Road to Shipyard 4.0:

The state of play, a brief history of maritime developments, and a future roadmap

Focusing on the Baltic Sea and Shipyards

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EXECUTIVE SUMMARY

ECOPRODIGI is an initiative of the EU-Interreg Baltic Sea Programme, whose mission is to improve and promote the eco-efficiency of shipping and maritime operations. This report is a product of the work package 4 (WP4); a foresight exercise, whose mandate is to provide a roadmap for the future of maritime operations in the Baltic Sea Region with a focus on shipbuilding and shipyard operations. A sister publication exists that provides a policy-innovation roadmap for Ro-Ro shipping, entitled *Maritime in the 21st century*.

This report is a product of inter-disciplinary collaboration. At the core of the team are the consortium members. Early drafts were validated through consultation with experts, and results were then summarised and validated together with wider industry and policy actors through surveys. For more information on the methodology, see Appendix 2.

The potential users of this roadmap include a wide variety of stakeholders. Policy makers can use it as an agenda-setting reference for promoting and championing eco-efficient policies, regulations, and standards. Industry stakeholders can use it to check against their own strategies for coherence. Researchers can use it to anticipate questions that might be of particular relevance over the next decade. Technology developers can use it to benchmark against their own expectations for technology development. In all, this roadmap can be a starting point for discussion so that all stakeholders can move together into the future, forward, by sharing the expectations for development in order to coordinate action to enact eco-efficiency in the Baltic Sea and beyond.

The report is organised as follows. The introduction will lay out the current state-of-play of eco-efficiency and the zeitgeist of the current situation on maritime that we find ourselves in, in 2020. The next section will provide some historical context looking back to 2010 and 2000 to trace the trajectory and developmental course that we are on.

The core contribution of this report is the Shipyard 4.0 Roadmap, that can be found in Figure 1 on page 9. This illustration plots the expectations for technological capabilities and policy from 2020 to 2030. The descriptions of the elements of the roadmap are provided in Appendix 1.

It should be acknowledged that the current COVID-19 pandemic has played a significant role in societies during the development of this roadmap. Indeed, the injection of such uncertainty has caused the authors of this report to reflect quite significantly. The ECOPRODIGI consortium considers this of utmost concern and thus requests that users of this roadmap take the status of the pandemic into consideration when using this roadmap. As it had always been thought of as a working roadmap of the future since its beginning, prudence is required in its use and it should be suggested that users create their own updates and assessments in an ongoing fashion as the future unfolds.

Introduction – the current state of play in 2020

By 2020, global maritime governance had become more effective than ever due to the new and improving regulations and enforcement from EU, IMO, and other international bodies. Industry, responding to the demand from consumers, had stepped up with the announcement of new environmental imperatives to join the calls for de-carbonisation, zero-emission, and the electrification of the seas. Green taxes, enabled through the detailed emissions and energy consumption record keeping was affecting vessels, shipyards, ports, and other elements of the ocean economies. Sustainable practices and circular-economy thinking has received widespread attention, and demonstrated results to this end were emerging, noticeably in the Baltic Sea region where clean shipping was having a positive impact in mitigating the problems with eutrophication.

At the onset of 2020, the future vision of many industries had been a fully digitalised and optimised one. Developments in AI, machine learning and machine vision have made progress through their nascent stages of development in the decade prior. More than ever, big data collected by the ever-increasing amount and kinds of sensors and cameras had begun to be processed on remote servers. Special attention and sustained investments were ensuring that the software and algorithms that had been developed to process, manage, and visualise the data so that operators could effectively optimise workflows.

The ongoing impact of digitalisation to maritime operations has been tremendous. Data-based decision support systems have been available to the industry for some time. Now these systems are beginning to suggest optimal sailing routes; performance and monitoring systems are providing estimates for required maintenance and repairs; decisions about hull and propeller maintenance, schedule design, retrofitting, and more, are improving because they are being made on the basis of data. Ship operators are optimising vessel stowage, reducing the use of ballast water, and improving on vessel utilisation. Different kinds of fault detection and early-warning systems are being implemented to avoid accidents and breakdowns.

Digital vessel performance monitoring is beginning to offer the opportunity for the ship's crew to navigate real-time in a more energy efficient manner using robust decision support tools and models providing overview of most optimal sailing route and speed and on-board equipment for monitoring the weather, current, wind, draft, cargo loading conditions, and more. The advancement in software and simulation has gradually made inroads towards the realisation of the grand vision for automated ships.

The benefits of digitalisation are not confined to the ship, but rather spread across the maritime value chain. Full digital data capture and AI models are enabling truly digital and integrated logistics. Digital transparency about cargo unit positions, states, and conditions, are enabling terminals to optimise cargo operations, gain efficiencies and shorten port stays, providing ship operators with more opportunities to sail slower, reduce fuel consumption, and provide better service quality to their customers. The ports, ships and supply chain are increasingly integrated in multi-modal data platforms that enhance the efficiencies of stowage and voyage planning and execution. Ship location data are beginning to be translated into real-time arrival estimates allowing ports to act and react on better information to lower time in port and increase time sailing. This intensive use of real-time data throughout the supply chain opens up for more secure and efficient coordination and planning of all operational links in the chain, and contributes to the competitiveness of Ro-Ro shipping, especially in relation to rubber wheel traffic / lorries on land, which continue to be a major contributor to negative environmental impacts.

3D scanners and computer vision have the potential to make stowage operations more efficient. Virtual reality and augmented reality technologies are providing process perspectives never seen before. Increased data sophistication, transparency, and management help to align incentives for improving cooperative performance, and giving insight into the magnitude of the inefficiencies that are yet to be mitigated, or in other words, the money left on the table and the unnecessary destruction to the environment.

