ALL HANDS ON DECK

European work heritage in shipwright for present and future

TECHNOLOGY FORECASTING

MODULE 10

Co-funded by the
Erasmus+ Programme
of the European Union

(Module 10) Technology Forecasting

Objective

At the end of this module, the student will be able to know the new technologies applied to the manufacture of ships, as well as tools and techniques to identify trends and technological prospects.

Duration

22 hours

Training content

Practices

- Technological surveillance in shipbuilding to detect future trends in the sector.
- Computer systems for the optimization of production processes.
- To determine innovative materials suitable for each purpose: weight reduction, anti-corrosion, promoting sustainability, etc.
- To determine new technologies for shipbuilding based on each need: safety, sustainability, efficiency, etc.

Theoretical knowledge

- Digital transformation: The evolution of digital transformation in shipbuilding 4.0.
- Technological surveillance: sources of information, surveillance factors and identification of trends.
- Innovative materials for shipbuilding and knowledge of their advantages and disadvantages.
- Coatings: New technologies for naval coatings.
- New technologies for shipbuilding: Augmented Reality, 3D printing, robotics.

Contents related to professionalism

- Digital transformation: Keeping up to date with the evolution that the naval sector has undergone, as well as its digital transformation and its future forecasting.
- Technological Surveillance: Identifying information needs within shipbuilding, as well as relevant information sources to implement a prospective and technological surveillance system.

- New technologies: R&D lines and new technologies applied to shipbuilding related to materials and industry 4.0.

Summary

1. Digital transformation in shipbuilding

The digital transformation of the shipbuilding sector is perhaps one of the most important challenges that the industry has faced in recent years; a sector that was severely affected by the financial crisis of 2008, which underwent a huge restructuring, over the years and after this restructuring, has evolved to implement the shipyards 4.0 and the technologies attached to it. The arrival of new technologies such as Artificial Intelligence (AI), the Internet of Things (IoT) or probabilistic models have left behind others such as 2D plans or outdated formats.

The advance of new platforms or product data managers, the need to comply with the different ISO manufacturing standards, as well as tighter control of spending on primary materials and the obligation to be more sustainable have led the sector to invest in modernisation.

1.1 Evolution of new technologies in shipbuilding

In the 1980s, the first software for the shipbuilding industry appeared, these programs controlled most of the analysis or manufacturing tests that ships needed during their commissioning. Stability analysis, filling capacity in case of accident or sinking, or finite element analysis, which were very repetitive, could be automated thanks to this software.

The main problem that arose was the enormous manpower required for the manufacture and assembly of the ships, together with the limited capacity of the designers and engineers to use the new technologies offered by this new software, such as the production of 2D plans and designs, and they were more inclined to keep drawings and plans on paper.

In the 1990s, a new generation of software appeared, including Product Data Managers (PDM), software used for the integral control of changes in manufacturing, thanks to which it was possible to control the large number of changes that ships underwent during the production process.

PDMs facilitated the work at all levels, from the creation, with the inclusion of 3D programmes that improved exponentially on the 2D ones, to the improvement in the control of manufacturing, materials and predictive analysis of the effort and alignment of the boats.

The 3D software offered solutions such as Dynamic Model Updating (hereinafter DMU), capable of displaying plans, measurements and solutions on a screen without the need to stop production due to different errors. It was also possible to simulate the flow of materials to control costs, as well as the assembly and assembly processes of the different parts of the ship.

These advances meant that much more complex ships could be built, although major problems arose in the area of manufacturing time and material costs.

In the 2000s, attempts were made to correct the different failures that had arisen previously, and the first digital shipyards appeared, much more computerised, with a new generation of software that offered a great capacity for improvement in all processes, some of which were:

- Greater and better control of the tasks in the production process.
- Improvement of the analysis capacity of the different stress or material tests of the ships.
- Improvement and control of the expenditure of materials, specifying materials for each ship.

All these improvements in the processes, both at the manufacturing and assembly line level and at the material and economic level, produced a higher quality in the production of boats, an improvement in delivery times and greater economic and material control.

With the arrival of the first digital shipyards during the 2010s, improvements in PDM and the implementation of Product Lifecycle Management (hereafter PLM) began to be added. They were a series of processes for the integral control of a product's lifecycle, from its conception and 3D design with the help of CAD, its optimisation during manufacture, and the application of all the materials used during its creation, in addition to the fact that these materials, once their use is complete, can be harnessed for the manufacture of other ships.

The main objectives sought with these improvements and the implementation of PLM were as follows:

- Much more affordable manufacturing.

- Use of more sustainable materials and reuse.
- Improved reliability in the production line.

During this stage, a huge financial crisis was installed all over the world, affecting the naval sector, which saw its income and aid for the manufacture of ships cut. For this reason, the improvements that were intended to be implemented with PLM were very important for the survival of the naval sector.

By the 2020s, digital shipyards will give way to shipyard 4.0, implementing technologies in manufacturing (3D, augmented reality, additive manufacturing among others), but above all focusing on Digital Twins.

Technologies such as robotics or Artificial Intelligence (AI), oriented towards cost and labour-saving control, will also be implemented in the analysis and stress or assembly tests.

With the implementation of new technologies in shipbuilding, the participation of all the companies involved in shipbuilding is also sought, improving communication and, thus, creating much more integrated work platforms.

The objectives to be achieved at this stage are as follows:

- Improvement of the production chain
- Greater control of the lifecycle of the final product
- Use of ISO standards in shipbuilding.
- Planning of models with 3D multi-CAD

The use of 3D models in multi-CAD environments to produce new ships facilitates the work of designers and engineers, using 3D models of ships already built and whose aerodynamic and hydrodynamic behaviour is already known, engineers have a plan with which to start working and can make different modifications based on the needs they have.

The JT™ format (ISO14306: 2017) defines the syntax and semantics of a file format for the visualisation and 3D interrogation of lightweight geometry and product manufacturing information derived from CAD systems, using visualisation software tools that do not require the full capability of a CAD system. This standard is applicable to the shipbuilding sector, thanks to the use of augmented reality technology and 3D; and the standardisation of this language in PLM or PDM will further help the shipbuilding industry to further evolve in all its processes.

Other more specific standards in the shipbuilding sector include:

- **ISO 12215-5 2008:** applies to the determination of design stresses and strains, and to the determination of scantlings, including internal structural members of monohull small craft constructed of fibre-reinforced plastics, aluminium alloys or steel, glued wood, or other suitable boat construction material, with a hull length according to ISO 8666, between 2.5 and 24 m.
- **ISO / TC 8 / SC 8 STANDARDS:** these standards provide guidance to the shipbuilding industry, they include several ISO standards focusing on shipbuilding, design, technology, typology or topology; these ISOs have been updated as new technologies and innovation have been implemented in the shipbuilding industry.
- **ISO 47.020:** shipbuilding and marine structures in general, including offshore structures, except offshore structures for the oil and natural gas and deep-sea mining industries.

To conclude this point, the new technologies, which has been used for some years now in shipyards 4.0, are evolving at a fast pace thanks to the arrival of other technologies such as Big Data, Internet of Things, Blockchain or probabilistic models.

One of the most innovative technologies is the digital twin technology, that can be defined as: the digital representation of an element, asset or physical system, describing its characteristics and properties as a set of equations; a ship, an engine, an electrical panel or even a much more complex system such as a port. In its strict definition, the digital twin encompasses from the micro atomic level to the macro geometric level.

