WHITE PAPER

Value proposition of 3D models for owner operators: Digital twins

Leveraging the 3D model through the ship lifecycle

Contents

1. Introduction

Change is the only constant when we talk about maintaining a fleet of ships. Often each ship is specifically fitted for certain missions or has already incorporated changes compared to the first in class due to lessons learned or availability of components. Another important aspect in the lifecycle of a ship is that these modifications often require detailed study and planning to determine the true impact of these modifications.

The benefits and value of data represented in the form of 3D models from the engineering contractor to improve engineering quality and efficiency are well-documented and no longer a subject of dispute in the industries. The benefits and value of data represented in 3D models to the owner operator, however, are less established. It is important to represent the data as close as possible to the physical world so that people can easily identify themselves with the data.3D models are a prime example on how this can be achieved. 3D models, when paired with infomaps, are an excellent way to display data or information related to a physical object.

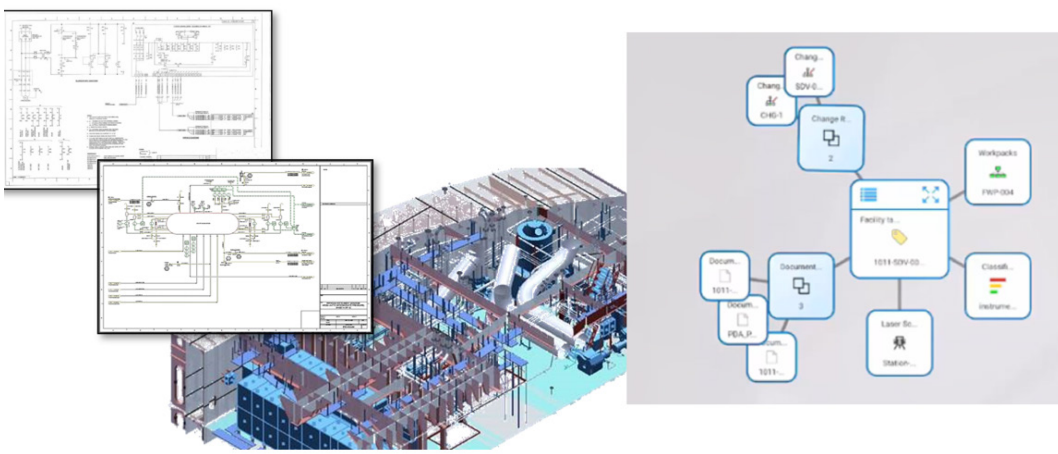


Figure 1: Infomap with data relationships to model and drawings

It is apparent, though, that owners are starting to make increased use of data shown in 3D models. A growing number of owner operators request the 3D model to be included in the scope of project deliverables. There is also a higher prevalence of laser scanning of existing facilities.

Availability of up-to-date integrated 3D models can help reduce time and cost for ship modifications and ship's life extensions, as well as help serve as a useful tool for several day-to-day tasks during the operation and maintenance of the asset. As shown in the summary on the next page:

More time at Sea

Single Source of Truth for As-Built

Integrated asset data management navigation

Operations	Maintenance	Safety
Operator Training	Small Ship Changes	Reduced SHE Exposure
Ship Familiarity	Ship Sustenance	Corrosion Management
Operations Planning	Turnaround Planning	HAZOP Studies

Mission and/or Major Upgrades

Figure 2: Potential ROI areas for the ship lifecycle

The increased intelligence in data shown through 3D models opens new possibilities and increases the value of the 3D model. For example, the solution can highlight where the design is not in line with regulatory authority requirements, such as where the number of risers in a flight of stairs without a landing is exceeded or where headroom in escape-ways is restricted; however, the engineering industries can be typified into three main groups, each having different ways of delivering data:

1. Those that have an integrated common data source, with a 3D and other representation of the data
2. Those that have a non-integrated data set, however, with a 3D model
3. Those that have no data and no 3D model available (this is often the case in legacy projects)

Going from 3 to 2 or 2 to 1 requires manual interventions. Tools are currently available to leverage the available information without performing costly conversions. These abilities, combined with the lower cost of maintaining 3D models, is driving increased recognition that 3D models reflecting the current "As-Built" status of a ship are prerequisites for operational excellence. Laser scan, point-cloud integration and the lower cost of converting legacy 3D CAD models have also lowered the barrier to adopting intelligent 3D solutions.