The evolution of the maritime and related industries towards digitalisation has meant that there are an increasing demand for different skillsets than before. The work that could be removed from the crew and captains has being assigned to partially autonomous systems at the benefit of increasing safety and decreasing human error. In other words, captains and crew are being challenged by new technologies, and new skills are required to be able to manage the technology effectively while also improving the work environment and occupational health. The arrival of big data requires more data analysts and improved data science architects. This, in turn, requires not only requirements for new ways of learning and training, i.e. through simulation, but effective and experienced managers and leaders are needed to see this transition through. Special attention must therefore be placed on making the image of the industry an attractive place to form a career.

In the midst of all this development, the continuance of these trends have been called into question. Not only due to the corona virus, but also e.g. cyberattacks have thwarted confidence in digitalisation: the quantity and magnitude of the attacks, spoofing, cyber-terrorism, and ransom, are reaching a critical point. And much goes unreported. To protect all sorts of assets, encryption technology and distributed ledgers are being considered to play an increasing role here.

The environmental agenda is also at stake. Initiatives from the International Maritime Organization (IMO) - the Marine Environment Protection Committee (MEPC) have put forward a series of measures aimed at reducing the total amount of greenhouse gas (GHG) emissions from ships in line with the UNFCC's Paris Agreement and UN 2030 Agenda for Sustainable Development. By April 2018, the IMO adopted an initial strategy to reduce annual GHG emissions by 50% by 2050 compared to the 2008 level. The effectiveness of this will unfold over the next decade.

If the disruptions of 2020 are overcome, the techno-regulatory regimes continue in their progress, and investments and policy can continue their trajectory, then the decade is likely to become a decade of eco-efficiency. However, advancing industry standards are needed in that standards organisations, classification societies, and industry continue to push for the establishment of harmonised rules and communication to unlock the value promised in an increasingly digital era.

Meyer Turku Shipyard (© Meyer Turku / Lavea Media)

A brief history of the maritime industry in the 21st century

Year 2000

Notwithstanding the dot com bubble burst in March of 2000, Europe was experiencing a period of healthy territorial, economic, and technological growth at the onset of the new millenium. Europe's Ministerial Intergovernmental Conference on Accession Negotiations with numerous Eastern European countries opened in January. Fuel prices had been low for some time, and industrial output was high, with China's entrance into the WTO resulting in the dramatic expansion of trade to and from Southeast Asia.

Confidence in the maritime industry was strong, and both large and small companies were succeeding. The demand for new vessels was high and the orderbooks at the shipyards were full. The low fuel prices, coupled with high demand and freight rates, meant profitable times for maritime transport.

Ships were getting bigger and faster. Prior to 2000, a large container ship could carry around 4000 TEU, and capacity would soon expand to carry 7000-8000 TEU. Roll-on Roll-off (Ro-Ro) vessels were also getting bigger and scheduling more frequent departures. To pace the increasing demand driven by global GDP growth, vessel types were diversifying: Demand for built-for-purpose vessels grew, with new mixed cargo, service, passenger and work ships filling the orderbooks in European yards. Yards were not making everything by themselves anymore, but outsourcing and sub-contracting practices spread, with the establishment of local and global supply chain networks. Shipbuilding had already evolved towards block construction that meant that not everything - hulls included - had to be both built and assembled on the spot. Ship design companies were internationalising and finding new markets globally. Yard orders were booming in years 2004 to 2008 with a large number of newly built yards being opened in Asia, and particularly in China. The delivery of main engines for propulsion of the growing fleet became the bottleneck.

Globalisation was beginning to affect the ownership of the companies across many parts of the value network - among maritime segments (i.e. container shipping and Ro-Ro), ports, and yards. The industry was moving towards a duality of huge companies and their smaller subcontractors.

With increased resources, more standards, and access to global solutions, the investment, development, and implementation of digital technologies in maritime and related industries had expanded - albeit gradually. Internet connections were more ubiquitous with the standardisation of Wi-Fi and growth of mobile telephony. Telefax was widely used in maritime, as there were computers in the offices, but typically few on board ships. The first web portals for tendering and purchase orders in the industry were starting to open. Morse code was finally discontinued in maritime communication in 1999.

In the year 2000, health, safety and environment (HSE) procedures were mostly already developed, however the industry experienced more accidents relative to today. Tragic accidents in the late 1980ies and early 1990ies lead to a series of new regulations that would come into force around 2000, such as an update to the IMO's Safety of Life at Sea (SOLAS) and the International Safety Management (ISM) code. These mandated not only new behaviours, such as checklist-based reporting procedures for monitoring and reporting, but also the shift in paradigm from deterministic to probabilistic methods and the further implementation of new technologies and stricter requirements for them. After the accident of the M/S Estonia in the Baltic Sea with the loss of 852 lives, new regulations resulted in safety retrofits for Ro-Ro vessels: new validation procedures and calculations on aspects such as stability requirements, flood control doors, watertight bulkheads, bow visors, ramp functionalities, video recording requirements, alarm systems, and more, were brought about in the Stockholm convention. The impact of new regulations had not been so great, arguably, since the Titanic, in the aftermath of the regulations that followed in the wake of the M/S Estonia.

