand, we will approach digitalization as "the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business" (Gartner, 2021). To sum up, digitization refers to the internal optimization of processes (e.g., work automation, paper minimization) and results in cost reductions. Conversely, digitalization is a strategy or process that goes beyond the implementation of technology to imply a deeper, core change to the entire business model and the evolution of work. Although digitalization is also used as an umbrella term to describe digital transformation, these terms are again very different. Digital transformation requires a much broader adoption of digital technology and cultural change. Digital transformation is more about people than it is about the adoption/exploitation of digital technology. It requires organizational changes that are customer-centric, backed by leadership, and driven by radical challenges to corporate culture and the leveraging of technologies that empower and enable employees (Culturedigitally, 2021; Gartner, 2021).

3. Materials and methods

During the last few years, numerous disruptive technologies that relate to the wider information and communications technology (ICT) domain (hereafter, the terms IT and ICT are used interchangeably) have been successfully applied within the port logistics field, as a result of the influence of the Fourth Industrial Revolution; the strongest indicative example of the benefits of this on-going trend of interconnection is clearly represented by the IoT concept. In line with the above, numerous stakeholders are developing and introducing smart port applications in the port industry. However, few studies have thoroughly investigated the economic impact of this trend. The port industry is still dominated by the forward linkage effect, which translates into the fact that the port is viewed as just an intermediary item or process connecting other industries. In any case, within the wider framework of the port industry, a "smart port" can have a very positive impact on

issues like overall productivity, value added and, last but not least, opening up new opportunities of employment. The main purpose of this paper is to identify the benefits of seaport operations associated with the use of a certain number of smart port applications, as well as to highlight the prospects opening by this transition into a new era, characterized by innovation. A very important conclusion that already stands out is that the exploitation of all these new technology applications goes hand by hand with certain technical and cultural challenges that must first be fully overcome in order to achieve a smooth upgrade of port operations, and then enjoy all related benefits in terms of effectiveness and boosting profits. In the first place, an exploratory review has been conducted in this paper, aiming at the provision of an overview of various innovative technologies adopted by a small number of smart ports around the world, and linking these technologies to sustainable development initiatives. This exploratory review involved an extensive survey of various sources, such as port authority websites and annual reports, as well as the academic literature, in order to give insight into the interrelation of the identified digitalization and sustainability initiatives.

Following this exploratory review, a conceptual framework was built for the analysis of the digital transformation of the Port of Gothenburg. As suggested by Yau et al. (2020), ports have significantly evolved over the years, with the fifth generation of ports encompassing "customer and community-centric smart ports" that are distinguished by five main features: (a) smart applications related to vessel and container management; (b) smart technologies, including automation, data center(s), networking, and communication; (c) sustainable technologies related to increased energy efficiency and reduced greenhouse gases emissions; and (d) development of hub infrastructures to foster collaboration among different ports. In Bessid et al. (2020), there were also identified certain design features of smart ports that include an Intelligent Information System that would enable better planning and management within ports and between them, as well as smart port logistics and, more specifically, intelligent traffic flow and smart port infrastructure. Taking into account both these approaches for the establishment of smart ports, the conceptual framework for the analysis of the case of the Port of Gothenburg was developed. The overall concept is shown in **Figure 2**; collection of the relevant data took place during the first half of the year 2021, and this paper is an expanded version of certain preliminary research results that have been presented by roughly the same authoring team in the International Maritime Transport & Logistics Conference (MARLOG 10), examining the topic "Digitalization in Ports & Maritime Industry" during June 2021 (Christodoulou et al., 2021).

