Maritime Technology and Research

https://so04.tci-thaijo.org/index.php/MTR

Review Article

Technology trends for ships and shipping of tomorrow

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Article information

Received: May 23, 2019
Revised: July 2, 2019
Accepted: July 7, 2019

Keywords
Technology trends,
Ship design,
Ship building,
Ship operation,
Shipping of tomorrow

Abstract

The paper discusses key trends in ship design, ship building, and ship operation, and extrapolates those trends into the future. Fast and unconventional craft will play only a minor role in this scenario. In fact, trends in shipping are towards lower speed and simpler hull shapes, wind assisted technologies, and propulsion improving devices. Cleaner fuels, most notably LNG, condition-based maintenance, remote instruction, and Augmented Reality will support the operation of low-crew ships. The proliferation of sensors and increased satellite bandwidth will fundamentally change logistics.

1. Introduction

In the 1970s book “Ships and Shipping of Tomorrow”, Schönknecht et al. (1973), wonderful artistic visions predicted a future with nuclear powered submarines transporting crude oil, giant hydrofoils for transatlantic passenger traffic, and streamlined catamarans carrying containers at speeds of up to 35 knots. Visions for future ships and shipping have changed over time, **Figure 1**, and while some predictions have proven to be correct, at least in some respects, many more have been shown to be completely wrong.

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Figure 1 Ships of the future over time: conveyor belt loading and unloading ro-ro ship, 1950s (top left), transatlantic giant hydrofoils, 1960s (top right), Luigi Colani design for fast container ships, 1970s (bottom left), 2010 NYK's Super ECO-ship, 2030 (bottom right).

When tasked with speculating on ships and shipping of the future, my first port of call (to borrow a maritime phrase) was to browse through the bookshelf and conduct research on the Internet. When you enter a Google search for "ships of the future" you could be misled into concluding that the world's future fleet will be evenly divided between sleek-looking cruise vessels and warships, but the reality of where maritime industries and associated technologies are heading might be much soberer.

The discussion in the following pages draws on my own research, industry best practices, and the views of key experts, intended to sketch a realistic scenario of the ships of the future (for definition purposes, let us say the "next-generation" ships, some 30 years from now). DNV GL's report "The future of shipping", Longva et al. (2014), has been a key resource in this endeavor.

2. Ships of tomorrow

Broadly speaking, ships of the future will evolve in line with economic trends and advancing technologies becoming widely available.

2.1 Ship types and hull shape

High-tech, lightweight vessels (navy ships, megayachts, ferries, cruise vessels) often influence public opinion about the appearance of future ships, involving exotic hull forms (such as multi-hulls), **Figure 2**, unconventional hydrodynamics (such as dynamic lift or air cushions), **Figure 3**, and materials (such as high-tech composites); in short, aerospace technology meeting creative design.

Figure 2 Futuristic SWATH design.
Source: Sean McCartan.

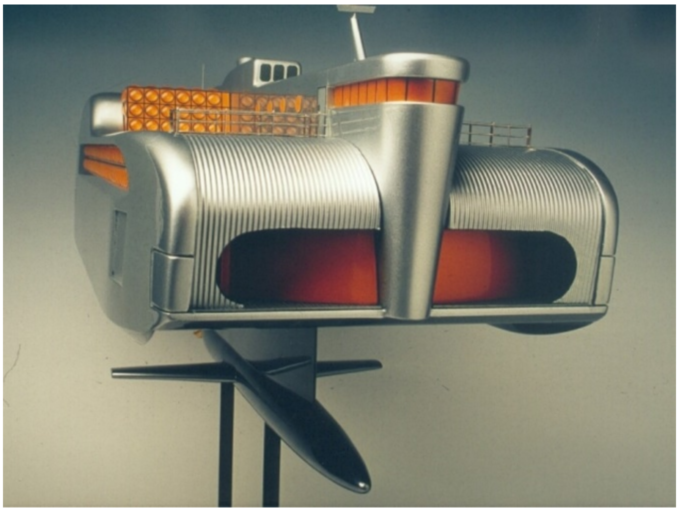

Figure 3 Futuristic hydrofoil ferry design.
Source: Jochen Marzi (EMIT).