As ships were required to record what they were doing in much greater detail, inspections were still conducted manually which left open the many possibilities for human error. The idea of dual officers who are familiar with both navigating and engineering was surfacing. Robots were becoming more common in manufacturing processes that would foreshadow the later automation of the workforce in European shipyards and ports. Yet the processing power of computers was making analysis more of an automated process. The first flowmeters for monitoring fuel usage that would revolutionise vessel performance management and optimisation, were being installed on vessels. Ship design companies were progressing in the migration to integrated 3D modelling software such as Computer-Aided Design (CAD). Likewise, improvements in Computational Fluid Dynamics (CFD) and materials were resulting in ships that could sail faster without increasing fuel usage. Accident reconstruction techniques improved as well that helped to further identify risks.

Consequences for human resources were also beginning to emerge. The idea of dual officers who are familiar with both navigating and engineering was surfacing. Robots were becoming more common in manufacturing processes that would foreshadow the

later automation of the workforce in European shipyards and ports. With the increasing use of subcontractors, supply chain management tools had to be developed in order to organise workflow efficiently.

Sustainability was not on the maritime agenda in the year 2000. Climate change was recognised, but no efforts had been initiated to mitigate it in the shipping industry. Other environmental issues, such as eutrophication of the Baltic Sea, were seen as more urgent, and the effect of ship emissions on air pollution was recognised and efforts to limit them began. The first Sulfur Oxides (SOx) regulations had been enforced in the late 1990s, and environmental cooperation around the Baltic Sea Region countries was increasing – in particular through the Helsinki Commission (HELCOM). In Gothenburg, the first shore-power electric connections were offered in order to decrease smog and air pollution in the area. The first Sulfur Emission Control Area (SECA) was implemented in Sweden in 2005, tightened and expanded in 2010, and then again in 2015.

Maritime Industry from 2010

2010 was characterised as a post-financial crisis pre-recovery low point for shipping and shipbuilding. The financial crisis and the subsequent recession led to lower demand for consumer goods and oil. Given that the largest container ships had quadrupled in size to 16000 TEU since 2000, overcapacity was resulting in a decline in asset values. The orderbooks for large vessels at European yards were empty, and what orders there were for large cargo vessels were being taken by Asian shipyards.

An increasing environmental consciousness had resulted in international debate and a series of political and regulatory actions that impacted the maritime industry. While initiatives with the aim of reducing pollution from the world's merchant fleet date back to at least 1973 when the first edition of the International Convention for the Prevention of Pollution from Ships (MARPOL) was adopted by IMO, many updates had followed. By 2010, the techniques and technologies for calculating emissions and corresponding energy efficiency had matured and were being incorporated into new ships. Further guidelines would follow, including the Annex VI regulations on Energy Efficiency Design Index (EEDI) aimed to reduce fuel consumption through technical and design-based measures, as well as the Energy Efficiency Operational Indicator (EEOI) and Ship Energy Efficiency Management Plan (SEEMP) to evaluate and improve the fuel efficiency of existing ships.

Further regulatory advancements had been in design and taking hold in the industry around 2010. Concerns over SOx emissions had grown over the previous decade, and the installation of the first sulphur scrubbers on ships began. Slow steaming was urged

as another approach to decrease emissions (a strategy that coincided with overcapacity). New SOLAS regulations were adapted to pay more attention to damage stability, and cabins were no longer allowed to be constructed under watertight decks.

These complexities boosted the role of advanced techniques in shipbuilding. While many of the new orders for large ships were headed to the Far East, European yards had begun specialising in high-tech and complex vessels that were in demand given the growth in emerging sectors such as offshore wind, as well as the growing popularity of the cruise tourism industry. Shipowners were experimenting with alternative fuels as a power source, for example LNG and methanol. The technology suppliers to the shipbuilding industry were, by this time, well-established across the global shipbuilding markets.

But although environmental disasters had been reduced by the improved regulations, techniques, and safety protocols, they did not disappear. The Deepwater Horizon oil disaster in 2010 would impact the offshore industry and usher in further HSE regulations. In line with the worldwide trend for sustainability that was garnering a foothold across industries, international emissions regulations were tightening, and the concept of clean shipping became more visible, especially in fragile areas such as the Arctic and the Baltic Sea Region. To decrease the hazards and material waste from the other end of the ship's life cycle, increasingly more attention was paid to developing proper ship recycling practices.

While leaps in connectivity had, by this time, integrated on-shore economies, shipping held onto older technologies. Over the seas and oceans, broadband connectivity, AIS data, and satellite coverage was limited and unreliable. Port operations and berthing was conducted via phone and radio. First generation of ECDIS (Electronic Chart Display and Information System) had been developed and implemented on ships more and more - but not without problems related to cybersecurity. Digital monitoring was becoming more common, but the majority of ships had yet to even install flowmeters or other devices to monitor their fuel consumption.

The purpose of this introduction has been to present a current state of play and a brief history of maritime and related industries since 2000. From here, the report will begin to lay out a vision for the future. The next section will present ECOPRODIGI's roadmap that illustrates a trajectory for the industry. Following the roadmap, descriptions of the events presented in the roadmap can be referenced for more information. In the appendix, readers can find details of the methods that were used to construct the roadmap.