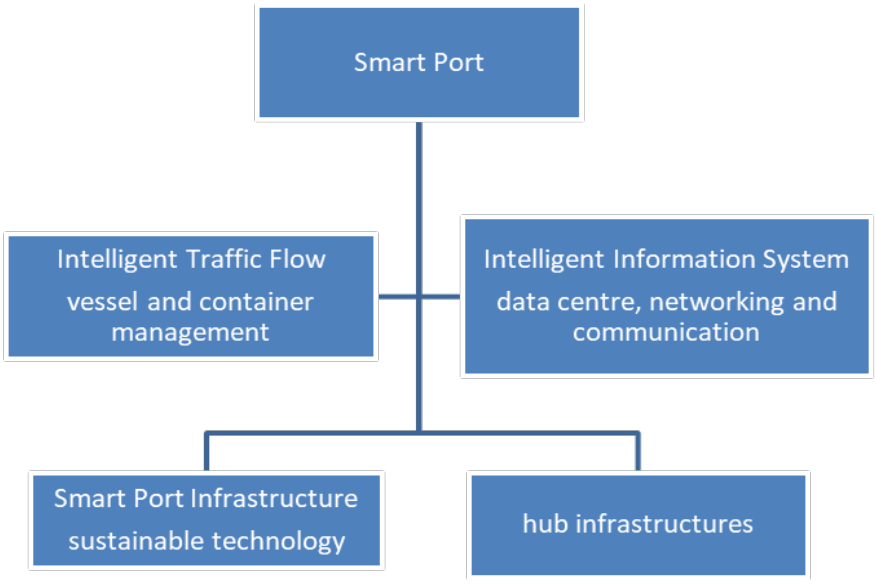

Figure 2 Conceptual framework. Adapted from Yau et al. (2020); Bessid et al. (2020).

4. Discussion of findings

4.1 Digital transformation of ports around the world

Today, the digital transformation of logistics no longer only entails technological changes, energy efficiency, or upgraded IT structures for specific logistic processes, e.g., for shipment tracking or related security, maintenance, and repair processes. Rather, it calls entire value chains into question. However, the introduction of automation in global transport will, most probably, be evolutionary, rather than revolutionary. While it affects mainly medium- and low-skilled groups, technological change is also impacted by various local factors (World Maritime University, 2019). Since Swedish society is already accustomed to the use of various advanced IT applications, the decision of the port of Gothenburg to intensify its digitalization efforts is not expected to meet obstacles at the wider society level. However, the skills and qualifications of related port workers are crucial towards success. Despite high levels of automation, qualified human resources with the right skill sets will still be needed in the foreseeable future. Steering the discussion towards the "new norm" and, although there is no single definition of smart ports, there are certain features that these ports share. As already highlighted, smart ports make use of innovative digital technologies including IoT, AI, big data, and blockchain to improve their performance and competitiveness, with data analytics also supporting the relevant decision-making processes. In smart ports, real-time information is shared among all port stakeholders, enabling effective communication and collaboration among the whole port ecosystem and ensuring seamless port operations, with benefits going beyond the port limits and with a positive impact upon the whole supply chain.

The sharing and data analysis of this real-time information at ports is enabled through several innovating technologies, including Christodoulou et al. (2021): a) **Big Data**: Truly vast quantities of data- which are often described as "Big Data" in the wider literature- are created, and the issue of how to effectively manage all the associated information clearly stands out (Johansson et al., 2019). With access to large datasets and predictive analysis, the shipping industry will be able to improve its logistics performance, by properly tracking cargo and preventing delays, and enhance the operational efficiency of the industry; b) **AI**: This can be used to optimize shipping routes and determine the best course/speed for each voyage (Dalaklis, 2020) and other similar optimization tasks; c) **IoT**: This concept will enable the reduction of operating costs, real-time tracking, and the monitoring of cargo, among others. IoT connectivity in ports will also provide data insights, and can pave the way to fully informed and data-driven decisions; d) **Blockchain Technology**: The shipping industry could benefit from this IT architecture through faster/more efficient services and improved data visibility, as the paper trail of millions of containers around the world could be managed/tracked, with numerous benefits ranging from cost reductions to customer satisfaction; e) **5G**: The efficient connection of all stakeholders involved in the supply chain would be enabled from data being transferred in a literally real-time manner, which this specific technology can offer.

