Shipyards, Shipbreaking industry and the contribution of the Industry 4.0

POURNARA A.[1] and KONSTANTINIDIS F.[2]

[1]Department of Maritime Studies, University of Piraeus
[2]Department of Production and Management Engineering, Democritus University of Thrace

e-mail: anthpour@gmail.com

Abstract Over the past years, a trend to monitor and control the procedures in various industries, has been attempted. It is known that the ship recycling procedure produces waste that turn to be highly dangerous for the environment, while the threat of atmospheric emissions is not yet solved. Today the majority of the ship building and ship breaking industrial activities take place in countries of eastern and south Asia, under the worst conditions in terms of working safety and environmental damage, even though there is an established legal framework. On the other hand, the initiative of Industry 4.0 offers a solution that can handle the environmental hazardous conditions and improve the recycling procedures. Environmental degradation, climate change, air pollution and other major environmental problems are the outcome of the rapid industrialization of the past centuries. The rise of the Fourth Industrial Revolution with the probable benefits of the new technologies can constitute the "payoff" to the environmental damage of the past. Main technology pillars of the Industry 4.0 in such as Big Data, Analytics, Machine Vision, Collaboration Platforms, Simulation and Additive Manufacturing Augmented Reality, can scientifically diminish the environmental footprint of the ship breaking and ship building industry.

Keywords: Ship breaking, Shipyard, Industry 4.0, Digital transformation.

1.Introduction

In the recent years the maritime industry, following the global trends, focused on the environmental impacts that are connected with its activities, especially on the advantages of the adoption of new technological methods (Lee et al., 2017).

1.1 Shipyards and shipbreaking yards

Shipbuilding, ship breaking, and repair are a set of different processes and activities that form the life cycle of a vessel, followed by multiple challenges in terms of environmental footprint, sustainability and carbon emissions. According to Raveendran (2013) the shipbuilding and repair industry can be characterized as strategic as agriculture, with the first one sector leading the international commerce and the second one being the major nourishing source. Both sectors have an immense influence on a country's economic growth and development. The sectors of ship building, and repair have contributed to the financial achievements of major Asian countries, as Japan, China and South Korea. The last years South Korea dominates the world shipbuilding market (Raveendran, 2013).

Dismantling or breaking is the final stage of the operating life cycle of all types of a vessel, from the small cruise ships to the huge tankers, bulk carriers and container ships (Demaria, 2010).

Today the majority of the ship building activities are concentrated in countries of Southeastern Asia and in some European countries? (Tantan, 2020). Any vessel is constructed to complete a full economic cycle, that starts from the shipyard, goes through transport and trade activities, passes by shipyards for maintenance and repair and finally ends up in a ship breaking yard where it's valuable materials can be sold as secondary raw materials, completing its economic life cycle. Shipyards are defined as the most important infrastructure when it comes to the existence of a ship, as the shipyard is the place where shipbuilding and repair are conducted (Tantan et al., 2020).

Within the maritime community there are demonstrated initiatives for the construction of sustainable vessels in the field of ship building, that are connected both to the desire of cleaner production and to the necessity for attunement with the IMO regulations (Lister et al., 2015). At this point the key that would lead the shipowners and the related takeholders one step closer to the achievement of the Sustainable Development Goals is the adaptation of the 4.0 Technology.

1.2 The industry 4.0

The generation of the 4th industrial revolution was spotted in 2013, when the German government announced the 'Industrie 4.0' program to keep the manufacturing competitiveness among the global market. The Industry 4.0 (I4.0) aims in the full digitalization of the factory and the supply chain network, applying vertical & horizontal integrations from the independent shopfloor network systems to the supplier management ones, including transportation and warehouse systems. Apart from that, the guidelines of the revolutionary initiative speeds up the transformation of the procedures utilizing innovative technologies such as Augmented Reality (AR), Digital Twin (DT), Big Data, Internet of Things (IoT), Edge Computing, Additive Manufacturing (AM) and Machine Vision (Kagermann, 2015).

The factory of the future offers data interoperability, autonomous collaboration and self-awareness enabling a fully automated environment where machines interact with the human operators, intelligent systems monitor the manufacturing process for quality and safety obligations and assets predict their failures to reconfigure their settings or schedule maintenance tasks (Bonci, 2018). In the supply chain network, intelligent transportation systems are totally integrated with port terminal and warehouse management systems, orchestrating the procedures of logistics to maximize the satisfaction of the users without unnecessary delays and unacceptable deliveries (Dossou, 2018).