Shipyard 4.0

An innovation and policy roadmap for digitalising shipyard operations

2023
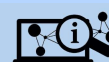01. Real-time planning tools track progress & report problems

02. Welding quality is digitally monitored in real-time.

2024
03. AI-enhanced documents anticipate, forecast, and warn on events

04. Digital databases improve task training and handover

2025
05. Biocide-free coating innovations surpass toxic anti-fouling paints

06. AR, VR, and 3D simulation used in task training

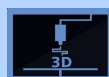07. AI systems control and manage warehouse inventory

08. 3D Scanning is standardised for ship inspections
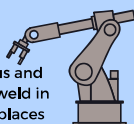
09. Aerial drones perform incremental 3D scans at yards

2026
10. Additive manufacturing of spare and missing parts

11. Microgrids supplement yards' electricity needs

2027
12. Autonomous and flexible robots weld in hard-to-reach places

13. Digital twin files are shared across stakeholders

14. Aerial drones perform basic services

15. Digital twins are used for virtual delivery inspections

2028
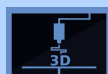16. Unmanned lifting vehicles displace tractor operators

17. Digital twins are used in planning repairs

18. Warehouse operations performed by automated drones

2029
19. 3D printers are used to print large blocks

2030
20. Composite materials are used for large vessel hulls

Appendix 1: Roadmap elements

01 Real-time digital planning tools, shared across stakeholders, are used to track progress and report problems at yards

Modern shipbuilding requires the coordination of hundreds of workers from different companies coming from many countries. Organising and coordinating work is done in worklist planning, but it remains a challenge to modify and update the worklist as contingencies arise. In the ECOPRODIGI project, it has been noted that there are many inefficiencies that could be overcome by improving situational awareness in the process and supply chain management with digital tools. [1]

With digital tools, progress and problem tracking can be done in real-time to improve synchronisation and thereby productivity. Lead times can be shortened by coordinating plans, resources, materials, and tools effectively. With a digital planner, it is easy to check out the facts and current work status, and to concentrate on one's actual work instead of spending extra time on investigating issues.

However, establishing situational awareness in real-time means that leadership must advocate its use, and the contractors must understand its value and use it. Special attention must therefore be paid to proper training and education of the workers.

References:

[1] ECOPRODIGI, (2020). Maritime industry processes in the Baltic Sea Region – Synthesis of eco-inefficiencies and the potential of digital technologies for solving them. Accessed 31 July 2020.

02 Welding quality is digitally monitored in real-time

Welding is a critical capability at yards. When welds are performed manually, quality is not easily measured, verified, or controlled, but instead inspected only with the human eye. More detailed information on welds would not only benefit the welders performing the work, but could also be shared with inspectors to allow for digital verifications, and with customers in the form of quality guarantees.

Tracking welding work digitally could collect data such as the identification and credentials of the worker, as well as applied parameters such as wire speed, torch

speed, voltage, and the structural situation at the site of the weld. This data would allow for cross-case analysis that can lead not only to improved performance, but also to best-practice identification, better error detection, and alerts for real-time process and decision support. [1]

Applying digital tools during welding operations will be made salient when customers and classification societies want more traceability on welding quality. Increasingly higher-strength steel structures require more precise process control and advanced digital welding quality tracking will support this.

References:

[1] Hout, (2013). Weld process monitoring. Qualitymag.com. Accessed 31 July 2020.

03 Smart shipbuilding documentation is used to anticipate events, produce forecasts, and alert early warnings, in the shipbuilding process

Smart documentation is that which is monitored, facilitated, and fulfilled by algorithms that are able to leverage prior data and patterns from a database or knowledge base that can imbue the process with information in a timely manner. Smart documentation, powered by AI, can anticipate events, produce forecasts, and signal early warnings.

Smart processes could provide reports, execute supplemental information requests, enabling smoother supply chain integration and customer interfacing, and speed-up services such as quality inspections and surveys.

In order to unlock such gains, integrated cyber-physical systems that can gather and process relevant data and leverage machine learning to simulate outcomes are required [1]. In addition to setting up systems, the processes themselves have to be standardised sufficiently to make sure that the inputs from the processes are of adequate quality.

References:

[1] Schumann, F et al. (2017) From Raw Data to Smart Documentation: Introducing A Semantic Fusion Process For Cyber-Physical Systems. DOI: 10.5281/zenodo.3581079. Accessed 31 July 2020.

04   Digital knowledge databases are used at shipyards to make changes from one contractor to another easier

Modern shipbuilding is a collaborative effort of a wide network of actors. While some contractors may work at a yard for a long time, there is a trend towards piecemeal project work. Trends in faster labour turnover are resulting in shorter tenure among workers and problematic knowledge gaps. Improved experience documentation could capture the lessons learned, meaning that learning curves would not necessarily have to start over from scratch.

Creating task-specific instructions and developing them through experience capture protocols could help orientate new workers and contractors, making training less expensive. With a digital knowledge base, information could be codified to protect it from being lost.

As most people have a mobile device, instructions with multi-language support and visual references would be a smart way to guide workers. Equipped with a built-in feedback system, capturing user experience could be easily introduced as a daily operating standard.

For example, yard workers could be asked by their mobile device to reflect on their day in the yard, what challenges they saw, and how they attempted to overcome them, and what worked and what did not work. Captured as daily video journals, photos, and written stories, these can be referenced, tagged, and made searchable.

05   Innovations in ship hull coating paints are capable of achieving the same results as toxic anti-fouling paints do

Ship hull fouling, the clinging of organisms to the hull of a ship, is a major source of eco-inefficiency because of the drag that is incurred and the resulting need for increased energy for propulsion. One of the most effective anti-fouling paints, developed in the 1960s containing toxic organotin tributyltin (TBT), was banned by the EU in 2008 because of the biocide's negative impact on the marine ecosystem.