It has already been mentioned that various ports around the world have already implemented, or are considering implementing, smart innovative technologies to maintain a competitive advantage, enhance their productivity and competitiveness, and correspond better to their customers' needs. Different ports are in different phases of digital transformation, with most of them focusing on the real-time information sharing and connectivity of port stakeholders (Jović et al., 2019). Examples of smart port initiatives can be found in different parts of the world- from Europe to Asia, Australia and North America (Yang et al., 2018), with European ports looking to be the ones leading the way to digitalization. This can be explained by their location in relation to the port-cities, as many of them are inner-city ports that suffer from congestion, and also by the highly competitive environment in which they operate and their need to offer a differentiated service to attract new customers and maintain the ones they already have. To capture the overall picture, **Table 1** below, summarizes a certain number of technology solutions and tools implemented by selected smart ports around the world (with the vast majority of them located in Europe) that were

identified via our brief exploratory review. The whole idea is not to provide a detailed or thorough list, but just an initial "orientation" of issues related to the main research topic.

Table 1 Technologies implemented by "smarts ports" around the world.

Port Authorities	Type of Technology
Port of Amsterdam (Netherlands)	- Intermodal Planner, a digital platform between transport operators and container terminals
Port of Antwerp (Belgium)	- Blockchain technology that enables a secure transfer of transaction rights to be exchanged between often competing parties - Central Booking Platform for transport customers
Port of Auckland (New Zealand)	- Vehicle Booking System that allows trucks to book slots in advance for picking up and dropping off containers; this encourages off-peak truck travel and contributes to travel predictability
Port of Botany (Australia)	- Terminal Appointment system, a digital platform for appointments between truck drivers and terminal operator - Trailer parking slots in order to prevent early or late arrivals at the gate
Port of Brisbane (Australia)	- Vehicle Booking System, an appointment system used by truck drivers (to deliver/collect containers), encouraging off-peak truck travel and improving travel predictability
Port of Felixstowe (UK)	- PARIS-HPH is a digital transport plan that targets the reduction of the number of empty containers being transported - RHIDES is an identity card for haulers at the port entrance
Port of Halifax (Canada)	- Using blockchain technology to increase supply chain security
Port of Hamburg (Germany)	- Sensors, cameras, and smart lights on roads that help monitor/optimize traffic and effectively contribute to reducing related emissions - 5G networks that enable virtual reality to be deployed for vital infrastructure monitoring purposes.
Port of Livorno (Italy)	- 5G networks and IoT solutions are optimizing logistic loading/unloading operations, at the same time minimizing idle times for ships and the transit times of goods
Port of Los Angeles (USA)	- Port Optimizer, an information portal designed to digitize maritime shipping data for cargo owners and supply chain stakeholders through secure, channeled access
Port of Qingdao (China)	- 5G connection supports control data for a programmable logic controller (PLC). These operations require millisecond-level latency control signals, as well as stable, remote, and real-time control requirements, which only key 5G technologies can deliver
Port of Rotterdam (Netherlands)	- IoT sensors used along a "digital twin"' to enable augmented intelligence through a simulation of the port's physical features, with multiple variables changed and tested quickly/effectively

Port Authorities	Type of Technology
	- A digital platform that enables the reduction of vessels' waiting times by up to 20 %, with autonomous, unmanned gantry cranes handling cargos efficiently and quickly.
Port of Seville (Spain)	- A "FIWARE Platform" that deploys IoT services for container tracking and manages railway traffic
Port of Valencia (Spain)	- A smart IoT network of cranes, straddle carriers, trucks, and forklifts that gather data on location, status of operations, and energy consumption
Port of Vancouver (Canada)	- A unique truck-tracing algorithm developed to reduce port bottlenecks, greatly improve turnaround times, and decrease emissions related to cargo operations

Besides all the above-listed innovative technologies adopted by individual ports, an international partnership, under the term ChainPORT, has also been established, initiated by the ports of Hamburg and Los Angeles, and joined by the ports of Antwerp, Barcelona, Busan, Felixstowe, Indonesia, Montreal, Panama, Rotterdam, Shanghai, Shenzhen, and Singapore. The main aim of this partnership is the sharing of knowledge and cooperation for the optimal application and investment on smart technologies at ports. In any case, despite these ongoing digital solutions implemented from the interested ports, there is currently no single definition of smart ports. In Molavi et al. (2020), a quantitative tool, the Smart Port Index (SPI), was proposed and developed for defining and assessing the performance of smart ports. The SPI is based on a number of Key Performance Indicators (KPIs) that encompass four distinct processes of a smart port: operations, environment, energy, and safety and security, and enables port authorities to assess their current operations for continuous improvement.