However, the world's fleet is, and will continue to be, much more mundane and pragmatic. Shipping of the future will still mean mainly dry bulk, liquid bulk, and general cargo, even if global trends (growing world population and economies, especially in Asia) will bring some slow shift in the mix of cargo types; for example:

- Oil Tankers: crude oil production has already passed beyond its zenith. As the production of remaining resources will become increasingly expensive, crude oil shipping will slowly decline, with fewer and, on average, smaller tankers available.
- LNG Carriers: Liquid natural gas (LNG) tankers are likely to increase in numbers and average size as transport and power generation worldwide become increasingly fueled by LNG.
- Bulk Carriers: Bulkers will continue to be the working horses of the world economy, transporting a steady stream of raw materials around the globe. The average carrier size should remain stable, with numbers slowly increasing as overall economic activities increase.

- Multi-Purpose Vessels (MPVs): MPVs are likely to decline as developing regions of the world catch up with container port infrastructure.
- Containerships: More containers will be shipped, with average and maximum containership size likely to increase, **Figure 4**. This development will be driven by economic frameworks (large alliances will bundle container volumes) and developing port infrastructure (faster and cheaper handling of containers in port by more autonomous, more efficient container handling).

The long-term economic and ecological pressure for energy efficiency will inevitably lead to lower ship speeds. Ship design processes will look at power requirements in realistic operational scenarios, i.e., variations of operational conditions (speed, load) and ambient conditions (sea state), to minimize yearly fuel consumption, as envisioned in Hochkirch and Bertram (2012). As a result, bulbous bows will be smaller, and some ships may even feature straight stems, as seen in DNV GL's concept studies, Green Dolphin (bulk carrier), **Figure 5**, and ReVolt (container feeder), **Figure 6**.

Figure 4 LNG-powered 20,000 TEU containership study PERFECT.
Source: DNV GL.

Figure 5 "Green Dolphin" bulk carrier design.
Source: DNV GL.

Figure 6 ReVolt container feeder concept.
Source: DNV GL

2.2 Materials

Ship hulls will continue to be made of steel, simply because this material is cheap, strong, and easy to recycle. Better coatings and inspection programs will compensate for steel's main shortcoming, corrosion. Intelligent condition monitoring schemes will extend the average lifespan of steel structures, while reducing (if not avoiding completely) the risk of structural failure:

- Big Data: embedded monitoring systems and surveying schemes will generate large volumes of data across fleets of ships in service and offshore platforms. Cross-referencing these data will support intelligent condition monitoring.
- Image Processing: image processing techniques are likely to be used to automatically detect and quantify paint defects, extent of corrosion, and cracks; for example, Mavi et al. (2012), Xie et al. (2018), Stensrud et al. (2019). The progression of such defects will likely be mapped and quantified through the use of images from different time periods. The availability of cheap miniature cameras (as embedded in mobile phones) is also likely to be an element in future (largely) automatic surveying schemes.
- Corrosion Prediction Schemes: using Artificial Intelligence techniques, classic corrosion prediction schemes will be improved, providing a more accurate prediction of location, extent, and type of corrosion. De-Masi et al. (2016) provide an example for pipelines.
- Simulation technology: using 3D ship product models and fast finite-element modelling techniques, Digital Twins will be updated in as-is condition for remaining fatigue life and ultimate strength; Wilken et al. (2011), Ommani et al. (2019).

In summary, the lifespan of ships will be extended, with 30 to 35 years likely to become the new norm. Composites will be increasingly used for high-speed craft (HSC), super-structures for stability-sensitive ships (like passenger ships or naval vessels), and selected equipment and outfitting. However, due to strength and production considerations, the use of composites in hulls will continue to be limited, mainly to vessels of up to 100 m length. Recycling issues will become more important for composites, following trends in automotive and aerospace applications; Gramann et al. (2008). This may lead to a reduction in traditional fiber-reinforced plastics and the promoted use of composites based on natural organic materials, **Figure 7**.