To obtain a result, the digital twin relies on mathematical models, historical data and the flow of digital data, generated, for example, by the IoT or AI.

It has its own hardware to acquire and work with the generated data, as well as software for the representation of this data.

2. Technology Surveillance in shipbuilding

2.1 Introduction to Technology Surveillance

For organisations, it is essential to have an information channel free from the enormous amount of data; this level of information saturation makes it difficult for organisations to carry out research. Competitive companies seek the necessary information for their innovation process, and this information must be clear, concise and fair. Therefore, with the aim of filtering this information so that only what is necessary reaches these organisations, the implementation of a technology watch system was initiated.

According to UNE 166006: 2018 (I+D+i Management: Monitoring and intelligence system), Technology Watch is "an organised, selective and permanent process to capture information from outside and within the organisation on science and technology, select it, analyse it, disseminate it

and communicate it, convert it into knowledge to make decisions with less risk and anticipate changes".

This system has a series of steps or phases, which must be followed with the utmost precision for its correct and effective operation, the phases are:

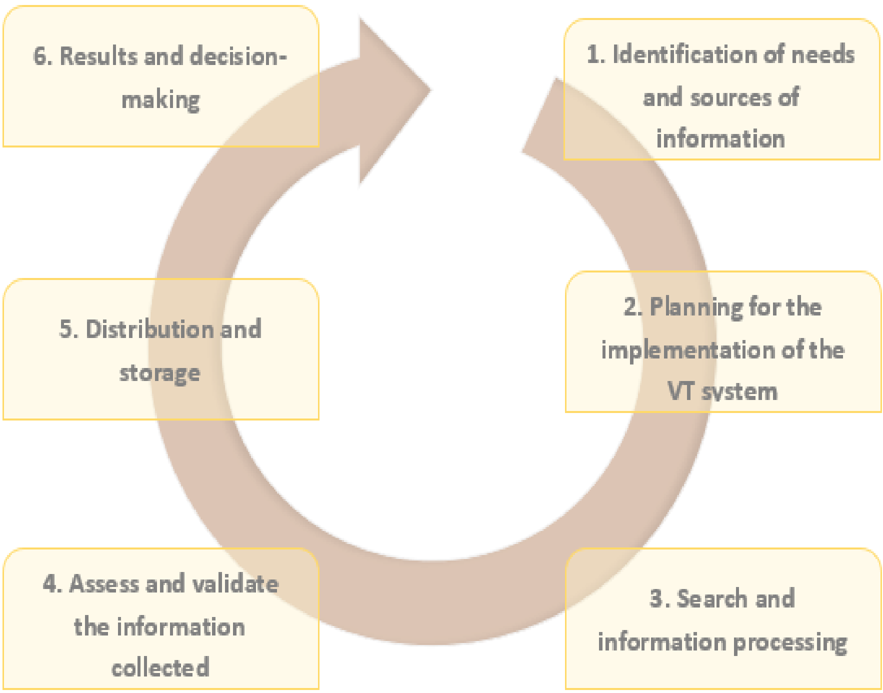


Figure 1: Stages of VT 1

2.1.1 Identification of needs and sources of information

Companies or organisations need to be aware of their environments, the latest technologies offered by the sector as well as the products that may appear on the markets and their evolutions. It is also important to be aware of reports, projects or patents related to the sector environment where these companies or organisations operate. Another objective of the technology watch is to investigate what competitors are doing, to know what products or patents they are proposing and to try to outdo them in research.

Therefore, the implementation of a technology watch system in organisations or companies is very important to respond to all the above questions, obtaining results, information on a previously raised topic and anticipating future needs.

The identification of needs within organisations is one of the main starting points for the implementation of a proper technology watch system. To this end, and as a first step within the technology watch system, it is essential to know the critical surveillance factors. The Critical Surveillance Factors, according to the UNE 166002:2021 standard, are issues, external to the organisation, whose evolution is crucial for its competitiveness.

Critical Surveillance Factors are usually grouped into general areas depending on their nature. Some groups are listed below:

- Technology
- Market
- Legislation
- Economic evolution
- Social demographic factors
- Competition

The search for different sources of information is another relevant point, these sources are necessary for the retrieval of quality information:

The main sources of information that can feed the technology surveillance function are:

- Direct personal contact with competitors, suppliers, research centres, universities, etc.
- Participation in seminars, colloquia, congresses and other scientific events.
- Specialised magazines
- Patents

2.1.2 Planning for the implementation of the VT system

At this point, the needs of each organisation should be reviewed, with two main objectives in mind:

- Search for research in unknown areas
- Follow-up of news in areas we already know

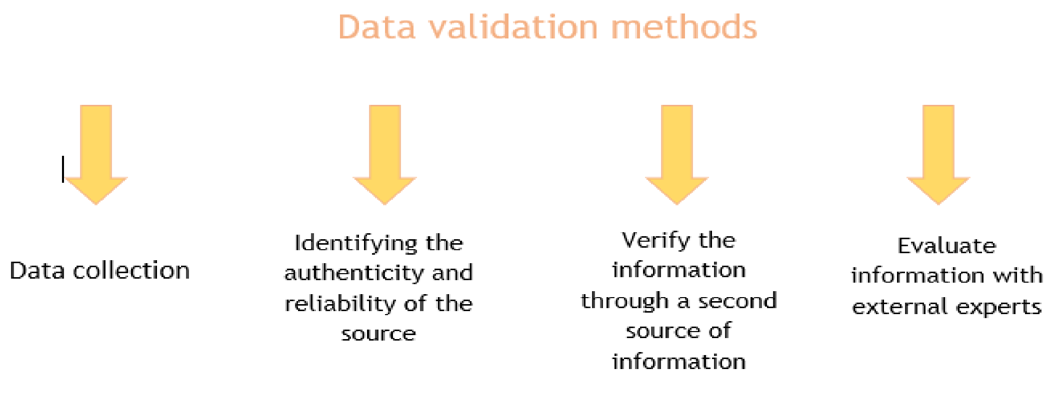
This whole process must be continuous and constant, as the VT system must be carried out systematically, periodically and updated on an almost daily basis to maintain the structure within the organisation.

2.1.3 Search and information processing

Once the most relevant sources of information have been selected, the different searches for the previously selected objectives are started and, after this action, the collection and selection of information is carried out.

The recovery of information is very important to achieve the objectives set, discarding invalid information and giving authenticity to the information that is useful, this information must be validated and corroborated for its subsequent use, generating a final product, some examples are: technological bulletins, state of the art or patent reports. A correct and effective search is linked to a correct selection of the sources of information; the more concrete and reliable the selected sources are, the better the results obtained will be.

Therefore, search strategies and actions are carried out, using, among others, descriptors, keywords, Boolean operators or different segmentations



such as time or place.

2.1.4 Assessment of information

After the collection of information, its treatment in storage, analysis, description and organisation should be as professional as possible, to be able to keep the information as close to hand as possible in future consultations.

After the information has been collected, it must be thoroughly analysed to discard the data that is not valid and keep the data that can provide value to the different possible decision-making processes.

Figure 2: Methods of validation

The analysis of the information resulting from the different searches must be carried out by experts in the field, analysts with sufficient creativity and capacity to be able to interpret the resulting data.

The aspects to be considered in this phase are:

- Integrating data from different sources, seeking synergy.
- Interpretation of the data, both the most accurate and the most relevant for decision-making.
- Creating infographics with the data to make it easier to understand.