Despite the Industry 4.0 flowers as a manufacturing-oriented initiative to improve the operational excellence of the factory, the revolutionary philosophy has also been applied in the other fields such as civil infrastructure, agriculture industry, port etc. Especially, Michalis et al. proposed the "Civil Infrastructure 4.0" architecture that highlighted the digitalization of civil assets at network level and explained how the technologies can be applied in the infrastructure industry (Michalis, 2019).

In the maritime industry, Vaio (et al., 2019) analyzed the operational functions of the ports, discussing the term "Port 4.0" that improves the entire efficiency and the environmental sustainability of ports. In this paper, based on the existing standalone digital systems already developed for the shipyard manufacturing or other industries and the actual needs of the shipyard, it is described the shipyard processes and the affections of digital technologies through the entire lifecycle, emphasizing the value and gaps of the technologies and finally propose the conceptualization of the Shipyard 4.0. In general, the use of Industry 4.0 approach to the ship dismantling procedures (in conjunction with ship building and repairing) in the shipyards would support the economical (and social and environmental) pillar of sustainability and make shipyards an attractive option for ship recycling.

2.Conventional Shipyard procedures

The ship-building shipyard is the starting point of the vessel's life cycle. Both the activities of shipbreaking and ship repair can take place at a pier or a dry dock, while shipbreaking in third countries is often conducted straight on the beach (Demaria, 2010).

The latest regulations regarding the ship dismantling activities except of strict, are also characterized by the high cost of the demanded procedures and measures, turning the ship breaking process in certified green yards economically unsustainable for the shipowners (Jain et al., 2017). Shipyards and ship-breaking yards installed in most countries have to be licensed by the local authorities in order to be able to operate (Fariya et.al, 2016). Consequently, it's self-evident that those plants meet the necessary standards related to environmental protection and occupational health and safety.

According to Sinwoo (et al., 2018) it seems that the shipyard sector has a higher environmental footprint than ship building, and this leads to the conclusion that more focus should be given to the adaptation of the 4.0 Technology into that sector in order to transform it into a sustainable industry. One possible solution in order to achieve the mitigation of the shipyards' environmental footprint is the application of the highest technology and tools, both opportunities given by the Industry 4.0, focusing on the upcycling and reuse of steel as a valuable secondary raw material by the steel industry according to the principles of Circular Economy (Pournara et al., 2020).

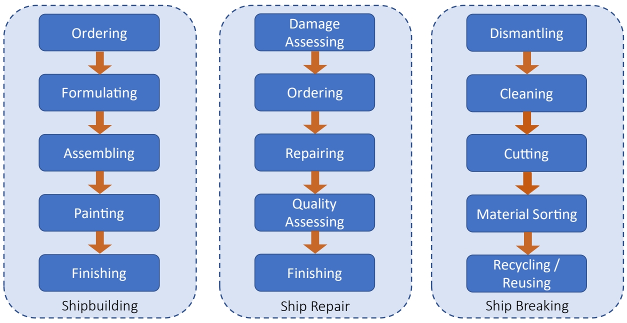

Figure 1. The isolated manufacturing processes of shipbuilding, ship repair and shipbreaking.

Ship building

The shipbuilding shipyard is the facility where the vessel's construction takes place. The key points and most important in the shipbuilding procedure are two: the design and the raw materials. In this shipyard the design and the raw materials are the input and the constructed ship is the final output. Through the shipbuilding process, welding and quality-related applications constitute the core of the shipbuilding activity.

Ship Repair

When it comes to the ship repair shipyard, the activity flow changes. The ship repair shipyard is the third-middle stage of the vessel's life cycle. In other words, that shipyard is the installation where the inspection and maintenance of an operating ship takes place. The most important/main elements in a ship repair shipyard are the inspection and the use of raw materials and spare parts.

Ship breaking

As it is already mentioned, the ship breaking yard is where the last stage of the vessel's life cycle takes place. In that case the input in the shipbreaking yard is the retired vessel and the final output is the steel scrap. The main activity in a ship recycling facility is the dismantling of the ship and more specifically the process of cutting. About 95% of the vessel's hull is made of steel, a highly recyclable and valuable raw material, which can be channelized to the steel industry to be upcycled as secondary raw material. Given the high value of steel as a raw material, the necessity for assurance of the traceability of steel flow is highlighted.

As previously described, the shipbuilding, ship repair and shipbreaking processes include various activities such as welding operation, cutting, dis-assembly tasks, quality inspection, material traceability, etc. Under the umbrella of Industry 4.0, cross-engineering solutions and improvements have been developed in the manufacturing environment improving the operations of the shipyards, that will be further explained in the following section.