According to the same findings, the ports of Hamburg, Singapore, Los Angeles, Vancouver, and Rotterdam are among the ports that have high SPIs, especially in relation to their Smart Environmental and Energy Sub-Indices (Molavi et al., 2020). In line with the Paris Climate Agreement that targets limiting the global average temperature increase to well below 2 °C above pre-industrial levels- and the Initial Strategy on the reduction of GHG emissions of the International Maritime Organization (IMO), that aims to at least halving emissions from international shipping by 2050, compared to 2008 levels- these ports have been proactive in the development of tools to facilitate the reduction of CO2 and other greenhouse gas emissions from shipping, port, and landside operations, and have taken various initiatives to enable energy transition, improve energy efficiency, and stimulate circular economy (UNFCCC, 2015; International Maritime Organization, 2018). Initiatives include providing onshore power supply (OPS), incentivizing best-performing vessels, investing in infrastructure to supply low carbon fuels and port call optimization, and improving energy efficiency of operations in port areas (Ölçer et al., 2018; Christodoulou, 2020; Christodoulou & Cullinane, 2019). An important characteristic of the sustainability initiatives of these ports is their holistic and comprehensive approach, since they cover the four dimensions of port-related operations: a) vessel operations, b) port operations, c) hinterland operations, and d) port-city interference (Alamoush et al., 2021; Christodoulou et al., 2021).

4.2 Smart ports and sustainable development

The modern business environment is characterized by continuous and intense changes, as well as fierce (international) competition. This situation often creates a pressing need for companies to identify and quickly adopt the right techniques/methods to ensure their survival, as well as to promote their further development and consolidation within the markets they operate. In their efforts to maintain their competitive advantages and address diverse challenges associated with their

operations (such as congestion and delays), negative impacts on the environment (i.e., air, water, and noise pollution, waste disposal), and energy consumption, ports around the world are adopting smart technologies that open up new horizons and approaches to port operations planning and management. Apart from the direct benefits towards operational efficiency, regulatory compliance, and customer satisfaction, smart ports establish themselves as important digital nodes in the global supply chain, but also as logistics information exchange hubs serving their regional transport ecosystems. By digitalizing their processes, smart ports establish a platform that enables the sharing of real-time information among all the participants in the cargo/freight and passenger ecosystems, enhancing collaboration, aligning activities, and supporting both an environmentally-sustainable and value-creating transport system. Through the digital transformation of their processes, smart ports also provide sustainable services through improved operations, and answer to the UN 2030 Agenda for Sustainable Development, especially SDGs 3 (good health and well-being), 7 (affordable and clean energy), 9 (industry, innovation and infrastructure), 11 (sustainable cities and communities), 13 (climate action) and 14 (life below water) (Alamoush et al., 2021).

It is also necessary to highlight that the use of the IoT concept enables real-time tracking and monitoring of the cargo, in addition to 5G networks that improve stakeholders' consistent and uninterrupted connectivity and, therefore, help to optimize loading and unloading times in ports, minimizing, at the same time, idle times for ships and transit time of goods, leading to fewer emissions. Reducing emissions at port areas brings about substantial health and environmental benefits. More specifically, local air pollutants such as sulfur oxides, nitrogen oxides, and particulate matter have severe health impacts on populations in close proximity to ports, and also cause eutrophication and acid rain (Corbett et al., 2007; Winnes et al., 2015; Christodoulou & Cullinane, 2020). At the same time, carbon dioxide emissions contribute to global warming and climate change; they obviously exercise a global impact (Styhre et al., 2017). Apart from these direct environmental benefits, "Just-in-Time" operations at ports, with the introduction of smart technologies, will also result in the optimal operating speed of vessels arriving at the port, as they will only approach the port when berthing availability is ensured. As vessels currently spend long times waiting at anchorage, this time could potentially be minimized, leading to optimal operational speed for vessels and reduced GHG emissions (Poulsen & Sampson, 2019). By using 5G routers and IoT sensor technology for the collection, aggregation, analysis, and communication of data, inventory management can be greatly improved, allowing ports to accommodate larger vessels and containers through the use of intelligent load automation. Finally, with the use of sensors and cameras that automatically collect and share information, such as weather, traffic, and pollution data, the traffic flow of ships can be determined automatically, therefore leading to shorter loading and unloading times and allowing more cargo to be cleared in less time (Dalaklis, 2018; Dalaklis et al., 2019).