All these aspects have one thing in common: the more data you have in that change process the better you can manage the eventual change itself. This is easily quantified through examples where the preparation of a modification is executed before the ship arrives at the dry dock, so that upon arrival the work can start right away instead of investigating what the ship actually looks like. Situations of 30% time reduction are common and therefore immediately impact the time at sea.

Knowing that the design in general accounts for 90% to 95% of the data already it is therefore imperative to conserve that information throughout the complete lifecycle of the ship in an as-built situation. So, the information needs to be available in the authoring tools, which will allow interfaces to existing analysis tools like MSC Apex - Nastran/Patran or other analysis tools as depicted in below picture, as well in the Lifecycle Tools (often a "light" version of the engineering data).

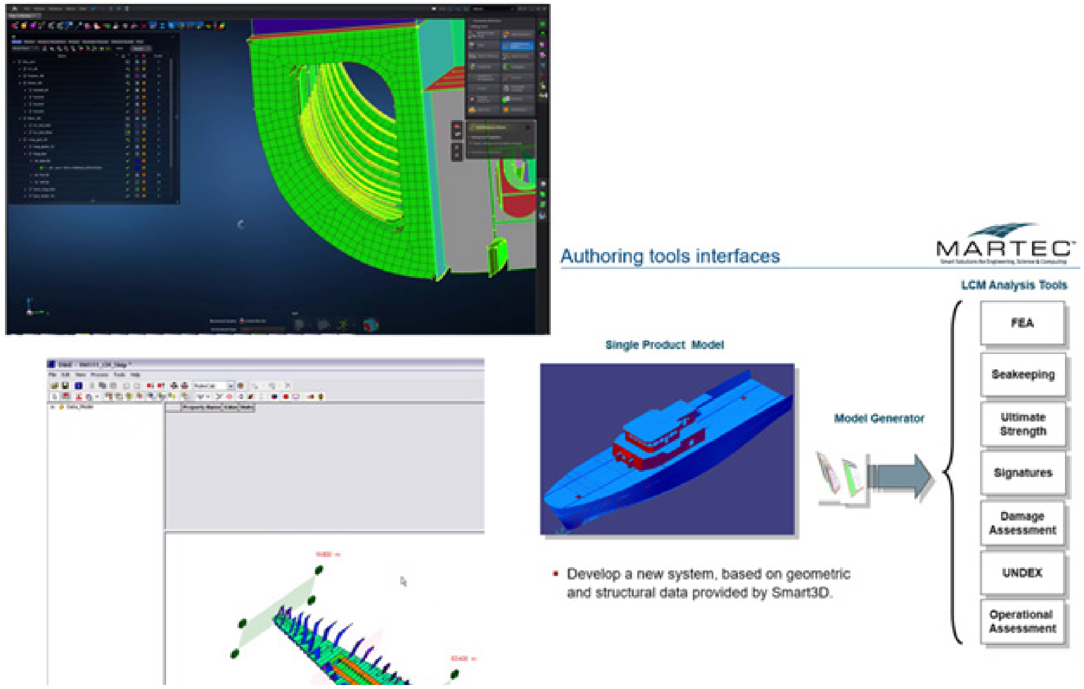


Figure 3: Authoring tools are valuable for interfacing to the analysis packages, like MSC, DIME, Martec, etc.