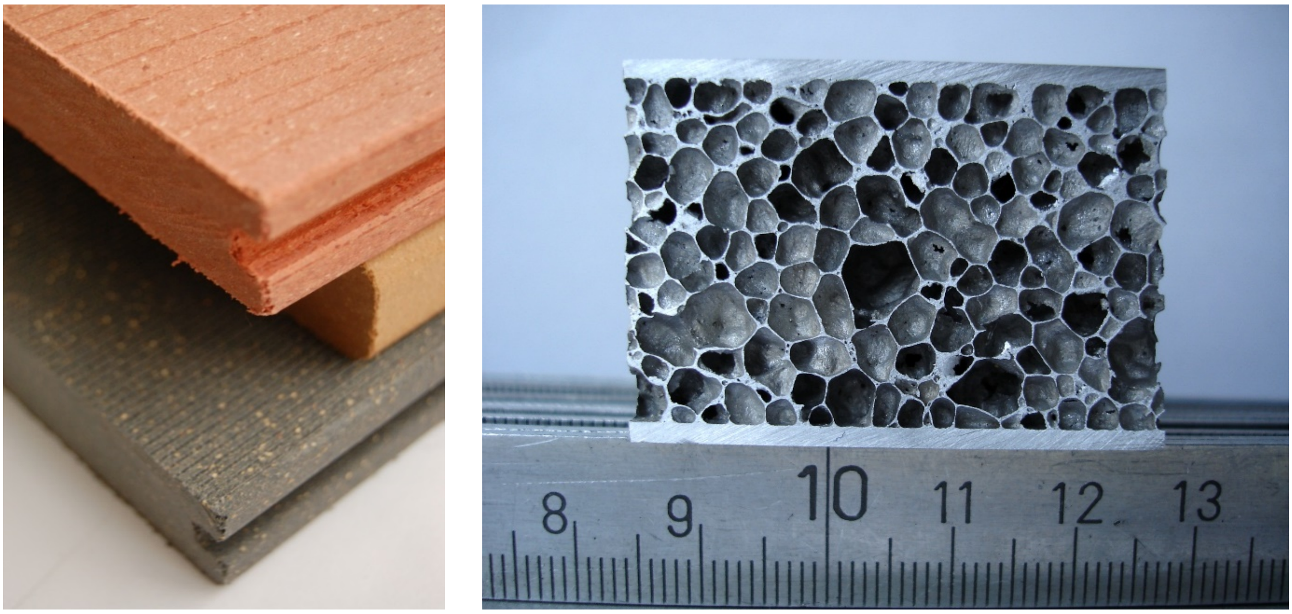

Figure 7 Composites based on renewables (left) and metal foam (right).
Source: Wikipedia.

Additive manufacturing will promote the use of now unconventional materials in maritime equipment, such as printable plastics and metals. The technology is progressing rapidly, Bergsma et al. (2016), Matsuo (2017), allowing larger and stronger components to be printed on demand, **Figure 8**.

Figure 8 3D printed metal propeller, https://3dprintingindustry.com/news/damen-shipyards-worlds-first-3d-printed-propeller-121112.

Metal foams (both aluminum and steel), **Figure 7**, offer interesting possibilities for ships, improving weight-to-strength ratios and noise and vibration characteristics, as well as thermal insulation. In the future, steel may well be combined with metal foams to give higher bending stiffness and lower weight than solid steel constructions. A sandwich panel with steel faces of 1 mm with a 14 mm metal foam core has similar bending stiffness to a 10 mm solid steel plate, but with only 35 % of the weight; Longva et al. (2014).

Figure 9 Floating fern under the microscope, source: Sciencephoto.

Figure 10 Hull cleaning robot, source: FleetCleaner.

Antifouling paint will see a shift towards more sustainable technologies for energy efficiency reasons, but also to prevent the spread of invasive species; for example:

- Mechanically-repellent surfaces: For example, nano-coatings with microscopic surface structures, making adhesion difficult, similar to anti-graffiti coatings on houses. Nano-coatings are mechanically more robust than foul release ("silicone") coatings.

- Air-trapping: Silberschmidt (2016) reports an antifouling effect of air lubrication systems. More recent research at the German Fraunhofer institute tries to mimic the air-trapping floating fern by microstructures, **Figure 9**, aiming at an air insulation film without the constant power requirements of a pump.
- Frequent robot-based grooming: Proactive grooming (mild cleaning) of hulls addresses both energy efficiency and the spread of invasive species. Autonomous underwater cleaning robots resemble lawn-mowing or pool-cleaning robots. In addition to these robots not yet being affordable or widely available, they also need to be equipped with cognitive, cooperative capabilities. Progress in this area may benefit from related work in robotic underwater surveys or robotic marine rescue operations; Odetti et al. (2016). The first commercial applications of largely autonomous hull cleaning robots indicate that this technology is on the threshold to becoming commercially viable, **Figure 10**; Noordstrand (2018), Doran (2019).
- Ultrasonic protection schemes: This is a complementary technology for regions that have limited or difficult access (difficult coating and cleaning); Kelling (2017).