Substituting toxic anti-fouling paints with non-toxic, biocide-free paints with the same or better characteristics has been a challenge. The objectives of new coating innovations are to improve the coating's performance and duration while eliminating any negative environmental impact [1]. Research in nanotechnology has over the past 15 years delivered significant improvements [2]. While

experiments with nanoparticles have demonstrated improvements of the abrasion resistance of paints, the hydrodynamic qualities in terms of boundary layer and resistance of a non-leaching anti-fouling remain important.

As coating technologies develop their materials and processes, shipyards will need to adapt their processes and equipment, for example in the introduction, operation, and maintenance of next-generation spraying robots.

References:

[1] EU Ecodock project. (2007). Environmentally Friendly Coatings for Ship Building and Ships in Operation. Accessed 31 July 2020.

[2] Kordas, (2019). Novel Antifouling and Self-Healing Eco-Friendly Coatings for Marine Applications Enhancing the Performance of Commercial Marine Paints. Accessed 31 July 2020.

06   Task training is improved by augmented reality, virtual reality, and 3D simulation applications

With the help of digital tools, production practices can be captured digitally. This means that they can be analysed at a level of detail currently not possible. With digital tools, it should be possible to find more areas for improvement and to make the processes as efficient as possible (see also element 04).

Wearable cameras and sensors (for motion capturing, for example) can provide necessary data that can be reproduced and visualised with the help of augmented reality, virtual reality, and 3D simulations [1].

In this way, welding instructions can be delivered in formats that offer welders visualised AR guidance for the process, making desired quality standards known. In other words, the instructions are delivered as a form of experience.

References:

[1] Sharma, P. et al. (2019), Experience Capturing with Wearable Technology in the WEKIT project. Accessed 31 July 2020.

07 AI systems are used to control and manage warehouse inventory at shipyards

Building a ship requires hundreds of thousands of parts, which get lost, run out of stock, or expire as excess inventory, and so searching for parts is a daily activity in the course of shipbuilding. Automated warehouses could optimise warehouse operations, reducing costs and improving the timing of their staging.

By recognising patterns of consumption and making decisions based on them, warehouse supervision by AI would result in the automation of inventory control and management. Digital product identification protocols could keep a record of the specifications for each part, a file of its digital twin, its current location in the yard, and inventory levels. A variety of techniques such as scanning of barcodes or RFID tags could be utilised for tracking the parts, depending on the case in question [1]. Installing cameras that use machine vision would automate the tracking of items around the yard.

Advanced warehousing would allow for a more integrated AI logistics system. Having a digital twin of the envisioned end product itself could mean that the AI system could know which parts would be needed for each end product, and it would be able to check inventory status and order more parts if needed.

In other industries, such as the online retail industry, warehouses have already implemented digital inventory applications, which could be used as models for shipyards. As the work at shipyards is delegated to a large number of independent subcontractors, developing a solution for shipyards would need to take this into account.

References:

[1] Quest solution. (Undated). The pros and cons of RFID for inventory management. Accessed 31 July 2020.

08 3D scanning is standardised and used in class inspections

Ship inspections are a regular part of shipbuilding. Current practice in the industry sees ships and ship modules such as blocks being visually inspected on the spot. Inspections take time, are one-off events, and rely heavily on the human eye and memory.

3D scanning is already becoming a part of regular practice in shipyards. 3D scanning technology creates precision images that could be useful in carrying out

ship inspections, improving their accuracy and the detection of anomalies. This significantly shortens installation times and reduces cut-out materials.

The files from 3D scanning are not necessarily transferable, making it a challenge for stakeholders to share data [1,2]. Standards are required to ease their transfer and readability, and necessary agreements on accessibility and the sharing of intellectual property are needed. In the end, the ability to combine multiple scans from across the value chain is needed to construct a more complete digital twin.

References:

[1] Maritime industry processes in the Baltic Sea Region – Synthesis of eco-inefficiencies and the potential of digital technologies for solving them. p. 37. Accessed 31 July 2020.

[2] Blom, M., (2018). Shipping gone 3D? Accessed 31 July 2020.

09   Aerial drones perform incremental 3D scans at yards

Setting up 3D scanners at yards entail costly interruptions to industrial processes and workflows, arranging and moving the stationary scanning devices between locations, and dangerous climbs for technicians [1]. With aerial drone-assisted 3D scanning, taking measurements and producing the data to support digital twinning activities could be undertaken while minimising the disturbances to day-to-day operations. This could improve safety, and save time and money.

With their ability to offer higher perspectives from more angles, and their ability to enter hard-to-reach spaces, higher quality scans should be possible when compared with traditional 3D scanning. Making use of automated coordinates would result in a single point cloud, which would eliminate the time consuming work of combining point clouds from different locations together.

Drone technology, including autonomous solutions, is advancing and the equipment trend is towards more affordability [1]. Meanwhile, drones are improving rapidly, being recombined with other technologies and equipment, and are increasingly able to carry more weight for longer durations.

References:

[1] Faro, (2019). Think 3d first to commercialize 3d drone scanning. Accessed 31 July 2020.

10   Additive manufacturing (3D printing) is used to make spare (and replacement) parts

Serious delays and bottlenecks can arise at shipyards when parts cannot be located or are held up in the supply chain. When these problems are encountered, workers and resources often have to be reassigned to secondary or tertiary value-adding activities. Using additive manufacturing (3D printing) to produce spare and missing parts on the spot could mitigate some instances of this problem.

Additive manufacturing technology (AM) is becoming more available, more versatile and flexible, and capable of manufacturing different parts from different materials. AM / 3D printing of spare and missing parts is already happening in other industries to address supply chain problems; the automotive industry, for example, is using AM on spare parts to reduce the need for warehouse capacity [1].