Although the development of sustainable smart ports can effectively promote operational and environmental aspects of the supply chain, only a few studies have discussed smart ports from a sustainable perspective. In Yang et al., (2020), a discussion of the triple bottom line theory was performed, and it was concluded that the most important parameters for the establishment of sustainable smart ports include policy support, integration, knowledge, and skills. The implications from the use of digital technologies at ports go beyond their strict boundaries, promoting the sustainable development of the city/region where they are located. An example of these applications is the Pixel Port project; real-time data are gathered through digital technologies that provide valuable information to cities concerning the impact of activities in the surrounding areas. Another practical example is related to the measurement of road traffic generated by the port activity and the related emissions. By enabling the gathering of this type of data, future models can be developed for the planning of vessel movements, the arrival/departure of trucks, or even personal mobility around/within cities, which lead to sustainable smart port ecosystems.

In contrast to port-city interaction in its current form, within a Smart Port Ecosystem, the interaction between ports and city is moving to a data-driven interaction, which should offer more transparency and, most probably, release the tension between global shipping corporations, local players, and society (Lind et al., 2018). In this context, ports will have a higher positive spillover effect, not only at the regional/national level, but also on the local level. Going far beyond the individual port and port region, port digitalization is anticipated to bring about the creation of "a wider network of hubs that are equally digitized and ambitious"- a Smart Port Network (World Ports Sustainability Program, 2020). Within this network, automated ports will connect and exchange real-time data, improving therefore the efficiency of their collective operations. The basis of a global logistic chain will be a Port Community System that will add value to all involved stakeholders through lower costs and faster delivery speeds and, at the same time, contribute to sustainable transport logistics due to the simplification of processes, as it will require a single submission of data into well-connected transport and logistics chains. This level of port digital transformation, though, seems quite far away at the moment, and presupposes massive capital investments from both sides: operators and the concerned government bodies.

Before moving in a different direction, it is necessary to note that the majority of ports around the world have been using digital solutions more extensively during the COVID-19 pandemic (which is still on-going) because of the enforced physical interaction restrictions and the need for ports to maintain an efficient workflow.

4.3 Port of Gothenburg's efforts towards digitalization

Digitalization is currently one of the top priorities at the Port of Gothenburg, as exactly those digital technologies and applications already implemented were proven to be essential during the pandemic. The port is currently investing in AI and digital connectivity through the development of a digital platform that is anticipated to advance freight flow transparency and lead to increased productivity, reduced lead times, and faster delivery capacity throughout the entire transport chain, benefiting everyone linked to the port (Port of Gothenburg, 2021). This information portal- called Port Optimizer- is a cloud-based software solution designed to digitize maritime shipping data for all stakeholders across the port ecosystem through secure, channeled access. By gathering disparate data sources from different stakeholders across the supply chain, the Port Optimizer creates a unique data source for the entire process, and helps address key port challenges, including the limited visibility of cargo in transit, disparate and inaccurate data sources, and conflicting objectives between different port stakeholders. The Port of Gothenburg will be the first European port using this software solution, as a similar platform is already in place at the Port of Los Angeles (Port of Gothenburg, 2021); this deployment has already resulted in enhanced productivity from vessels to shore, and from the terminals to the customers, as well as increased throughput and improved efficiency for that specific port.

The greatest challenge for the effective implementation of this digital solution is related to bringing together the various actors- shipping companies, terminal operators, rail operators, forwarding companies, freight owners, and inland terminals- that cooperate in the Port of Gothenburg and form a rather complex freight transport network. The integration of this platform in the port's processes means that all the fragmented information of the separate IT systems of the different port stakeholders will be processed in order to visualize and optimize the numerous tasks and activities at the port and enable a new digital services "ecosystem"; this in turn requires the adoption of a cohesive approach, working with all the parties concerned. Rapid, high-quality information will facilitate flexible planning and collaboration between the different operators at the port, with clear benefits for all involved parties. The importance of real-time cargo tracking and information exchange for the development of efficient maritime supply chains was also highlighted in the findings of Christodoulou & Kappelin (2020), with major shippers indicating the need for digital solutions for enhanced port operations. For example, significant environmental gains from

just-in-time arrival can come about for the shipping companies, while freight owners, rail operators, and terminal operators will benefit from real-time tracking of their goods. This will enhance the role of the Port of Gothenburg as a freight hub, and even transform it into a "digital hub" of the supply chain.