2.3 Fuels and machinery

The broader trend towards cleaner fuels combined with lower design speeds will affect maritime propulsion profoundly. With the 2020 Global Sulphur Cap, heavy fuel oil (HFO) will cease to be the standard fuel option. In the future, we will see a more diverse portfolio of fuels, probably with LNG as the most popular fuel, Chryssakis et al. (2015), albeit unlikely to reach the market share of HFO in past decades. Low-sulphur distillates and blended fuels (akin to land-based diesel fuel), biofuels, and methanol are viable alternatives over the next 30 years.

The change in fuels will affect the whole machinery system. Diesel engines will no longer need separators and filters, as the fuels themselves are so clean. As for cars, we are likely to see more hybrid systems, e.g., combining combustion engines with electric drives; **Figure 11**. With LNG as a fuel, today's 4-stroke diesel engine generator sets as the standard option for auxiliary power may be replaced by fuel cells and batteries. Combining technologies will maximize individual strengths: highly efficient fuel cells will supply rather constant base load; batteries will supplement them for short-term peaks in power requirement and fast reaction. Overall, cleaner fuels and a more redundant set-up of the engine room will reduce the workload of the engine department.

Figure 11 Zero-emission ferry design with fuel cells and batteries, supplemented by Flettner rotors harnessing wind energy; Rohde et al. (2013).

Nuclear power remains the wild card. The pressure to reduce carbon footprint, especially in shipping, is the main argument in its favor. Liability issues (possibly also for the flag state), a shortage of marine engineers who are qualified in nuclear reactor operation, and the general political climate (at present) towards nuclear energy are the main arguments against. Of course, the conditions may well change over the next 30 years, with progress in nuclear technology and changes in the political and public perception of fossil fuels versus nuclear fuels perhaps swinging the balance. However, any prediction in this area remains highly speculative. The scenario of nuclear shipping cannot be ruled out. However, we are unlikely to witness it in the next 30 years, as we should still have abundant sources of LNG available by 2050, with most stakeholders far more comfortable with this option as a standard fuel for shipping.

The quest for transport efficiency (reducing fuel bills and emissions alike) will favor lower ship speeds. In response, hydrodynamically optimized ships are likely to become wider and shorter, with propellers having fewer blades. Propulsion improving devices (PIDs, also known as energy saving devices, ESDs) may become standard. There are various technical solutions, some dating back to the 1970s, Carlton (2012), Bertram (2012), which may see a widespread renaissance:

- Asymmetric sterns may see wider adoption after patent claims expire.
- Pre-swirl fins (often combined with nozzles, such as in the popular Mewis duct for full hulls or twisted fins for slender hulls, **Figure 12**) can be attached to gain 2 - 3 %.
- Contra-rotating propellers or vane wheels are likely to play a larger role, as better design procedures and lubricants solve traditional issues with these devices.
- Costa bulbs or similar devices (for example, “the Ultimate Rudder” of Nakashima Propellers) may become standard, possibly combined with twisted rudders.

Air lubrication has enjoyed much attention over the past decade; Thill (2016). The technology has matured and evolved from laboratory tests and theoretical consideration to several installations worldwide. While it is too early to predict the future of air lubrication, if the recent installations of the European Silverstream system, Silberschmidt (2016), De Freitas et al. (2019), and the Japanese MALS system live up to expectations, we can expect to see a lot more of such installations. The general trend towards lower speeds and wider ships points in favor of air lubrication technology (**Figure 13**).

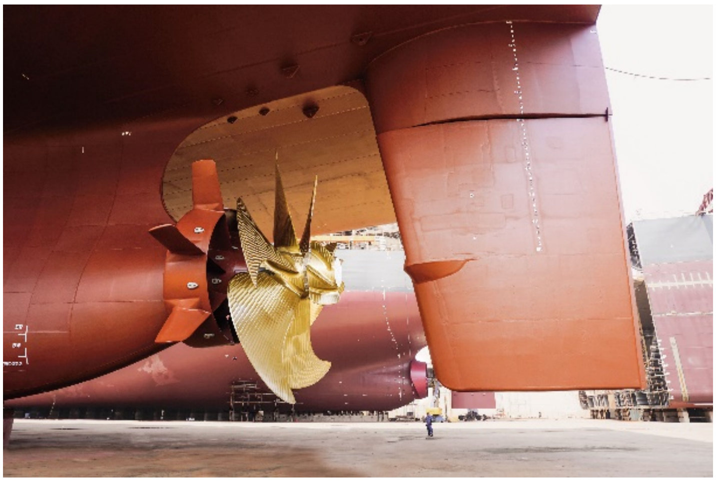

Figure 12 Twisted fin as typical PDI.
Source: Becker Marine.