An important obstacle for implementing AM is the lack of experienced workers that can determine how and when additive manufacturing would be suitable at yards. Furthermore, quality assurances about whether the AM part would match the features of the original part are difficult to acertain. Spare parts are often designed to be manufactured using traditional processes, which means that those manufactured by AM need to be redesigned. Therefore, using AM for spare parts provides the best results when its use in service has also been taken into account when the original parts being designed.

References:

[1] Deloitte Consulting, (2020). 3D opportunity for the supply chain: Additive manufacturing delivers. Accessed 31 July 2020.

11   Yards install microgrids to supplement their electric grids

Microgrids were developed as a solution to inconsistent power supply at remote industrial sites. However, as the maritime industry explores ways to decarbonise, microgrids at yards could supplement electric grids to optimise electricity use. Powering microgrids using solar, tidal, wind, hydrogen or other electrofuels will decrease yards' environmental footprint [1,2].

Microgrids at yards will enable the increased electrification of lifting and transport machinery, and will provide test beds for shore power for vessels to help the fleet

transition to cold ironing, a practice that is currently limited because city grids cannot bear the load when large vessels dock at yards.

The global microgrid market is growing at 11% per year, and is projected to reach $46bn by 2025 [3,4]. Ongoing challenges at yards include allocating the space—also for the installation of renewable energy generating technologies—and procuring the knowledge and resources to oversee and control it.

References:

[1] Flaherty, (2018). Schneider Electric creates microgrid at Long Beach. Accessed 31 July 2020.

[2] A. Zahetian-Hosseini, Y. Sangsefidi and A. Mehrizi-Sani, (2018). Multi-Port DC Microgrids: Online Parameter Adaptation in Model Predictive Control, IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society, Washington, DC, 2018, pp. 5314-5319, doi: 10.1109/IECON.2018.8591044. Accessed 31 July 2020.

[3] A. Misra, G. Venkataramani, S. Gowrishankar, E. Ayyasam & V. Ramalingam (2017) Renewable Energy Based Smart Microgrids—A Pathway To Green Port Development, Strategic Planning for Energy and the Environment, 37:2, 17-32, DOI: 10.1080/10485236.2017.11907880. Accessed 31 July 2020.

[4] Marketwatch.com (2020) Remote Power System Microgrid Market Share. Accessed 31 July 2020.

12 Autonomous, mobile, and flexible robots are used in welding in hard-to-reach spaces

In advanced shipyards, automated welding robots, equipped with machine vision and 3D model feature recognition, operate in parallel to construct hulls. They have made the yard a safer place while simultaneously providing higher-quality and more uniform welds. However, when welds need to be made outside the panel lines, automation becomes much more challenging. For example, panel robots can't reach into a double bottom hull structure or get inside tanks and other hard-to-reach areas.

Mobile and flexible welding robots will be able to crawl inside constrained spaces and perform welding without the help of humans. To achieve this, research and development must be conducted on new kinds of welding robots such as autonomous welding tractors and snake robots [1]. New flexible robots could also lead to the uptake of laser and plasma welding, not currently in use at yards.

References:

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13 Digital twin file formats are standardised and easily shared across stakeholders

Vessels are constructed to last many years which means that they will undergo multiple upgrades over their lifespan to incorporate new technology and enable them to perform new tasks. Such retrofittings and conversions require detailed planning, which is currently based on drawings. With the advent of digital twins, these plans can be digitised and the work can be simulated in advance to rehearse work, allowing planners to identify more details and potential problems before dry docking.

However, digital twin file formats are not easily shared. The technologies that are used for scanning and measuring vary across suppliers, resulting in non-compatible formats and proprietary software programs to be able to use them. The international classification society is currently working on creating cross-industry standards on the use of digital twins [1,2].

Digital twin standards would allow virtual delivery and virtual arrival to shipyards, meaning that stakeholders could better compare and choose the service providers after engaging in deeper specification and exploration. This advanced sharing of information would give yards more time to plan and prepare for vessel modifications, ultimately improving estimates, communication, and expectations with the shipowners and operators contracting the services. In turn, this would result in shorter dry docking times and more streamlined work processes at shipyards.

References:

[1] ISO Ongoing Projects. Accessed 31 July 2020.

[2] ISO/DIS 23247-1 - Automation systems and integration — Digital Twin framework for manufacturing. Accessed 31 July 2020.

14 Aerial drones, stationed at yards, begin performing basic services such as part delivery

Many working hours at yards are spent on inventory control, retrieval and staging of parts, and locating items and tools across the yard. Multipurpose aerial drones, stationed at yards, could support a number of these tasks to support yard workers.

As drone technology advances, new applications are being developed, and as such, the commercial drone market is expected to grow tenfold from 3.4 billion euros in 2018 to around 34 billion euros in 2023. [1,2]

An important task for aerial drones on the construction site would be the transportation of items to hard-to-reach places. This activity requires precision navigation and landing, and here we see drones being trained to recognise their surroundings with machine learning and using beacons to guide landing and the placement of objects. They are furthermore being equipped with sensors and lasers that can detect and measure obstacles, substances and distances of all kinds. Drones can even carry up to 200kg, and concepts under development are targeting carrying capacities of a half-tonne.

References:

[1] Joshi, D. (2019), Drone Technology Uses and Applications for Commercial, Industrial and Military drones in 2020 and the Future. Accessed 31 July 2020.

[2] McGee, P. (2019), How the Commercial Drone Market became Big Business. Accessed 31 July 2020.