Additionally, the Energy sector of the Port of Gothenburg is the largest Nordic open access energy port, with 24 berths that receive over 2,500 calls and handle more than 23 million tons of energy products each year (Karas, 2020). In order to respond to the need of quicker and more efficient handling of goods in such a high-intensity environment, the Gothenburg Port Authority launched a unique data system in 2019- called Permesso- designed to coordinate and monitor work at the Port of Gothenburg Energy Port (Port of Gothenburg, 2021). The integration of smart automation and digitized processes has led to quicker and more efficient handling of goods, while maintaining safety as the first priority. The main novelty of Permesso- that, interestingly enough, was designed and developed in-house- is that work permits at the Energy Port can now be issued online and coordinated digitally for planned and ongoing maintenance and development. The system enables a clear overview of all projects in progress in various parts of the Energy Port on any given day and simplifies the process of issuing permits for all the work of different customers involving a large number of contractors. The permit necessary to carry out work can now be issued online, instead of dealing with the paperwork manually, as the port staff can approve a permit or request additional information directly on the platform. In this way, the new system saves an incredible amount of time and effort for customers, contractors, and port administration. Besides Permesso, at the beginning of April 2020, the Gothenburg Port Authority also launched a smart digital application designed to make bunkering at the Energy Port easier and quicker. The "Bunkering App", which is one of the first in the world to offer this range of functionality, is dedicated to bunkering operators in the Energy Port. It eliminates reports that were, until recently, submitted via e-mail or telephone. Bunkering notifications are now sent through the application, while it also synchronizes bunkering statistics and makes planning and carrying out loading operations easier for operators. The implementation of the application has led to increased efficiency at the Energy Port and has maximized the use of bunker wharves (Karas, 2020).

APM terminals Gothenburg (which is clearly the Nordic region's largest container port, based on the quite "privileged" geographic position of the port and the easy access it provides for ships sailing the North Sea) handles more than 8,000 containers every week, a quite complex and elegant logistics task (APM Terminals Gothenburg, 2021). Despite the fact that the cargo volumes accommodated at the Port of Gothenburg are by far the largest in the Nordic region, it is quite challenging for the port to attract large vessels, due to its geographical location being the actual terminal point of the world's largest trade corridor: Asia-Europe. Gothenburg's location, on the other hand, offers certain advantages, due to the close proximity for vessels to reach the dock from open sea, and the central location of Gothenburg between Sweden and Norway with 25 daily rail shuttle departures to over 300 destinations in both countries. APM Terminals have proceeded with large investments that have enabled the reception of the world's large containerships, offering, at the same time, world-class logistics services, enhancing the port's competitiveness. These investments include, among others: a) diesel-electric straddle carriers, b) Super-Post Panamax cranes for loading and unloading the largest vessels, c) new reach-stackers (large counter-weight trucks for lifting heavy containers), and d) a self-service gate for trucks. These major investments made by APM Terminals Gothenburg have increased capacity and efficiency, with handling time at the truck bays reduced by 40 % and increased customer satisfaction. An indicative fact is that, in January 2019, 4,350 containers were handled during a single vessel call- a new record for the entire Nordic region- that reaches handling capacity at major European ports. Digital technologies, along with skilled employees and good co-operation with customers, made this achievement possible.