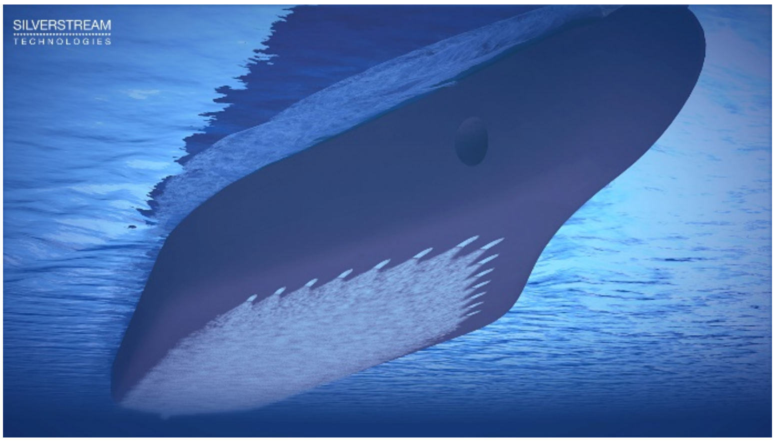

Figure 13 Air lubrication.
Source: Silverstream

Low speed also helps the case of wind-assisted propulsion. There is no shortage of debate on this theme, so far mainly coming from academic studies and small players in the market. In 2019, there were very few (< 10) full-scale installations of wind-assisted propulsion systems on cargo ships. However, with increasing fuel prices and consolidation in the wind-assisted propulsion technology market, with small vendors being acquired by larger players, we may see a proliferation of professional systems for harnessing wind energy for ships. In this context, only robust and highly automated systems make sense; for example, those based on Flettner rotors, **Figures 11** and **14**.

Figure 14 Flettner rotor on German E-ship 1.
Source: Eon.

Falling costs for sensors, computing power, and satellite communications make it a safe prediction that ships of the future will be "smart", i.e., they will be equipped with various embedded data processing. Sensors will become smaller, more robust, and cheaper to acquire. As a result, they will be more widely distributed with redundancy built-in, coupled with options for intelligent sensor fusion. We envisage sensors being literally "everywhere", in the hull, main engine, auxiliary machinery, and even small equipment items. They will also be smart; "Today's mobile phones have the processing power of desktop computers 10 years ago. In 2020, mobile phones will have the power of today's PCs. Cheap and small distributed sensors will have the abilities of today's mobile phones, and so on," Longva et al. (2014). Much of the "Big Data" collected by these sensors will be processed locally (Edge Computing), and also often be converted into decision support on board.

3. Software: Design, construction, and operation of tomorrow

3.1 Design

Progress in CAD (computer aided design) systems towards 3D product data models (PDMs) allows us to not only perform a large variety of analyses and simulations, but also deliver photo-realistic virtual reality displays. Traditionally experience-based ship design has already moved considerably towards simulation-based (a.k.a., first-principle) design, **Figure 15**. The exchange of information between different software and more intelligent pre-processors has dramatically cut down the time and cost associated with running simulations. Cloud-computing with on-demand business schemes gives advanced simulation access to small and medium enterprises, e.g., Hildebrandt and Reyer (2015), Hildebrandt et al. (2017). Simulations are also getting more sophisticated, with increased detail represented in captured geometry and more advanced physical models; for example, Köhlmoos and Bertram (2012), Peric and Bertram (2012), Goodwin and Dodkins (2019). We also see the scope of simulations expanding beyond the classical stability, strength, and hydrodynamic simulations; for example, aerodynamics, fire, icebreaking, evacuation, manufacturing, energy generation, and consumption in ship systems, etc. Systematic simulations may be used to derive tailored "numerical series" or knowledge bases. These simulation-based knowledge bases provide highly accurate estimates that are virtually instantaneous; Harries (2010), Couser et al. (2011).