15   Digital twins and 3D imaging technologies are used for virtual inspections at the time when a ship is delivered

Many modifications to- and deviations from- a ship's original design are made during construction. This results in the reality that a delivered ship never has the exact specifications as initially planned. This presents a challenge to the ship inspector, who identifies deviations from the design that are not always logged and accounted for.

These deviations from the design to the final ship become a problem again when subsequent work is being planned based on designs, but the actual ship being worked on does not match the schematics. In such instances, shipyards are required to re-work the plan and begin producing the parts when the actual ship comes into the yard, resulting in expensive delays.

Creating a digital twin of the ship as it is being constructed would give shipowners and yards better starting points for planning retrofits and rebuilds [1]. Other sectors incorporating digital twins into inspections have improved the effectiveness by 10% [2,3].

References:

[1] Future Market Insights, (2018). An Incisive, In-depth Analysis on the Ship Repair And Maintenance Services Market. Accessed 31 July 2020.

[2] Safety4Sea, (2019). The Digital Twin Concept explained. Accessed 31 July 2020.

[3] Safety4Sea, (2018). Ten technologies that will lead the way in the next five years. Accessed 31 July 2020.

16   Unmanned lifting vehicles displace tractor operators

Lifting, transporting, and staging ship components for assembly is an important part of shipyard operations. Currently, the machines that assist in performing these tasks are operated by drivers who connect, attach, and lift components so that they can be carried, pulled, or pushed into position.

In ports, for example, automated equipment to support operations is expected to increase by 20% from 7,7 billion euros to 9,2 billion euros by 2023 [1]. Automated guided vehicles (AGV) and lift AGVs are improving in their e-navigation capabilities, as well as in making unmanned connections with trailers. While it is sometimes difficult to recruit experienced tractor and lift operators, accompanying this transition will be the demand for remote oversight over the transport operations. [2]

AGVs and lift AGVs can operate without major changes to the infrastructure of most yards, allowing for gradual and flexible transitions, in parallel with procuring the skills required for operation. Benefits of autonomous operation include more precise positioning, lower personnel costs, improved safety, and reduced CO_2 emissions.

References:

[1] Icontainers, (2018). The future of automation at terminals and ports. Accessed 31 July 2020.

[2] Terberg.com, (2019). Roadmap to autonomous operation. Accessed 31 July 2020.

17   Digital twins are used to plan the retrofitting and rebuilding of ships before they arrive at the yard

Vessels that are brought to shipyards for repair, retrofitting, and repurposing, are inspected and measured upon arrival. This is a time-consuming task that extends the vessel's time out of operational service. These inspections will often reveal findings that result in unforeseen challenges to the work order, causing delays and adjustments to the original plan [1].

3D images of the vessel - also known as digital twins - could be used by the yard in order to better prepare for the work. Digital twins would provide more accurate measurements and information, thus improving the quality of planning, and reducing the needs for making ad-hoc changes [1]. Better estimations of the materials and skills required would make the process more efficient. A significant improvement could see yards producing matching replacement parts even before the ship starts its journey to the repair yard [2]. Furthermore, assessing and verifying the outcomes of the work could be accomplished more effectively.

Based on the results of the piloting activities conducted in the ECOPRODIGI project, a reduction of 40% in materials and 25% installation time could be expected. However, to make virtual arrival for repair a common practice in the industry, ECOPRODIGI recommends that the classification societies and stakeholders establish standards to ease the transfer and usability of 3D imaging. [3]

References:

[1] Aveva, (2013). On the beam: How 3D laser scanning technology brings new opportunities in ship refitting and conversion. Accessed 31 July 2020.

[2] ECOPRODIGI, (2020). Maritime industry processes in the Baltic Sea Region – Synthesis of eco-inefficiencies and the potential of digital technologies for solving them. p. 38. Accessed 31 July 2020.

[3] ECOPRODIGI, (2020). Much ado about standardization. Accessed 04 Sept 2020.

18   Warehouse operations performed by automated drones

Efficient warehouse logistics and operations at shipyards are critical to productivity. Workers use time to check databases and shelves for items, and often must revert to their memories, or the memories of others, to locate items.

Machine-assisted yard inventory would decrease the need for warehouse workers and free up the workforce for use elsewhere. Drones, either aerial or terrestrial, equipped with item scanners, could be used to improve the automation and validation of warehouse processes. Drones can be used to retrieve items, shelve new items that have just arrived to the shipyard, and control inventory.

Other industries such as grocery and online retail business can be used for inspiration [1]. Unresolved issues regarding the technology, including the adaptiveness of the robots and AI remain a challenge for their implementation at shipyards [2].

References:

[1] Tech insider, (2018). Inside a warehouse where thousands of robots pack groceries. Accessed 31 July 2020.

[2] The verge, (2019). Amazon warehouse robotics automation on AI 10 years away. Accessed 31 July 2020.

19   3D printers are used to print large blocks

In principle, there is no size limit in what can be 3D printed or constructed by additive manufacturing (AM) processes. Challenges, however, are the limitations provided in the trade-offs between scale, speed, materials, and quality. [1] At the largest scales, objects are printed on rail systems that move the object as it is manufactured.

Taking into account the raw material stock and machine maintenance, printers can operate 24/7. AM furthermore allows for faster iterative product designs and a decrease in raw materials. Capabilities are also developing: Concrete is used to produce houses; Plastics are used to make furniture, small cars and boat hulls; Metal structures are being printed for bridges, fighter jet frames, and jet engines. In 2017, one research project was able to additively manufacture a class approved nickel aluminium bronze alloy boat propeller [2].