Another important aspect is the economy of scale within a project that arises from a multitude of efforts; however, these are more process and organizational instead of 3D related:

- Purchasing identical components (project as well as spare parts)
- Identifying components that are interchangeable

This can be achieved by having a catalog system in place that is linked to the design tools, which then allows you to handle two major aspects:

1. Being able to uniquely identify the item
2. Based on continuously progressing insight of technical aspects that will identify the item (i.e. at P&ID level you know you have a pump with certain technical capabilities, in the initial 3D model you have an initial horizontal pump, replacement of the final pump upon vendor selection in the 3D model to have the accurate nozzle orientations)

This also ties into the timely replacement of ships and equipment which is a process that requires the ability to predict asset lifecycles based on costing information, utilization, and asset age. Funding requirements are also an issue because many organizations, especially government organizations, purchase ships with cash. The ad hoc nature and traditional low-funding levels with cash has put many operations in an aged fleet. This lack of adequate funding for replacement can also result in higher maintenance costs due to aged ships.

Combining all of these aspects leads to unique ships within the fleet that should be managed as such.

More time at Sea - 30% less time in the dry dock

Single Source of Truth for As-Built - 0.25% projected OPEX costs

Additional time dealing with equipment maintenance problems due to missing information

Operations - 0.1%	Maintenance ~ 10%	Safety - 0.2%
Improved Sailor Training	Waste from carrying costs of excess and obsolete material, excess charges for rush orders	Especially on the hull HAZOP Studies

Mission and/or Major Upgrades - 0.1% to 0.5% projected OPEX Costs

Figure 4: Example ROI values

All these items have an impact on the overall lifecycle costs of a ship. A conservative estimate on a $10B program could equate to a $50M saving from an effectively instantiated digital twin and a well-architected digital thread.

This paper briefly outlines the main areas where ship owners are deriving benefit today or potentially could derive benefit from leveraging the 3D model throughout the ship lifecycle using Hexagon solutions with their customer and existing tools.

1.1. Value through the ship lifecycle

The 3D model provides value to the owner operator throughout the ship lifecycle – from early pre-FEED evaluation of alternative facility layouts, during CAPEX execution, during operations and maintenance, through to ensuring safe and environmentally responsible planning and execution of decommissioning activities.

Figure 5 illustrates the value of 3D models throughout the ship lifecycle. For the sake of simplicity, only one turnaround and only one modification/extension project is shown, but in practice these will be repeated on a cycle, the frequency of which will vary according to ship type, missions as well as advancements in technology.