All this analysed information will be valid when it can satisfy the previously detected needs, but it is necessary to know if the analysed information is truthful and reliable, with different methods.

2.1.5 Distribution and storage

The last two steps of a good surveillance system are the storage of the selected and validated information and the production of results once all valid information has been analysed.

The information must be distributed according to the needs of each department within the organisation itself, using the different communication and information transfer channels available, monitoring the entire distribution process to ensure the correct distribution of this information.

The storage of this information is also important; it must be stored following the processes previously implemented within organisations so that it can be retrieved as easily as possible by the members of the different departments.

2.1.6 Results and decision-making

The results obtained from the analysis of the information that was considered acceptable are the own knowledge that the organisation acquires, helping in future decision-making with a solid knowledge base.

The UNE 166006:2018 standard divides the knowledge acquired into two parts: actions derived from technological vigilance and environments of interest to the organisation.

Actions derived from the VT can be conditioned by factors external to the system itself, some of the main categories being:

- **Anticipation:** Prior decision-making after analysis of an environment and its possible changes.
- **Taking advantage of opportunities:** Exploiting identified advantages.
- **Risk reduction:** Proposals to overcome access to a market or a specific technology.
- **Lines of improvement:** Overcoming identified weaknesses.
- **Innovation:** New I+D+I ideas or projects.
- **Collaboration:** Support or collaboration with new identified partners.

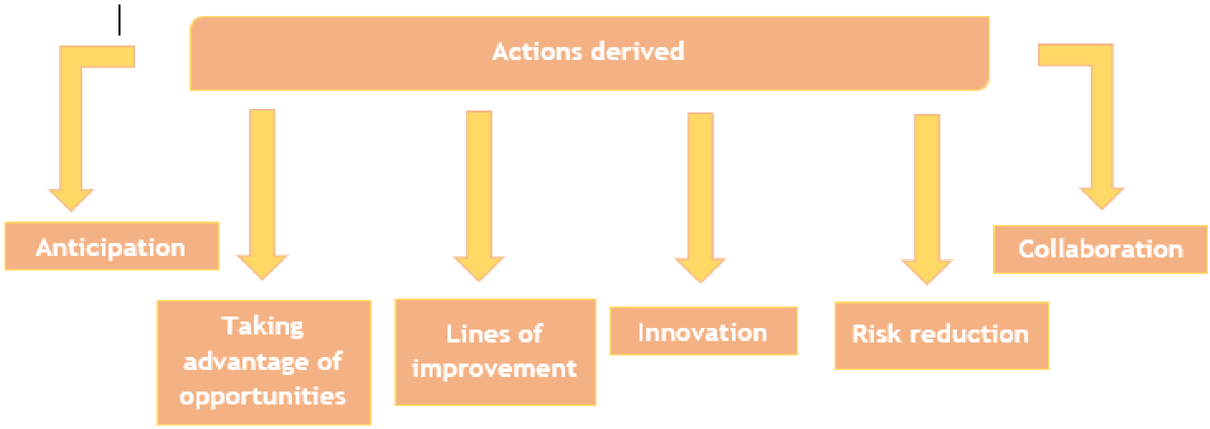


Figure 3: Actions derived from VT

The environments of interest for the organisation are another of the knowledge that is acquired after the analysis of information; thanks to this type of results, a series of interests can be obtained in new sectors or technological branches to begin new research, or to abandon technological environments due to lack of advances in the field.

This information includes aspects such as:

- Assessing technological or market options
- Impact and interaction between technologies, products and processes
- Evolution of technologies
- Investment opportunities
- Social trends

2.2 Identification of technological trends in shipbuilding

After explaining how a technology watch process should be carried out in an organisation, we are going to focus our knowledge on the shipbuilding sector to identify the different technological trends within the sector. To do this, we use the VT process, step by step, using the shipbuilding industry as a case study.

The process will be carried out from the beginning and will serve as a practical example of how to carry out a correct technological monitoring system.

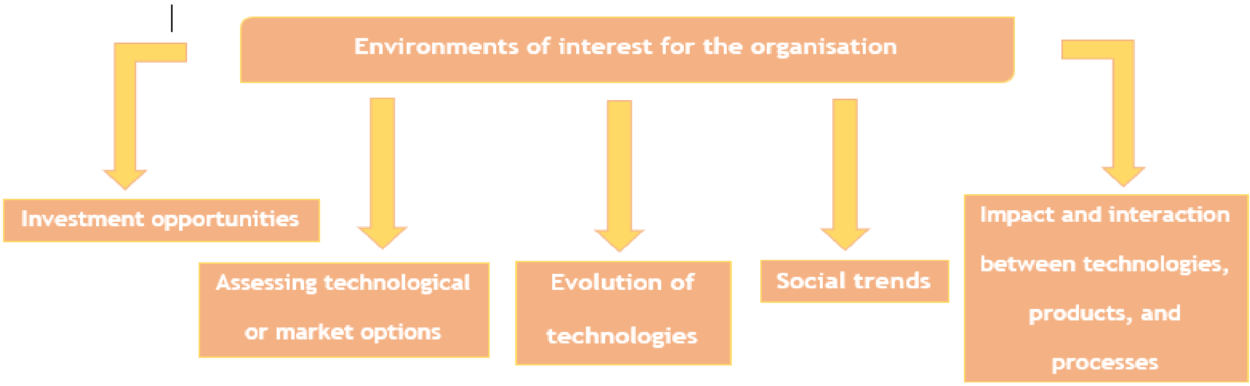


Figure 4: Environments of interest for the organisation

2.2.1 Identification of needs and sources of information

The shipbuilding sector has been evolving until the implementation of Shipyards 4.0 and the use of technologies such as IoT or AI. One of the main critical factors would therefore be the 4.0 technologies applied to the shipbuilding sector, both in the design of new ships, as well as in their construction, maintenance and commissioning. It is important to add that 4.0 technologies include, in addition to IoT or Artificial Intelligence, blockchain, robotics, Augmented Reality, 3D printing of parts or plans, and digital twins, among others.

The search for ships that pollute less, that are more efficient in their start-up, with technologies such as hybrid engines or the incorporation of intelligent sails, as well as the implementation of systems that can lead a ship to fully autonomous driving with different technologies such as Artificial Intelligence or the Internet of Things can be encompassed to shape another critical factor.

Ships need to be increasingly efficient and sustainable, and this is an important point in terms of their manufacture and fitting. Research into new, lighter or more flexible, efficient and environmentally sustainable materials is progressing rapidly: new polymers, metal alloys or reinforced carbon fibre, together with coating materials, especially anti-corrosive ones. Materials are therefore another field of research to be considered in this sector.

Therefore, the main critical factors on which information analysis will focus with the main objective of identifying technological trends in the shipbuilding sector are:

- Innovative materials and coatings in shipbuilding
- The ship of the future
- Technologies 4.0 in shipbuilding

With the choice of the critical factors for the selection of the different trends, we have completed an important part, but we need some terms or keywords to be able to make a much more specific selection of information; each critical factor must be accompanied by a series of keywords to refine the searches and obtain different information, group them according to the needs and analyse them to know whether or not they can be given validity. Thus, our organisation will have detailed and validated information on all the aforementioned needs.

Critical surveillance factor	Keywords
Innovative materials and coatings in shipbuilding	Sustainable materials, innovators, anti-corrosives, lightweights, adaptable, ecological
The ship of the future	Energetic efficiency, low emissions, autonomous ships, electric motors, hybrid motors
Technologies 4.0 in shipbuilding	Robotics, electronics, Artificial Intelligence, Internet of Things, 3D

	printing, AugmentedRreality, shipyard 4.0, digital twins, blockchain

2.2.2 Identification of sources of information

The sources of information must be of quality, reliable and in line with the need for information.