While the advantages are clear, the technology needs large investments and there is a need for more research in, for example, testing the fatigue life of AM layered manufactured parts. The opportunities, however, are plentiful. For vessel subframes, wire DED AM technology could work over 10kg/h of metal with one industrial robot and one AM tool to complete a 150-ton block. While one robot could print this in 625 days, twenty robots cooperating could build it in little more than 31 days.

References:

[1] Formlabs, 2020. What Does Resolution Mean in 3D Printing? Accessed 31 July 2020.

[2] Damen 2017. World's first class approved 3D ship's propeller unveiled. Accessed 31 July 2020.

20 Composite materials are used in the construction of hulls for large ship

Novel composite materials are finding new applications in maritime and ocean industries, for example as underwater pump covers, offshore underwater structures, and floating oil storage tanks [1]. While composites have been used for the construction of hulls for small boats, high-speed naval vessels, and many other specialised vessels for some time, the use of composite hulls is spreading to increasingly larger ships.

Composite hulls offer a number of advantages over steel hulls. Significant weight reductions can be made, resulting in lesser fuel consumption and thereby lower greenhouse gas emissions. Developing new and more eco-efficient materials is thus needed. Corrosion maintenance and abatement costs could also be reduced, and less vibrations improve the vessel's underwater acoustic signature. It should though be noted, however, that current composite materials can not be recycled, and instead add to their environmental footprint.

The usage of composite hull materials for large ship hulls will require modifications or adjustments to current SOLAS regulations; if steel is not used, assessments are to be undertaken to demonstrate satisfactory fire and safety levels, i.e. at least equivalent to those levels achieved when using steel. However, developing and certifying them can create a new shipbuilding market which could boost competitiveness against those using traditional technologies [2].

References:

[1] Veazy, (2020). Chinese Firm Building Floating Oil Storage Tanks. Accessed 31 July 2020.

[2] Gardiner, (2019). FIBRESHIP demonstrates ship hull section built in fiber-reinforced composite. Accessed 31 July 2020.

Appendix 2: Methods

This report was developed as a part of the ECOPRODIGI WP4 on foresight. Foresight is widely used in public policy, industry, and research domains to generate knowledge about the future in order to be able to anticipate and plan for it. This appendix will briefly outline the contribution of a series of applied tools, primarily belonging to the domain of strategic foresight, that were used in connection with WP4. The methods deployed in the project integrate a horizon scanning with a modified consensus forecast and technology roadmapping. Most of the approach has been of a qualitative nature, but there are also quantitative elements.

Any approach to map the future is, by its very nature, interdisciplinary. As such, this report is primarily a product of a series of workshops, supported in the interim between by the post processing of the results, and preparation of engagement materials for each subsequent workshop.

Horizon scanning is the exercise of collecting and curating information and expectations about the future, that, when compiled, becomes a reference library of strategic intelligence. Humans are doing some form of scanning in our personal and professional lives every day—whether conscious about it or not. While Horizon Scanning often includes dynamic changes such as trends, in this report and in the work of ECOPRODIGI, horizon scanning was used to source discrete events expected to happen in the future, primarily 1) anticipated innovations 2) forthcoming policies, regulations, and standards, that are expected to impact Ro-Ro and Ro-Pax shipping in the future. This scanning activity was the result of desk research and interviews, and some were borrowed from the Interreg North Sea Region PERISCOPE project. This resulted in an extensive list of events that were then brought into workshops for assessment by the consortium partners. Those that garnered the attention of participants were developed further into venture concepts, or short descriptions of a discrete technology-market event that would result in a value-adding capability, or a policy event that would alter the rules of the industry in the future.

Discrete events that were deemed critical to the development of the industry were selected for the establishment of a forecast of their "time to accepted practice" or time to their "commercial availability." In workshops, these were presented to the consortium partners, who were asked to estimate when in the future they expect that the event would occur. Using the median of these guesses as the crowdsourced forecast, the events were placed on the roadmap to serve as an "anchor" in the roadmap, around which other elements could be organised and ideated. Subsequent workshops were used to re-assess the outputs from previous workshops and place a number of other discrete

events resulting from interim horizon scanning, new ideas developed during the post-processing of the workshops, and some were borrowed from the PERISCOPE project. Pictures of the roadmaps and videos of the presentations were taken to support in this content development.

The content was then moved online and shared across the consortium. The partners were asked to write 200-word descriptions of the different discrete events that described the problem that the technology was being applied to, and the current approach that industry actors are employing to accomplish the task (see appendix 1).

By this time, the three different roadmaps had been developed in parallel, one for Ro-Ro and Ro-Pax logistics, one for vessel operations, and one for shipyards. However, a decision was made that resulted in that two roadmaps were merged (logistics and operations) into an integrated Ro-Ro and Ro-Pax operations roadmap, in order to provide a more comprehensive assessment of the future because they had been borrowing and co-developing content across the roadmap. The shipyard roadmap was also borrowing and co-developing content from the other roadmaps, but in the end, the audience and professionals that would use the shipyard roadmap was established to be quite separate from those that would be using the integrated Ro-Ro/Ro-Pax roadmap.

When the roadmap had stabilised, outstanding questions remained on how to engage and incorporate the perspectives of the wider industry ecosystem into the roadmap. A survey with questions on each element in the roadmap was developed to this end that asked respondents to assess "how many years from now" that the discrete events would become "accepted practice" or "commercially available." At first it was distributed to the project team in order to validate the event and its clarity, and then it was distributed to other stakeholders in the project as well as practitioners. The median date for each of the events was used to position each of the discrete events on the roadmap.

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