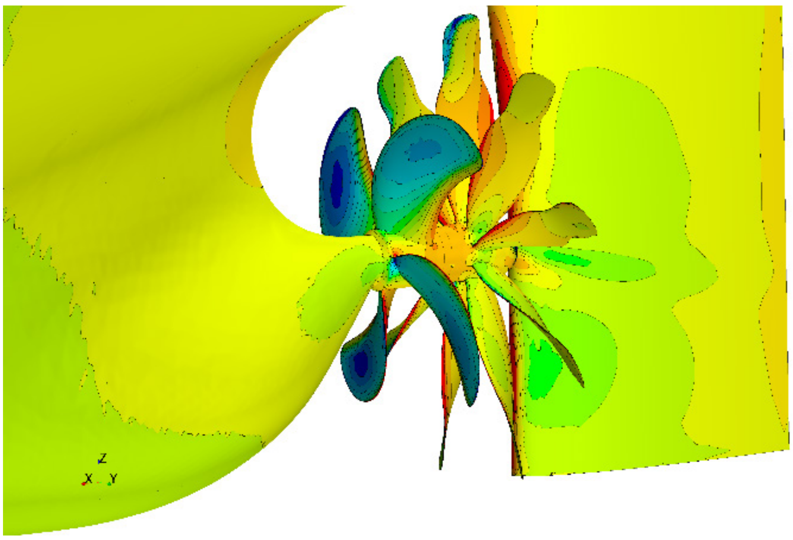

Figure 15 CFD simulation for energy saving device with contra-rotating propellers.
Source: DNV GL.

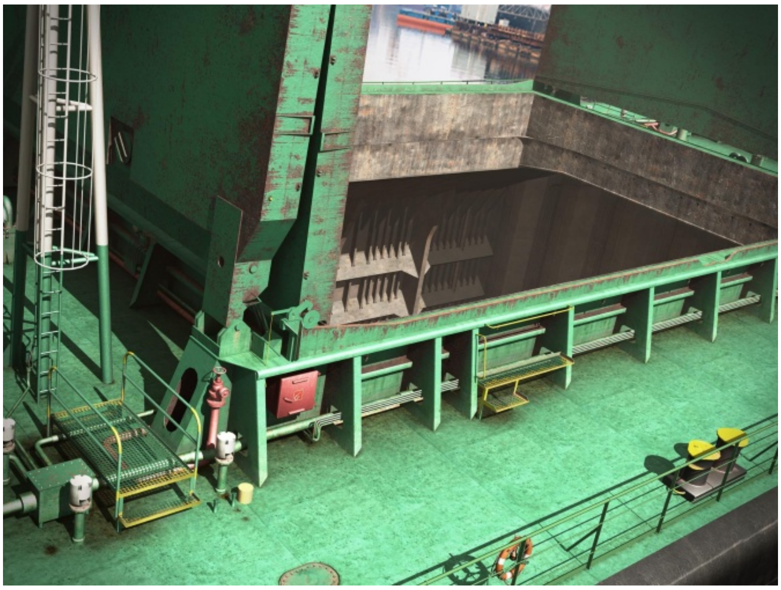

Figure 16 VR model ship deck for training.
Source: DNV GL

When human interaction is important, we increasingly use Virtual Reality as a key technology. Virtual Reality uses 3D models of the world, with fly-through or walk-through capabilities and, typically, some user interaction; in essence, it is the same technology used in video games. This technology is gaining popularity for training, Bertram and Plowman (2018), **Figure 16**, but also for aesthetics (interior design), Lukas et al. (2015), orientation in ships (cruise vessels or large navy ships), and operational aspects in design (producibility, reachability, visibility), Goh (2019). Considerable progress has been made by adding real-time physics, thanks to "physics engines", fast emulators of typical kinematics and dynamics of objects. This progress in simulations has been accompanied by similar advances in visualization techniques. In many cases, we can analyze the time-dependent performance of a system in photo-realistic 3D simulations, while the visualization allows intuitive assessment; Chaves and Gaspar (2016).

Despite numerous attempts, no single monolithic software program has emerged that is optimal for all ship design tasks. There is wide consensus in the maritime CAD community that coupling dedicated software packages is a better strategy than trying to develop the "one code to solve all problems". In short: cooperation beats integration. A "plug-and-play" culture is developing, where software codes and companies learn to work smoothly together to provide better or new solutions. Best-of-breed solutions are being developed across geographical and company boundaries, using flexible alliances and web-based technology; for example, Morais et al. (2016), Harries et al. (2015).

3.2 Construction

With 3D product data models (PDMs) available, the door to Virtual Reality (VR) and Augmented Reality (AR) is wide open for ship construction and maintenance/repair. The 3D models will be updated as the ship is built and modified over its lifecycle. "As-built" PDMs will be passed to owners for asset management; Thomson and Gordon (2016). Affordable 3D scanning will be widely used, both from the outside (for example, for more accurate performance monitoring models) and the inside (for as-built/as-modified models), **Figure 17**, Morais et al. (2011), supplying an important element of the vision of a true "Digital Twin".