All factors have tools in common such as:

- Patent databases: Espacenet, Patentscope, invenes, USPTO
- Databases of I+D+i projects: Cordis
- Databases of technology: Seimed
- Repositories of scientific articles: Researchgate, Scholar, ScienceDirect, Mdpi and Nature
- Major shipbuilding companies

2.2.3 Evaluation of information

After analysing the sources of information, using the right keywords, and focusing on the three critical factors, the information gathered should be evaluated. This process consist not in loading up with as much information as possible, but in selecting the information that we need for this case.

With all these elements, and after a thorough analysis of the different resources obtained through the critical factors and keyword searches, the trends in the shipbuilding sector are oriented towards three very specific branches.

Materials, both at the level of boat construction and coating, with the intention of making a more sustainable, lighter boat that can better withstand the harsh conditions of the sea.

Another trend is the search for a ship that pollutes less, with lower fuel emissions, taking advantage of the regulations implemented in 2020 by the IMO on fuels with greenhouse gas emissions and

their reduction, as well as the implementation of ships with greater autonomy to save fuel and improve transport routes.

Finally, the trends that investigate the implementation of 4.0 technologies and their applications in this sector include the use of Artificial Intelligence to facilitate the construction of the ship, as well as the Internet of Things; digital twins to have a 3D plan of the ship at all times and to be able to correct faults in real time, saving time and economic costs; 3D printing of materials for use in the construction phase; the use of robots to facilitate both assembly and commissioning tasks and those of maintenance and fault detection; and the use of Augmented Reality in the process of creating ship models to be able to modify plans and parts without actually building them, saving costs.

These trends are explained and detailed step by step in the following points of this syllabus.

2.2.4 Decision-making

After collecting data, reviewing and analysing the different sources of information, and after selecting the different types of trends that will be most useful and discarding the less valid points, we must put all this information to good use, and explain how we should use it within the organisation so as not to lose anything that could be valuable. All this information and trends generate a series of products that must respond to the objective of implementing the surveillance and intelligence system; success lies in the capacity for analysis and projection that they offer.

Some of these products are:

- Technology watch reports
- Newsletters
- Reports on products or materials
- State of the art

3. Innovative materials and coatings in shipbuilding

The need to innovate in the different materials and coatings for the construction of ships aiming at their constant improvement and evolution, and in order to meet the IMO's objectives in terms of pollution and more sustainable ships, has led the sector to research new materials, both sustainable and efficient. Some of them such as metal, wood or fibres are already well known, but constant innovation looks for them to be more efficient; other materials such as graphene or new polymer fibres are also emerging, which can offer good performance for this sector.

Coatings are another area where research continues to improve their use and performance. Coatings such as pigments and additives are the most widely used, but the key is to continue researching to find new materials that improve existing ones.

3.1 Anticorrosive materials

Boats are made of different materials, such as steel, wood, aluminium or fibreglass, but all these materials have a common problem when in contact with water: corrosion and wear.

There are several types of corrosion, but the one related to boats is galvanic or electrochemical corrosion. This occurs when two dissimilar metals are immersed in water (electrolyte), causing the lower potential metal to lose mass to the higher potential metal (corrosion pile).

Corrosion can be affected by different reasons, generally the main factors affecting this problem are salinity, temperature, oxygen content, sulphur, chlorides, etc.

To avoid this problem, there are different solutions, mainly the coating of the main material (steel, aluminium, fibre or wood) with different types of materials such as paint, polymers or resins, both synthetic and natural.

The solutions to this problem, which can cost up to 30% of the manufacturing budget, are diverse, mainly anti-corrosion paints to coat the different parts of the boat that are in contact with water. In this sense, innovation in different paints by adding other materials, additives or pigments has been growing during the last few years, especially from 2012 to 2018[1], which shows the need to improve the different solutions available to prevent corrosion on ships.

The most researched material during the last few years to be combined with paint are epoxy resins, some natural and some artificial; 30%[2] of the total number of patents generated during the years 2010 to 2021 belong to applications using this material, which shows the great importance it has over the rest of the materials.

Other materials that are being researched to improve their performance are:

- Solvents: These are added to coatings to disperse the rest of the paint components and reduce their viscosity, thus facilitating the application of the coating. It is common to find combinations of several solvents in paint formulations.

- Pigments: Insoluble substances of organic (natural) or inorganic (synthetic) materials that are dispersed in the coating to give colour and opacity to a substrate or to improve its mechanical resistance. There are different types of pigments depending on the need of use and the material to be applied. Some of the most important are functional pigments, reinforcement pigments, inert or filler pigments, metallic pigments or white pigments.

- **Additives:** These are materials that improve the physical and chemical properties of the coating, such as drying, gloss, stabilisation, etc. There is a great variety of these additives, adaptable to different materials and uses, the most important being biocides and fungicides, thickeners, and driers.

In addition to the different materials applicable in paints, research with other materials has not stopped generating new solutions

[1]https://worldwide.espacenet.com/patent/search/family/051908153/publication/CN104164161A?f=publications.pd%3Ain%3D19810101-20211231&q=ti%20all%20%22anticorrosive%22%20AND%20ta%20all%20%22ship%22

[2]https://worldwide.espacenet.com/patent/search?q=ctxt%20all%20%22anticorrosive%22%20AND%20ctxt%20all%20%22ship%22%20AND%20pd%20within%20%222010%202021%22%20AND%20pd%20within%20%222010-01-01%3A2021-12-31%22

such as graphene, a material that can be combined with practically anything to make any element, part or shape.

Graphene is used as an additive element, in this case using talphene, a functionalised graphene-based additive that takes advantage of the intrinsic properties of graphene, such as its high chemical resistance, strength and impermeability.

3.2 Sustainable and efficient materials

The need to build more efficient and sustainable ships due to factors such as the carbon footprint or climate change has led the sector to carry out new lines of research in the recycling of materials. Their aim is to avoid further pollution and to manufacture ships that are cheaper, more sustainable and more efficient.

One of the keys is the recycling of disused ships, and the use of parts that can become raw material in the manufacturing chain of new ships; the other key is to find more sustainable and durable materials, extending the life of ships, so that they can be recycled at the end of their useful life and prevent them from continuing to pollute. Shipbuilding is a process that pollutes from the planning and creation of the ship to the end of its life.

Among the different materials that can be recovered are fibres, polymers or steel itself, which is the main driver of the ship recycling industry.

While it is true that metal is the main material for shipbuilding, it is a material that pollutes from the beginning of its manufacture to the end of its useful life and is difficult to recycle, which is why the International Maritime Organisation (IMO) regulated in 2009 a convention that gave guidelines and standards for the recycling of ships at the end of their useful life. For this reason, other types of steel are being also investigated, such as HTS steel, which has experienced a great growth in its use in shipbuilding.