Continuing the discussion in the same direction, APM Terminals use the terminal operating system- called Navis- which is employed by the vast majority of container terminals around the

world (Yap et al., 2013). This system has improved terminal management efficiency due to, according to APM Terminals Gothenburg, "the specification of the fastest routes for straddle carriers to take in the terminal and the enhanced interface and digital data exchange with customers, including planning and payment details". APM Terminals have also launched the digital Track and Trace initiative that enables customers to save time by checking the status of containers at the terminal digitally. The self-service gates at APM Terminals allows truck drivers to manage their business on their own, 'with equipment automatically scanning and photographing the containers and vehicles to verify that everything is correct increasing the number of service hours per day' (APM Terminals Gothenburg). Longer opening hours for the automatic gates for trucks, introduced by APM Terminals, enable the port's customers to use their trucks more efficiently, leading at the same time to reduced handling time for trucks. It is worthwhile to mention that the average gate handling time at APM Terminals Gothenburg is 26 min, compared to 56 min, which is the European average (APM Terminals Gothenburg, 2021; Yap et al., 2013).

Table 2 Digital efforts and other initiatives implemented at the Port of Gothenburg.

Main Domain/Area	**Type of Technologies/Applications**
Intelligent Traffic Flow- vessel and container management	- Bunkering App - Navis - Track and Trace initiative - diesel-electric straddle carriers - Super-Post Panamax cranes for loading and unloading the largest vessels - Reach-stackers (large counter-weight trucks for lifting heavy containers)
Intelligent Information System- data center, networking and communication	- Permesso - Port Optimizer - Automatic gates for trucks
Smart Port Infrastructure- sustainable technology	- OPS - LNG fueling points - Alternative energy sources for buildings - Environmentally differentiated port tariffs - LNG charging stations for vessels
Hub Infrastructures	- Nordic ports network - World Ports Climate Action Program (WPCAP)

As can be seen in **Table 2**, there is a variety of digital applications adopted by the Port of Gothenburg to facilitate and enhance vessel and container management, which includes the "Bunkering App" that enables bunkering notifications to be sent digitally to customers, to the investment in automated cranes for the quicker and efficient loading and unloading of the largest containerships. The port has also invested in digital technologies that enable data sharing, networking, and communication with the "Port Optimizer", being a milestone for the digital transformation of the port processes. Sustainable technology is another area where the port has invested largely, with investments targeting reduced energy consumption and addressing the

negative environmental impact of port operations. The Port of Gothenburg has been the first port worldwide to invest in OPS as a possible solution to tackle the pollution problem from ships at berth, which originates largely from onboard power generation based on heavy fuel oil or diesel oil.

The Port of Gothenburg has also developed hub infrastructures to foster collaboration among different ports being part of regional and global networks that cooperate and interact to tackle climate and environmental challenges related to port operations. Although this port is currently a major transshipment hub in the region, and an important information exchange hub, the level of automation and digitalization of the ports in general does not allow the creation of a Smart Port Network with automated ports inter-connected and able to exchange real-time data between them. Such a development presupposes structural organizational advances and massive capital investments in the future.

5. Conclusions

In the course of history, significant developments leading to the introduction of new technologies and higher levels of automation in transportation have taken place. There is a very strong interrelation between ships and ports; historically, ports have served as supply chain nodes, providing docking facilities for ships to load and unload cargo and passengers. Over the course of time, and especially under growing efficiency demands from an expanding global economy, it has become a pressing necessity for ports to adjust their "raison d'être" in order to offer and deliver more productive and competitive services. Additionally, during the last two decades, the role of ports has become broader, with their transformation into information exchange hubs gathering data from shipping lines, trucking, and off-dock storage providers, expanding their traditional role as transshipments hubs. Ports are transitioning to "Smart Port" status by incorporating 4IR technologies in their operations, including integrating and collaborating with intermodal partners and other stakeholders to enhance global supply chain efficiencies. It is very clear that the future of ports is automated, taking advantage of the opportunity to transform into more efficient, reliable, and predictable logistics hubs. When implemented successfully, automated processes not only optimize the port itself, but also its entire ecosystem, including transportation networks and supply chains. Furthermore, the effective integration of digitalization and automation into ports' processes and operations is already taking place in various major ports around the world. Digital processes and the real-time exchange of data do not only have a positive impact on ports themselves, since they can strengthen their competitive advantage and keep up with their customers' changing needs, but also create value for all stakeholders involved in shipping operations through collaboration, aligned activities, and decision-making that improves vital processes across all levels of operations.