In Augmented Reality, computers (for example, tablets) overlay a live image with computer-generated information. For example, a building block may be shown with a part to be installed, illustrating how both fit together; **Figure 18**, Kohei (2016). The fitting of parts becomes very intuitive, reducing assembly time and the likelihood of errors. A number of advanced shipbuilding nations are active in Augmented Reality applications for shipbuilding. This technology becomes truly powerful when used in combination with vision technologies (for example, marker recognition), PDMs, positioning methods, hands-free operation technology (smart glasses), etc.; Patterson and Webb (2016).

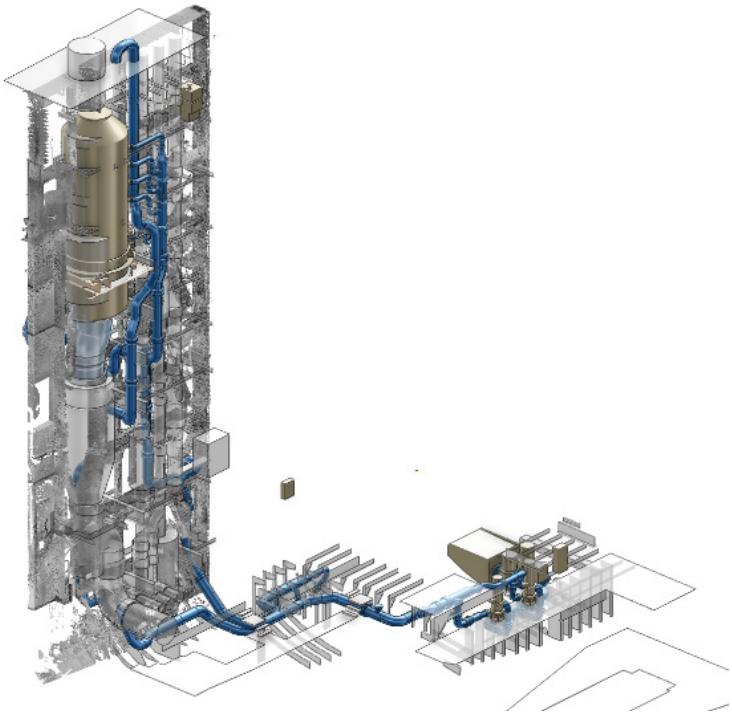

Figure 17 3D laser scan of engine room with CAD model overlaid.
Source: Blom.

Figure 18 Augmented Reality in ship construction Source: NMRI.

Industry 4.0 will also encompass shipyards and the maritime supply industry. The Internet of Things will change (and accelerate) logistics, especially for time-critical and highly interconnected supply networks; Borgia (2014), Etienne and Sayers (2016). Drones may be used to deliver required parts to remote areas, such as ships, as demonstrated in 2016 by Maersk. However, often, delivery will no longer be needed. Instead, 3D printing may generate required parts, mainly in the supply industry and on ships; Bergsma et al. (2016). 3D printing is particularly attractive for spare parts.

3.3 Operation

General developments in ICT (information and communications technologies) will have a profound effect on the shipping industry. Of course, ICT allows us to perform traditional tasks better (faster, cheaper, or more accurately) but, perhaps even more importantly, ICT opens the door for us to consider completely new options. Some predict that ICT will "revolutionize" shipping. However, the truth is that computers and telecommunications are not new to shipping, and evolution will continue, albeit at an accelerated pace. We will witness "more" of the same trends as in the past decades: an increase in the exchange of data and more collaboration between stakeholders.

Various developments will make ships easier to operate. Examples are condition-based maintenance systems, involving diagnosing eventual problems at an early stage and supporting the fixing of the problem, for example, by ordering spare parts, preparing 3D printing, or guiding repair by ordinary persons without expert knowledge on the system, using Augmented Reality for intuitive guidance. Along with reduced workload in the engine room, due to cleaner fuels, this will allow further reductions in minimum crew sizes. This development resembles trends in the automotive industry; we have smart cars (automatic brake systems if pedestrians are crossing; valet parking; self-monitoring tire pressure; the ability to drive autonomously on highways, etc.), as well as Google's self-driving car. For ships, we will have low-crew smart ships (with automatic collision avoidance; automatic berthing; self-monitoring of hull, engine, and cargo; the ability to sail autonomously for limited times in certain conditions, etc.), Bertram (2016), and no-crew drones for specific applications (for example, short-distance ferries, tugs, and fireboats).

The digital transformation of ships will mirror land-based digital transformation of the logistics industry. Highly automated smart ships will serve highly automated smart ports, **Figure 19**, which in turn connect to highly automated smart trains and trucks.