Wood is another of the most widely used materials in shipbuilding, but its slow growth has forced the sector to investigate new solutions that include the use of this material, which is also recyclable and sustainable. Research has led to the use of treated and modified wood. These are woods that, in principle, do not have the right characteristics to be used in the manufacture of naval parts, but if they are thermally or chemically treated, they undergo an improvement in their main characteristics, which makes them valid for the use of naval composites, while remaining a sustainable and recyclable material. Finally, fibre-reinforced polymers (FRP) are another material used for shipbuilding, although they are polluting materials in the production phase, as the fibres have their origin in petroleum or its derivatives and are therefore not sustainable. In recent years, the emergent solutions include the search for fibres of natural origin and natural compounds, far removed from the oil industry. Research into new fibres of plant origin such as flax, bamboo, hemp, kenaf and jute have significant potential to replace glass as reinforcement in composite materials, offering interesting properties such as specific stiffness, impact resistance and ductility.

As for composites, those from renewable sources are replacing traditional oil-based synthetics. In addition, due to the limitations of thermoplastic resins, such as their high viscosity and resistance to low temperatures, thermoplastic resins are being developed from vegetable oils.

The manufacture of boats with these materials is still complicated due to the lack of research into more sustainable materials, and because the manufacture of materials such as steel or chemical fibres are, to date, the cheapest and safest option. Therefore, there is still a long way to go to be able to manufacture 100% sustainable and efficient boats, and for the moment the combination of sustainable materials is the most widely used option.

In this sense, the RAMSSES project carried out by different European companies and partners is a pioneering project in the search for sustainable and efficient materials for boat construction. The particularity of this demonstration project is that the whole cycle is being developed and tested, from product design, the development of new resins, alternative fibre architectures, new joining solutions, the extension of infusion technology, the validation of large composite structures and their risk-based design, all under the auspices of the classification society Bureau Veritas (BV).

3.3 Lightweight materials

Fuel consumption and the resulting emissions of the main pollutants into the atmosphere by ships, is driving the industry to search for and research lighter and more resistant materials to avoid higher fuel consumption and the pollution it causes. Even more so since, as of 1 January 2020, the International Maritime Organisation (IMO) introduced a new regulation for the maritime sector whereby the overall limit for sulphur content in bunker fuels must be reduced from 3.5% to 0.5%. To achieve this reduction, ships must be lighter and more efficient.

As with the other types of more efficient and environmentally friendly materials, research into new materials in this field focuses on the combination of different types of material; innovative examples include:

- **Basalt fibre:** a material of volcanic origin. The yarns are made from a molten, lava-like material that is passed through a spinneret and then vitrified by flash cooling. Basalt, the main component, is supplemented with various minerals to improve and guarantee the chemical and mechanical characteristics of the fibre. It is a material of sustainable origin, and its characteristics make it much lighter and harder than other materials, as well as being 100% recyclable, the only drawback being the enormous amount of energy required to obtain it through its different chemical and thermal processes.
- **FRP:** fibre reinforced polymers, the increasing use of these types of combined materials has generated several research and projects due to the enormous potential that can be developed. An example of this is the GreenLight project[3], whose main objective is to develop bio-based composites with intrinsic fire safety for use in load-bearing structures in shipbuilding. Other research objectives will be to cover manufacturing and recycling concepts. In addition, the FIBRESHIP

[3] https://www.compositesworld.com/news/greenlight-project-explores-fire-resistant-and-bio-based-frps-for-structural-lightweight-design-in-ships

project[4] aims to overcome current market difficulties and technological gaps to make more innovative and lightweight shipbuilding feasible. The use of these composite materials will generate a significant reduction in the structural weight of the vessel which will imply a reduction in energy consumption and an increase in payload capacity, among other benefits such as cost reduction.

4. The ship of the future

The need to reduce fossil fuel emissions and the obligation to seek new methods to make ships more efficient has led the shipping industry to research and implement new systems for ships to operate without the need to consume diesel and petroleum derivatives, fuels that are highly polluting. The environmental report on European maritime transport[5], presented by the European Environment Agency and the European Maritime Safety Agency, states, among other things, that this sector is responsible for 13.5% of all greenhouse gas emissions from transport in the EU. Therefore, the International Maritime Organisation (IMO) published a standard in 2020, obliging all ships to reduce their sulphur emissions from 3.5% to 0.5%. This new regulation has prompted the industry to start using new forms of propulsion for ships, from hybrid engines (electric and diesel), electric engines and engines powered by liquefied natural gas or LNG.

Another of the improvements that are intended to be implemented in the sector is the capacity of ships to move with greater autonomy without the need to be controlled by a person, autonomous ships with their own management capacity, controlled by artificial intelligence from intelligent or shipyards 4.0.

[4] http://www.fibreship.eu/
[5] https://www.eea.europa.eu/publications/maritime-transport/

4.1 Energy efficiency and low emissions

As we have already explained, the new regulations imposed by the IMO oblige the shipping industry to look for solutions so that ships do not pollute at current levels. New solutions are already being used in the construction and commissioning of medium and large ships, although it is still too early to see them applied to ships carrying large cargoes.

The most innovative solutions in the sector are the following:

- **Hybrid engines (electric-diesel):** The system that is most used at present mixes the power of a diesel-powered mechanical engine with an electric motor capable of moving the boat and servicing the consumables on board. This is supported by a series of solar panels that are installed on the roof of the boat, with an adequate capacity to recharge the boat's batteries. Its functionality is simple, if the diesel engine handles the operation, the engine layout will be greater, more power, while the electric motor is responsible for recharging the batteries to generate electricity to the consumables of the boat. When it is the electric motor that is working, the boat does not generate any type of pollution although its power decreases. The electrical part of the system consists of the electric motor, a generator, a series of batteries and the solar panels together with an accumulator. This system achieves lower fuel consumption, as the diesel engine will not need to always run thanks to the electric motor, which will have a certain capacity depending on the number of batteries in the system.
- **Electric motors:** 100% electric motors are another novelty in the nautical sector, and their research and development are on the rise, just as in the automotive sector. While it is true that the manoeuvrability and power of an electric motor is less than that of a petrol or diesel engine, they are 0% polluting and therefore much more sustainable. The technical characteristics of the engines are conditioned by the characteristics of the boat, but the system is the same for all boats. The system consists of an electric propulsion motor, a generator, a rectifier and an

inverter. The charging batteries can store electricity, which will be transformed by the rectifier from alternating to direct current, which will be responsible for supplying energy to the propulsion motor to move the boat's propellers. Further research is being conducted about this system, looking for more powerful engines and systems that can accumulate more electrical charge in their batteries, and even systems that are capable of self-recharging.

- **Liquefied natural gas engines (LNG):** Natural gas-fuelled engines are nowadays widely used in the naval sector, as natural gas is an abundant fuel, easy to transport and store for consumption in the engines prepared for it. This system generates between 90% and 95% less sulphur during its use, which is why, although it is still polluting, it is the system that is best received within the naval sector due to the combination of its low emissions and the price for ships. Although this natural gas fuel system greatly reduces sulphur emissions and complies with IMO regulations, the new regulations that will come into force in 2050 on greenhouse gas emissions will be even more restrictive leaving LNG in a position of not compliance with these regulations.
- **Hydrogen engine:** With the various problems that have arisen with LNG, research has focused on the use of hydrogen in engines, which requires adapting the engine supply system and adding a complex fuel cell system to generate the hydrogen. This system requires a large amount of energy to produce the resulting hydrogen for the engine. One of the problems with hydrogen engines is the enormous expense of creating the hydrogen, as well as the fact that the production of this element generates a great deal of pollution due to the need to use fossil fuels burned to produce it. Another problem is the need for further research into hydrogen reactions, as it is an element that has unique properties, including the ability to detonate and to be more flammable than natural gas. These properties, if

properly targeted, can offer better solutions than LNG. Although, they are also dangerous and further research is needed to address this solution. Therefore, research is being carried out on how to generate H2 naturally, by means of electrolysis or through renewable energies to be able to use this system. If hydrogen can be generated in a way that does not pollute, it will be a 100% green and renewable fuel.