The contemporary era is very frequently referred to as "the information age"; it is, therefore, not a coincidence that modern economic activities are very highly dependent on data. Besides the operational and financial benefits for ports, achieving the status of a smart port through digitalization also strengthens the vital role of ports in contributing to the UN Sustainable Development Goals (UNSDGs) and aligning their operations with the requirements of the Paris Agreement and the Initial IMO Greenhouse Gases (GHG) Strategy for the reduction of GHG emissions from shipping. Different digital solutions can help ports around the world to effectively address diverse challenges associated with their operations (such as congestion and delays), negative impacts on the environment (air, water, and noise pollution, waste disposal), and energy consumption, and even open up new horizons and approaches to port operations planning and management.

The implications from the use of digital initiatives and related technologies at ports extend well beyond their strict geographical boundaries, promoting the sustainable development of the whole city/region where these ports are located. By gathering real-time data through digital technologies, interested stakeholders can have immediate and easy access to valuable information concerning the impact of port activities in the surrounding areas; therefore, there can be better

decision making in terms of city planning and governance activities. Moreover, simulation activities can also be integrated into the same efforts. For example, future models can be developed for the planning of vessel movements, the arrival/departure of trucks, or even personal mobility around/within the city's boundaries. All of these can lead to sustainable port ecosystems. In this strategic context, a smart port will have a very high positive spillover effect, not only at the local level, but also expanding to the regional level, and even possibly to the national one. Smart ports, as high performing ports, utilize ICT to provide a wide range of digital applications, resulting in vastly improved vessels and container management among other benefits, which subsequently improve the competitiveness and sustainability of the national economy.

Going far beyond the individual port and port region, port digitalization is anticipated to bring about the creation of "a wider network of hubs that are equally digitized and ambitious"- a notion that can be described as a Smart Port Network that will enable automated ports to inert-connect and exchange real-time data, therefore improving as a whole the efficiency of their collective operations. It is important to remember that technology and automation are often triggered by safety and efficiency concerns of operations, and not always motivated by increasing profits or reducing costs. This wider-in-scope level of port digital transformation, though, seems quite difficult at the moment, and presupposes massive capital investments from both involved operators and associated government bodies. The need for massive capital investments from major port operators for the efficient connection of ports with all relevant stakeholders- including shipping companies, shippers, freight forwarders- is also underlined through the case of the Port of Gothenburg. Although the port under discussion has deployed a series of digital initiatives, with a quite forward-looking approach, the issue of "cultural change" for all people involved with the conduct of operations should also be addressed in the near future, most probably via seminars and/or training activities.

It is true that the exploitation of Big Data and the role of certain software applications in accessing and managing this large volume of information are key factors for improving/optimizing the conduct of operations and management activities; the establishment of a "Data Driven Culture" within a company can clearly improve the current business model and, at the same time, promote sustainability. However, if we look at the different stages of technological progress in history, the previous waves of technological development had significant impacts on jobs, employment, and working conditions in general. As a result, there is a keen interest in the discussion of what the consequences of the 4IR will be, and how the concerned employers can be prepared for the transformations that may arise from the further introduction of advanced digital technologies and automation. Quite often, an important barrier to ports' digital transformation comes from the advanced and multiple skills required from port employees and logistics operators to provide advanced planning and services at the port, under the fear of "losing their job" or simply because they are "afraid of change". There is, therefore, a raising need for ports to focus heavily on both training their personnel and on the recruitment of the people with the right cultural mentality to promote and stimulate their on-going digital transformation.

The major limitations of this research are that the exploratory review conducted is not exhaustive of all ports' digitalization initiatives; rather, it is indicative and representative of the various implications of these digital tools on ports' efficiency, productivity, and sustainable development. Moreover, a case study- in our case, the digital transformation of the Port of Gothenburg- cannot be considered as representative of ports worldwide, as the port is located in Northern Europe, where high sustainability requirements are applied and ports demonstrate a very strong commitment to sustainable development. The results might be different in other geographical regions of the world.

The study provides implications for further research. More case studies on ports' digitalization efforts and initiatives could be analyzed, giving some insight into the opportunities and challenges related to their practical implementation. The case study methodology could also be

supplemented with quantitative studies that could further explore and highlight the potential benefits and general implications from the digital transformation of ports.

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