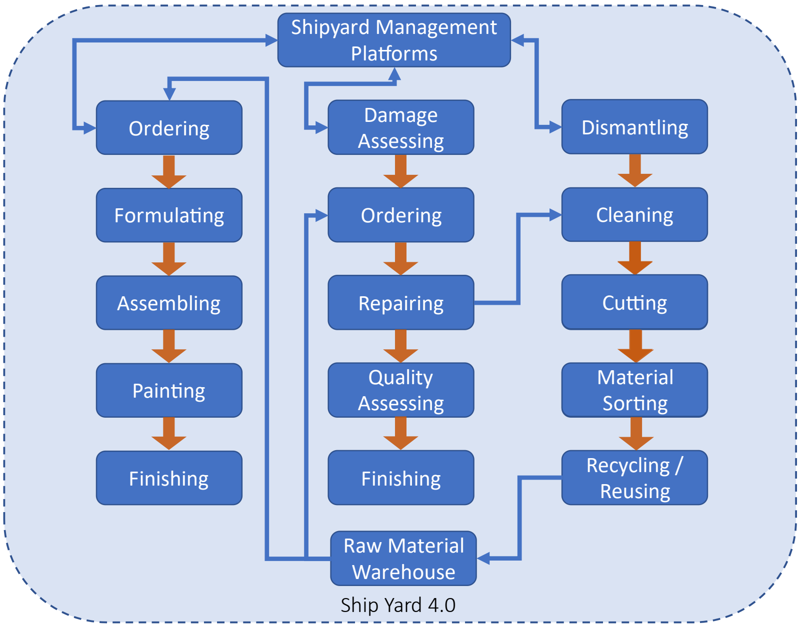

Figure 2. In the shipyard 4.0, the processes are integrated without silos in the entire ship lifecycle.

3.Interoperable Ship Yard 4.0

In the shipyard of the future, the three aforementioned isolated procedures are part of a main interoperable process where the management systems are integrated, the machines are aware of their actions and the data strengthen the workers. As presented in Fig. 2, interconnections are applied among the procedures. In the Shipyard 4.0 ecosystem, when a vessel was dismantling or repaired, a significant quantity of metals is gathered, cleaned, separated and stored to the "Raw Material Warehouse" to be furthered used in building or repair procedures, ensuring the minimum environmental footprint. To achieve this, cutting-edge technologies such as machine vision, digital twins, additive manufacturing, augmented reality are utilized that further described in the following paragraphs.

The sustainable production planning of ships requires customized steel planes plates? and optimized processes that reduce the cost with the minimum environmental footprint. In the ship salvage, sustainable induction-plasma cutting processes have also been invented, increasing the efficiency and the time of the cutting (Jones et al., 2020). In the production phase, autonomous self-welding stations equipped with machine vision methods and tailored for ship building production have been developed (Han et al., 2020). Despite these disruptive technologies meet the criteria of I4.0, advanced ship building platforms should be used to synchronize the cutting and welding operations, reducing the scraps and shortening the lead times.

One of the most critical points is the traceability of the raw materials through the production. In the manufacturing environment, traceability techniques have been developed using machine vision and artificial intelligence to track the material and update the progress over the cloud in real-time (Konstantinidis et al., 2018). This technology should be used in shipyard 4.0 to track the raw materials inside the shipyards from the shipbreaking to the ship reproductions. The yard's tracing platforms should also be integrated with out of the factory sustainable system that track the scrap (secondary raw material) from the shipbreaking yard to the steel industry.

A significant part of the procedures is the human element, which decides and performs quality metal inspection, maintenance performances, welding and material handling operations. Augmented reality empowers workers by providing them digital work instructions for welding and maintenance operations (Konstantinidis et al., 2020). Furthermore, in the "Shipyard 4.0", Augmented Reality headset or smartphones are connected with the warehouse management system and quality-related platform, supplying workers information about the next material movement tasks and the characteristics of the recycled parts. As result the overall efficiency of the yard will be increased by reducing the human errors.

Critical technologies of "Shipyard 4.0" concept are the Digital Twins and Additive Manufacturing. Digital Twin is a virtual reality replica of assets, fed by data to enable simulations in real-time. The adoption of digital twins transforms the production life cycle ensuring sustainability and prediction of future plans with the minimum environmental footprint (Pang et al., 2021). Nowadays, using Additive manufacturing in the shipyard, expert operators can produce spare parts with environmental-friendly materials without waiting for supplier's delivery. This technology is very promising for the shipyards as surveys show that additive manufacturing will be used to produce large parts of the ships without producing any scraps (Strickland, 2016).

4.Conclusions

The sectors of shipbuilding, ship repair and ship recycling have to deal with plenty of challenges in terms of environmental performance and resource efficiency. The greening of different stages of the ship building, ship repair and ship breaking procedures, can increase the productivity of the shipyards and turn them into contemporary, sustainable and competitive businesses.