- **Other systems:** While these solutions may be efficient and reduce sulphur and CO_2 emissions by large amounts at best, they are not solutions that can meet the new pollution regulations that will come into force from 2050 onwards. Therefore, the need for further research into greener and more efficient alternatives remains a priority.

  One of the main research projects focused on the quest for zero emissions is being conducted by researchers at Northwestern University[6]. The invention would use a solid oxide fuel cell that would process the fuel in a closed loop. The fuel would be converted into energy and the CO_2 produced in the process would be 100% 'liquefied' in a tank for later use as fuel or for permanent storage.

  Other alternatives such as biodiesel, with vegetable or animal origin, is processed with oils and is a material that will generate much less CO_2 and sulphur emissions, although they will still be polluting fuels.

  Ammonia is another material that is being analysed as a substitute for fossil fuels. Now, research must continue on how to avoid manufacturing ammonia from carbon, to avoid polluting the manufacturing process, always aiming for 0% greenhouse gas emissions.

4.2 Introduction of autonomous technology on ships

In the automotive sector, autonomous cars are a reality, in aviation there are drones or planes capable of flying themselves. In the naval sector,

6 https://news.northwestern.edu/stories/2021/08/the-case-for-onboard-carbon-dioxide-capture-on-long-range-vehicles/

the technologies needed to generate autonomous ships are advancing rapidly. The integration of technologies such as Artificial Intelligence, the Internet of Things or the use of sensors to monitor all parts (physical and digital) of the boat make the idea of a boat driven by a computer possible, or even prototypes are already being tested to check their functionality.

The IMO carried out a study/analysis of the state of the art of all the technology surrounding this sector, to know the progress of the autonomous maritime surface ships (called MASS). This analysis tried to find the capabilities of the autonomous ships according to the standards that the organisation itself proposed to apply or are already in operation. With this study, different levels of autonomy were obtained, which were identified and explained as follows:

- **Grade 1.** A ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and sometimes unsupervised, but with seafarers on board ready to take control.
- **Grade 2.** A remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are on board, available to take control and operate the ship's shipboard systems and functions.
- **Grade 3.** A remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
- **Grade 4.** A fully autonomous ship: The ship's operating system can make decisions and determining actions on its own.

This new technology is highly complex, which is why the IMO in its study has been obliged to analyse several maritime safety treaties to certify that ships with autonomy are reliable and safe, some of the treaties that were put into practice were:

- **SOLAS:** International Convention for the Safety of Life at Sea
- **FTP:** Fire Test Procedures
- **INF:** Carriage of Irradiated Nuclear
- **COLREG:** collision regulations

- **CSC:** Convention on Safe Containers

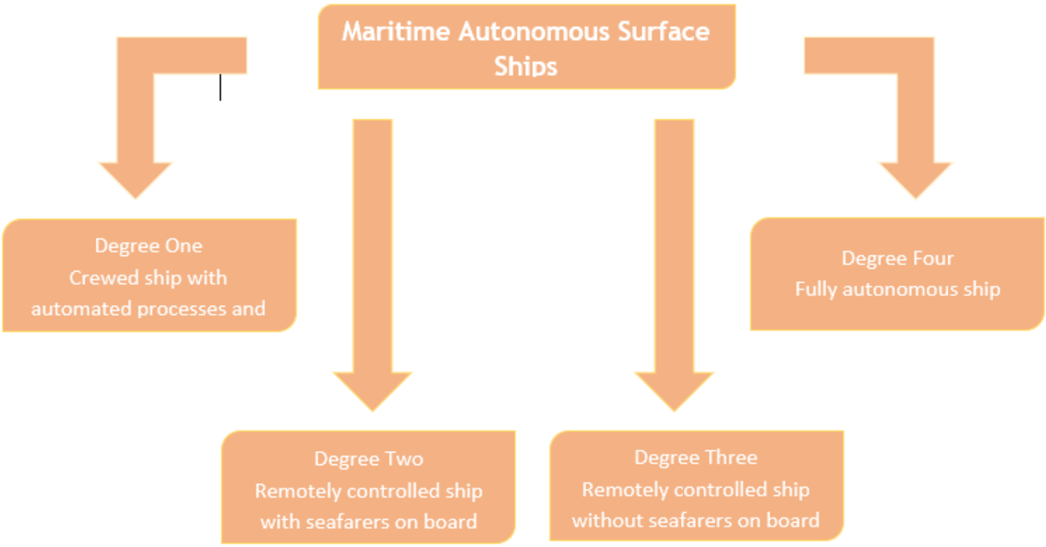


Figure 6: Classification MASS

Autonomous ships encompass a large amount of technologies that are applied in the total control of the ship's systems. It is necessary to have a constant monitoring of all its variables to be able to know at all times how and where the ship is. We have previously mentioned the use of artificial intelligence to drive the ship, and the use of sensors to have knowledge of the state of the ship; some of the technologies applied in the ship are:

- **GPS:** Global Positioning System
- **INS:** Inertial Navigation System
- **IR:** optical and infrared cameras
- **LIDAR:** Light Detection And Ranging
- **RADAR:** radio detection and ranging
- High resolution sonar
- Microphones
- Wind and pressure sensors
- **IA:** Fully transparent, port-accessible decision-making process

5. Technologies 4.0 in shipbuilding

The new technologies that will be implemented on ships and in ports related to Industry 4.0 range from the idea of creating the ship, its design and assembly, to its operation and recycling. Previously we have tackled with the use of new materials for their manufacture, with different objectives such as being more sustainable, consuming less and being lighter. Another of the research focuses on the use of technologies that make the boats more efficient and with more moderate consumption, as well as having greater autonomy in the integral management of the whole boat and its

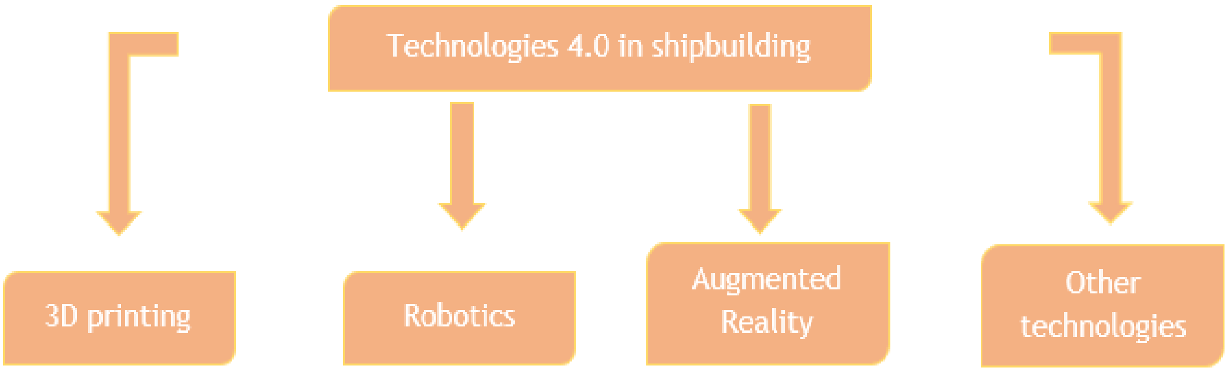


Figure 7: Types of 4.0 technology

systems.