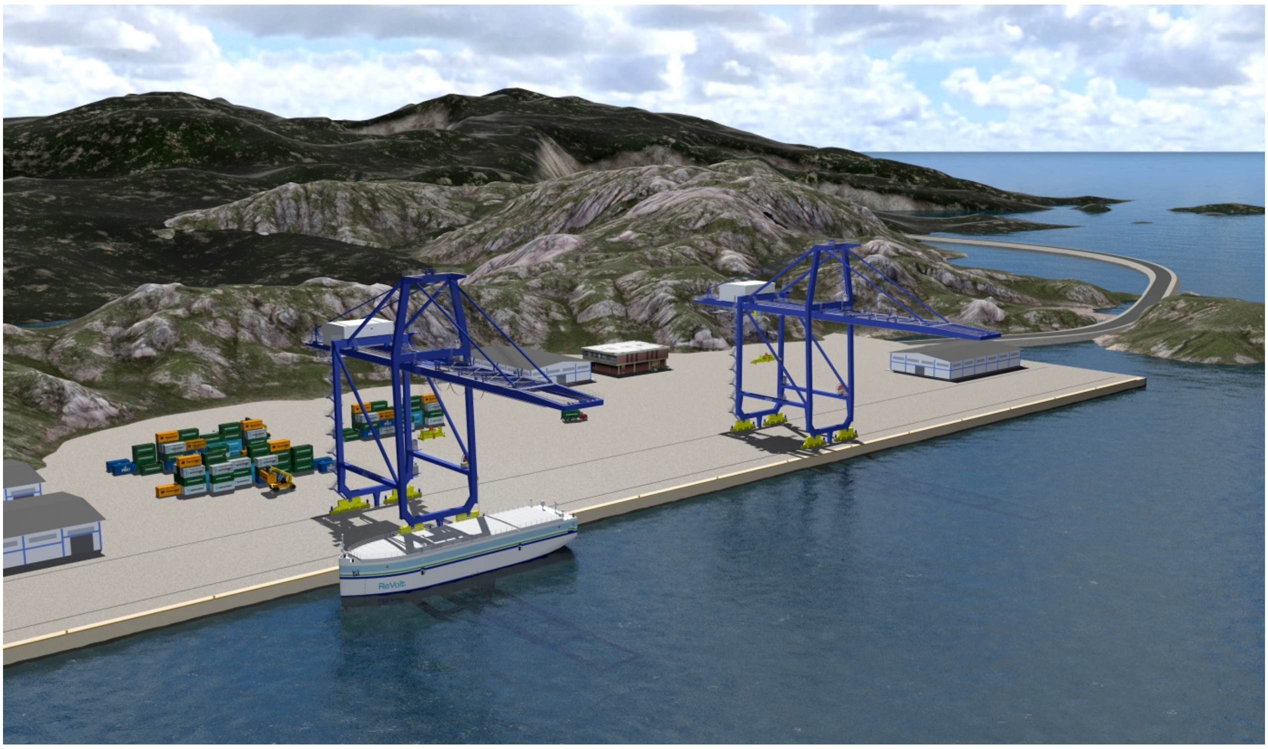

Figure 19 Highly automated smart ships with low or no crew will serve highly automated smart ports.
Source: DNV GL.

Whether ships are operated locally or by remote control, operational decisions will be data driven; for example, using AIS (Automatic Identification System, which is a satellite-based data exchange, allowing tracking of virtually all cargo ships) for ship routing, factoring in weather conditions, traffic situations, and port capacities. Combining (big) data, simulations, and Artificial Intelligence techniques will deliver business and logistics transparency with both economic and ecological benefits. The Internet of Things will play a key role in this development.

With ICT becoming an indispensable part of shipping, cybersecurity will become a key concern, both for autonomous and manned shipping. Awareness of the cybersecurity issue is already evident in the maritime industry, with at least partial solutions on the horizon, for example, Rødseth and Lee (2015) and DNV GL's cybersecurity recommended practice. The technology on ships will largely follow the cybersecurity technology employed for other large assets, such as power plants, traffic control centers, etc.

4. Conclusions

The future lies in technologies coming together. We have seen this already in assorted applications; simulation tools with Virtual Reality displays and Artificial Intelligence for user guidance, Big Data collected by IoT harvested by Artificial Intelligence to derive operational profiles used in hull optimization, etc.

The coming together of technologies also requires the coming together of companies and different experts. An open culture of connecting technologies and people will be the key to success in this respect.

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