Under that prism Industry 4.0 has the ability to cover the technological gaps of the shipyard's procedures using the valuable tools of Digital Twin, Augmented Reality and Additive Manufacturing, solving at the same time the problem of material traceability and supporting the reuse of raw materials following the Circular Economy model. Consequently, the technology of the 4.0 Industry can update the obsolete recycling processes and turn them to state of the art, contemporary and sustainable activities, synthesizing the "Shipyard 4.0".

References

Bonci A., Pirani M., & Longhi S. (2018). Tiny cyber-physical systems for performance improvement in the factory of the future. *IEEE Transactions on Industrial Informatics*, **15(3)**, 1598-1608.

Demaria F. (2010), Shipbreaking at Alang–Sosiya (India): An ecological distribution conflict, *Ecological Economics*, **70,** 250-260.

Di Vaio A. and Varriale L. (2019). Port 4.0: Accounting, controlling and reporting tools in the organizational and operational processes for sustainable performance.

Dossou P. E. (2018). Impact of Sustainability on the supply chain 4.0 performance. Procedia Manufacturing, **17**, 452-459.

Fariya S., Manfaat D. and Suastika K. (2016), Technical Analysis of the Development of Ship Recycling Yard in Indonesia, *The 2nd International Seminar on Science and Technology,* **9**.

Han Y., Xu Y., Kou D., and Hou Z. (2020). The Key Technology of Robotic Autonomous Welding in More Subsections of Large Ship. *Transactions on Intelligent Welding Manufacturing*, 109-126

Jain K., Pruyn J. and Hopman J. (2017), Material flow analysis (MFA) as a tool to improve ship recycling, *Ocean Engineering*, **130**, 674-683.

Jones J. E., Rhoades V. L., Mann M. D., Surufka T. S., Holverson T. E., and Dydo J. R. (2020). New Hybrid Induction Cutting Processes for Ship Salvage and Recycling. SNAME Maritime Convention. The Society of Naval Architects and Marine Engineers.

Kagermann H. (2015). Change through digitization—Value creation in the age of Industry 4.0. *Management of permanent change*, 23-45, Springer Gabler, Wiesbaden.

Konstantinidis F. K., Gasteratos A., and Mouroutsos S. G. (2018). Vision-based product tracking method for cyber-physical production systems in industry 4.0. In 2018 IEEE International Conference on Imaging Systems and Techniques (IST), 1-6, Krakow, Poland

Konstantinidis F. K., Kansizoglou I., Santavas N., Mouroutsos S. G. and Gasteratos A. (2020). MARMA: A Mobile Augmented Reality Maintenance Assistant for Fast-Track Repair Procedures in the Context of Industry 4.0. *Machines*, **8**, 88.

Lee T. and Nam H. (2017), A Study on Green Shipping in Major Countries: In the View of Shipyards, Shipping Companies, Ports, and Policies, *The Asian Journal of Shipping and Logistics,* **33**, 253-262.

Lister J., Poulsen R.T. and Ponte S. (2015), Orchestrating transnational environmental governance in maritime shipping, *Global Environmental Chang*e, **34**, 185–195.

Michalis, P. Konstantinidis F. and Valyrakis M. (2019). The road towards Civil Infrastructure 4.0 for proactive asset management of critical infrastructure systems. In Proceedings of the 2nd International Conference on Natural Hazards & Infrastructure (ICONHIC), 23-26, Chania, Greece.

Pang T. Y., Pelaez Restrepo J. D., Cheng C. T., Yasin A., Lim H., and Miletic M. (2021). Developing a digital twin and digital thread framework for an 'Industry 4.0' Shipyard. *Applied Sciences*, **11(3)**, 1097.

Pournara A., Mai S., Kalavrouziotis I. and Sakkas V. (2020), Circular Economy in the Ship breaking industry: Recovery of precious materials and opportunities of utilization by the industrial sector. Case study of steel, *Online Symposium on Circular Economy and Sustainability, 1-3 July 2020, Alexandroupolis, Greece.*

Raveendran K. (2013),. Organizational Study Report at Cochin Shipyard Limited, Caarmel Engineering College, Perunadu.

Sinwoo L., Dong-Woon N., Dong-hyun O. (2018), Characterizing the Difference between Indirect and Direct CO2 Emissions: Evidence from Korean Manufacturing Industries, 2004–2010, *Sustainability*, **8**, 2711.

Strickland J. D. (2016). Applications of additive manufacturing in the marine industry. Proceedings of PRADS2016, **4**, 8th.

Tantan M. and Camgoz-Akdag H. (2020), Sustainability concept in turkish shipyards, *Sustainable Development and Planning,* **241**, 269-281.