Shipyards 4. 0 are beginning to have an enormous importance in the naval sector, the creation of ships on paper will be replaced by digital prints, 3D plans or digital twins, the assembly of the whole ship will cease to be manual and robots will be in charge of carrying out the operations. The control of the manufacture and assembly of the ship will be seen through Augmented Reality or the digital twin, being able to replace parts before final assembly. The emergence of technologies such as the Internet of Things to improve the connectivity of the ship with its systems or Artificial Intelligence for the self-control of the ship itself will facilitate the entry into Industry 4. 0 in the naval sector.

5.1 3D printing

3D printing applied to the naval sector is a fairly new technology. The use of additive materials such as those seen in previous points has led shipyards to the creation and assembly of 3D printers to create much lighter parts, but with a great resistance and usability. There are different types of 3D printing applicable to the naval sector, namely:

- Extrusion uses a heated nozzle to extrude material, such as plastic, metal or cement, to form layers that are bonded together as they cool.

- Vat polymerisation uses focused ultraviolet light to harden layers in a vat of photopolymer resin.
- Powder bed fusion relies on laser or electron beams to fuse layers of powdered material, such as powdered metals, together.
- Material jetting employs a printhead to lay down layers of UV-curable material, which are then cured by successive exposure to UV light.
- A binder jetting printhead deposits droplets of binder fluid onto an energy substrate, curing it in layers.
- Foil lamination uses ultrasonic welding or adhesive to bond paper or metal ribbons. The final shape is completed by subtractive processes.
- In directed energy deposition, a multi-axis nozzle extrudes material, usually metal powders, which are then melted by lasers. This can be used for repairs or to add to an existing object.

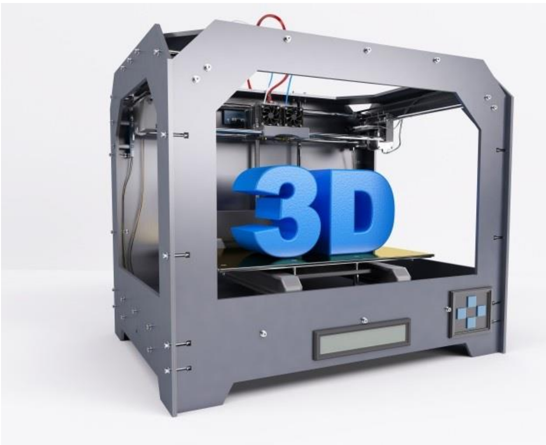
The use of 3D printing and additive manufacturing has evolved from the creation of small parts that can go inside a boat, to the manufacture of a complete boat. Today, there are different examples of boats created from 3D printers, something that was unthinkable a few years ago.

The main advantages of including this technology in the naval sector are:

- **Complex designs:** It allows the manufacture of very complex parts in shape, which are not possible with conventional manufacturing techniques (subtractive, moulding, etc.). Possibility of customising products and producing short series, reducing the necessary investment.
- **Rapid re-design:** Very high re-design speed (hours or days) compared to other manufacturing techniques (weeks or months).
- **Speed:** Parts can be manufactured as prototypes or products just after finishing the digital CAD files corresponding to their design. This avoids downtime in the production process.
- **Ease:** Complex parts can be manufactured easily, due to the automated digital manufacturing nature of the process.

- **Material savings:** Almost all the input material is part of the final part, unlike subtractive techniques where all the subtracted material is discarded.
- **Reduced need for joining techniques:** One-off parts can be produced, which may be manufactured in a single process, but which would require manufacturing in several parts to later be joined together if other manufacturing techniques were used. Less management and maintenance.
- **Environmental benefits:** Less use of fluids, less need to use and produce tooling, less energy expenditure during production, creation of lighter parts (due to design), which equals lower fuel costs in transport, local manufacturing, less need for storage due to production speed and reduced part size.

3D printing has great solutions for the naval sector, the manufacture of much cheaper, lighter and more resistant parts has led this sector to increase its interest in being able to manufacture elements in 3D. Thus, companies such as the Spanish company Navantia, which has several projects related to additive manufacturing and 3D, or the team of the Centre for Advanced Structures and Composites at the University of Maine, which has manufactured the largest 3D ship in history, are at the forefront of the use of this technology, which provides increasingly greater solutions to the shipping industry.



5.2 Robotics

Robotics is a technology that offers endless options in multiple sectors, within the naval sector and with the arrival of Industry 4.0 and Shipyards 4.0, the applications for the use of robotics are very broad. From the manufacture of ships with the use of collaborative robots oriented to the assembly or welding of parts, the maintenance of ships once built, to the use of different robots incorporated into the ship that can monitor the various processes such as loading and unloading of materials, safety or fuel consumption.

The use of robots has evolved to become an indispensable technology in sectors such as the automotive and industrial sectors. The arrival of collaborative robots or Cobots has facilitated the integration of these robots in assembly lines to help operators in the manufacture and fine-tuning of different products or materials such as vehicles, cabinets or warehouse control. In the shipbuilding industry, robots offer different solutions within the assembly line of ships, their main uses can be:

- **Cutting robots:** Steel cutting is perhaps the most easily automated task. For many years, almost all shipyards have had machines for cutting steel sheets, cutting profiles and even cutting pipes. These are very basic robots with offline programming and hardly any sensors to perceive their environment. They are in cells isolated from the operators. Such cutting machines or robots can use oxy-fuel, plasma and laser cutting technology. Usually, the programming of these robots is done offline.
- **Welding robots:** If we talk about robotised welding, we may find ourselves in the star area of robotisation in the naval sector. The implementation of welding robots has implied a leap of enormous magnitude, all the large shipyards in the world have robots for the welding of the elements that make up the ship. The technology available today makes it possible to automate the welding of:
    - The steel plates making up the hull, decks or bulkheads of the ship.
    - Welding of the reinforcements of the above elements (longitudinal and transverse).
    - Welding of larger elements (bulkheads) for the fabrication of blocks.
- **Robots for sheet metal forming:** With less implementation in shipyards, we find, for example, robots for sheet metal forming (giving the steel the curvature necessary to manufacture the steel sheets that form the hull of the ship). This is a traditionally manual

task (almost artisanal) for which mechanical means are usually applied (cylinders, presses, etc.) or mechanical and thermal means (providing heat at specific points before mechanically shaping the steel).

- **Robots for blasting and painting:** Another task in shipbuilding where robots are starting to be used is blasting and painting. The use of robots in these tasks can lead to great savings in time and cost, mainly due to the savings in scaffolding assembly.

As far as Cobots are concerned, the naval sector has neglected the research and implementation of this type of robot, as, for the moment, they are robots with a low weight load capacity, something that is very important and necessary in this sector. Advances in other sectors with Cobots will also be useful in the future for the naval sector, adding that these Cobots have the capacity to function in other robots, in this case in AGV robots or automatic Guided Vehicle, which are transport robots with unlimited mobility depending on the model.

As for the latest robotic innovations in the naval sector, there are new developments in the use of this technology; some of them are:

- **Hull cleaning robots:** With an increasing awareness for environmentally friendly shipping. Technologies that help to increase fuel efficiency and reduce carbon dioxide emissions are in high demand. Hull roughness management by hull cleaning robots can play a key role in this respect. The build-up of marine organisms on the ship's hull, also called biofouling, reduces the ship's speed by up to 10%. To compensate for the drag, it is said that a ship may have to use approximately 40% more fuel. Toxic coatings are sometimes applied to prevent biofouling, but they pose a threat to marine ecology.

- **Robot ship surveyors:** Traditionally, inspecting large cargo ships for cracks, corrosion or any wear and tear to ensure they meet increasing safety standards is a time-consuming task for surveyors. In addition, they must risk their own safety to climb into every nook and cranny of the ship themselves. Therefore, robotic technology is emerging that can assist in this process and save owners time and money by improving the accuracy and quality of these important inspections. These robots can be controlled via a wireless transmitter with live video streaming and their four infrared distance sensors help detect edges and obstacles.
- **Anti-Piracy Robots:** The dumbbell-sized robot can be fired from cannon within 5 seconds and can survive throws up to 120 feet. Its magnetic wheels help it to crawl on the ship's hull before it reaches the deck. It can be controlled by joystick from the nearby command centre. The robots can keep eye on piracy activities using its cameras that can see even in darkness using infrared mode. The developer aims to quickly bring marsupial robot deployment system which enables the robot to break apart to eject smaller robots.

5.3 Augmented Reality

Augmented reality, or AR, is a technology that is increasingly gaining market share in different sectors, some of which, such as manufacturing, automotive and education, already have huge advances in this field, and its capabilities for use are limitless. AR can be defined as: a technology that allows interaction between virtual environments and the physical world, enabling both to intermingle through a technological device such as webcams, mobile phones (IOS or Android), tablets, among others. Its main features are:

- Combine the real and virtual worlds
- Offering real-time interaction
- Adapting to the environment in which it is inserted

- Interacting with all the physical capabilities of the environment (in three dimensions)

Augmented Reality is a technology widely used in other sectors, as it was mentioned above, but in the naval sector it has started to be implemented a few years ago for different uses, taking advantage of its multiple applications. The naval sector has had to make enormous economic efforts to evolve and not fall behind other sectors.

In training, for example, it can be used for operators to learn different assembly or maintenance processes with virtual models of the ship they are building.

Other utilities that this technology offers in the naval sector are:

- **Maintenance and inspection:** Maintenance and inspection tasks can also be facilitated through Augmented Reality. Applying this technology with a digital model to observe the parts to be analysed, detecting faults or problems without the need for a physical inspection of the ship saves time and maintenance costs.
- **Productivity and operations:** Augmented Reality has unlimited possibilities to increase productivity and operations in the shipbuilding sector. For example, the ship's crew can look at the entire ship in the form of a digital model without the need for large computers. The digital model can help to analyse the vessel from all angles, highlight areas of interest, show the main engine, etc. Therefore, the interaction becomes more realistic and natural than seeing the boat physically. Another useful aid that Augmented Reality can offer to the maritime sector is e-navigation and improved navigation safety.
- **Shipbuilding and ship design review:** Shipbuilding and ship design review is another area where Augmented Reality can be beneficial. Virtual models can replace real models and evaluate the design in the early stages. This can help reduce the cost of shipbuilding by allowing designers to analyse, update or alter designs, thus speeding up the whole process and achieving the desired results with much less effort, both physically and economically.

- **Direct control on the bridge of the ship:** The AR can not only be used with the boat in port. During voyages the AR can facilitate the process of piloting and controlling the boat, offering views of the route to avoid risky situations, monitoring the boat's constants (speed, wind, weather, etc.) or providing real-time response to any problem with the boat, so that it can be located and solved without the need to go to port.

This technology has not yet reached a sufficient degree of maturity for use. Except for some shipyards in the Netherlands or Singapore that have been implementing these processes, it is still an application that must grow and improve to achieve its full potential in the naval sector.

5.4 Other technologies

After the arrival of these technologies with the implementation of shipyard 4.0, there are others that can be as important as the previous ones, from the implementation of IoT (Internet of Things), cybersecurity or the use of the digital twin, very useful applications with diverse uses in the naval sector.

- **Internet of Things:** This type of technology, which comes hand in hand with Industry 4.0, is mainly used to improve connectivity between the different components of the ship and the people on board or in port. The need to have all systems under control, from consumption, to the route or the amount of cargo the ship is carrying, makes this technology a very useful tool to rely on. Improving connectivity between the port and the ship is an indispensable matter for the improvement of routes and safer and more efficient transport. With IoT and its tools these needs can be solved very favourably and thus make journeys faster, more efficient, and safer.

Another of the uses offered by this technology is the control of the construction of the ship and the information generated during this process. Thanks to the sensors and cameras, an operator can always know and without waiting times, what the current state of the ship is in the manufacturing process, as well as knowing the possible faults and their correction to save time and economic costs.

- **Digital twins:** Among the different uses of the Internet of Things is the application of the digital twin, a technology that makes it possible to link the physical and virtual environments of the vessel using applications such as cloud computing or machine learning. In the virtual environment, the data obtained during the entire lifecycle (from design to maintenance) is analysed to generate simulations that allow corrective measures to be identified and preventive actions to be recommended. Some of the main advantages offered by this technology are:
    - Optimisation of the design or operation of systems.
    - Predictive, state and condition-based maintenance.
    - Support workers with up-to-date information.
    - Production planning based on real-time situation instead of historical situation.
    - Identification of deficiencies by comparing the physical system with its digital models.

Digital twins can also help to address the high level of concern about cyber security threats as cyber-physical systems and connectivity multiply. Cyber-physical systems and connectivity multiply. Corporate IT and OT systems are exposed to more and more external networks and devices through the Industrial Internet of Things, leading to an increasing number of assets being remotely monitored, controlled, and maintained.

- **Cybersecurity:** Cyber threats in the shipping industry are becoming increasingly common, with the advent of information and communication technologies and other technologies such as IoT and AI, which have led to the industry being under enormous threats from hackers in all its operational systems, from the route to the cargo data contained in the ships themselves. There are different types of cyber-attacks, divided into untargeted and targeted attacks:

Untargeted

  - **Malicious software:** This is an attack aimed at accessing or damaging a computer from the ship's or carrier's network, including Trojans, spyware, ransomware, viruses and worms.
  - **Data hijacking:** This is a cyber-attack using software that encrypts data files on individual workstations or databases, to which the user has no access until a ransom is paid.
  - **Phishing:** This is an email attack on multiple user addresses to gain access to personal and/or confidential information, request a visit to a fake website and other fraudulent activities.

Targeted

  - **Social engineering:** This is a non-technical approach to cyber-attacks, which is used to manipulate and coerce staff into breaching security requirements through interaction via social networks.
  - **Brute force:** This is a cyber-attack through repeated attempts to crack the password of the network or the password of the device connected to the network.
  - **Denial of Service (DoS):** This is a classic cyber-attack to prevent authorised users from accessing information,

usually by flooding network devices (computers and servers) with advertising-type data or fake links.

- **Man-in-the-middle:** A form of active eavesdropping attack in which the attacker intercepts to read or modify data communications to impersonate one or more of the ship's entities involved.
- **Supply chain:** An adversary inserts a vulnerability in the hardware or software of the ship or transport company to manipulate those systems at the location of the developer, assembler or designer. It can be triggered at a later point in time without direct access by the attacker.
- **Spoofing:** A false signal is emitted with the intention of misleading the receiver of the message or communication, such as a global positioning system or an e-mail user.

The main cause of all these problems at the digital level is that the shipbuilding sector is still in a phase of growth and implementation of applications capable of protecting both the shipyard and the ship from all these attacks. There is still a long way to go and research to be done to make the shipbuilding industry more secure and able to control or repel cyber-attacks.

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