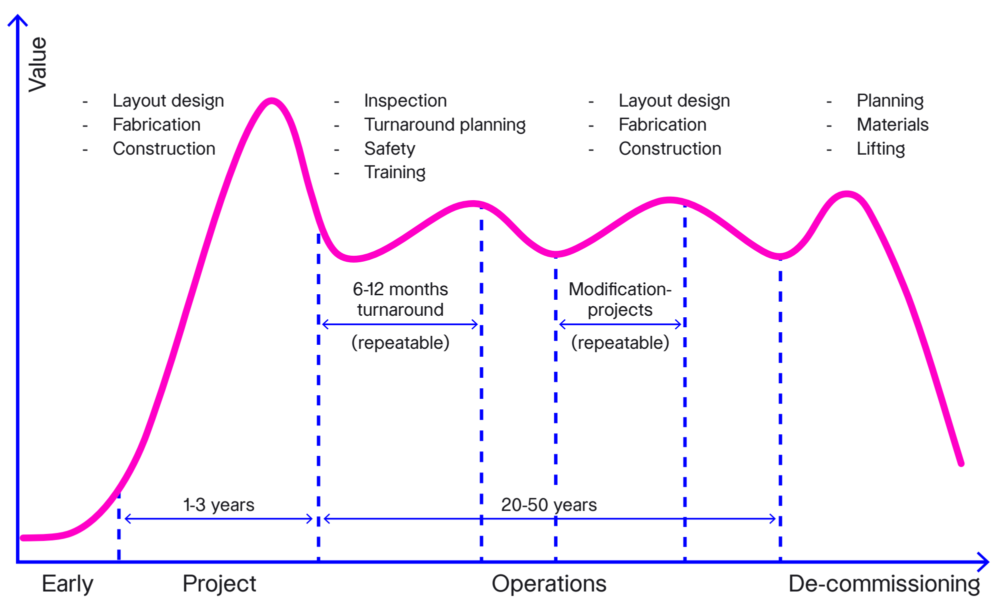


Figure 5: Value of 3D data throughout the ship lifecycle

2. Benefits during the build phase of the ship lifecycle

The benefits described below are in addition to the benefits intelligent 3D models can provide for the engineering, fabrication and construction contractors. In the end, benefits for these parties will also benefit the owner, as the final project cost is paid for by the owner. By specifying, encouraging and actively participating in use of 3D systems during the engineering, fabrication and construction phases, owners can reduce risk of delays and cost overruns, while increasing the value of the 3D model received as handover.

2.1. Improved project management decisions and operational readiness

The owner operator typically requires access to key engineering deliverables during build projects to:

- Verify project progress
- Ensure that the design is in line with the approved design basis
- Use as a basis to undertake activities to prepare for operations

The owner can use the 3D model to help verify the safe operation of the ship. For example, the owner can perform escape route planning by checking that the spaces are large enough.

Safety rules can be incorporated into the design stage through the usage of background rules processing, enabling several of the design review checklist items to be checked by software on a continuous basis rather than only in the design review meetings. Examples of such checks can be:

- Check that minimum distances are maintained between objects such as Remotely Operated Valves and Depressurizing Valves
- Check that hot and cold pipes and surfaces near walkways are properly insulated for personnel protection
- Only pumps handling non-flammable liquids may be placed under pipe racks or structures

Benefits during the build phase of the ship lifecycle

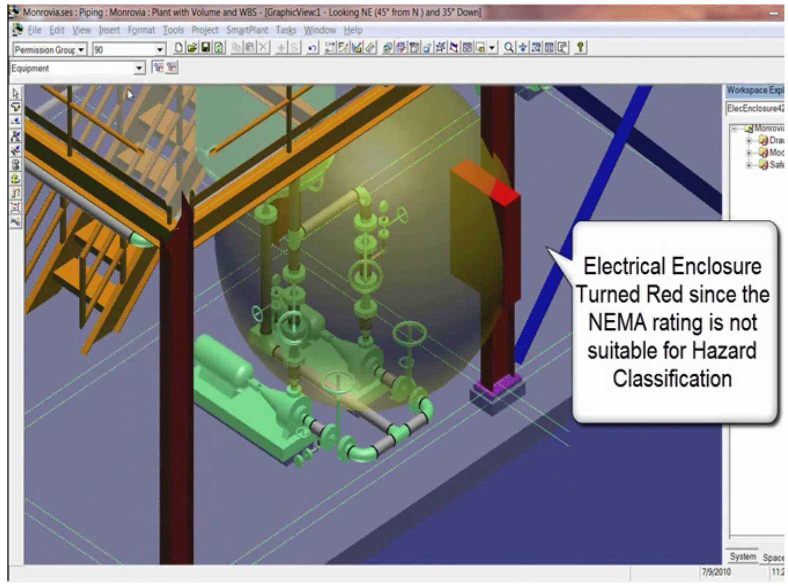


Figure 6: Smart 3D background rule example showing area classification and related safety checks

The 3D model itself can be managed via online workshare between contractors across the globe or made available in a hosted environment. This enables cross-contractor/location reviews to be performed efficiently, speeding up the detection and solving of potential problems.

This can be achieved through a tight integration, comparison and change control between the 3D model and other key engineering design deliverables, including:

- Intelligent 2D schematics (P&IDs, single lines and instrument loops)
- Engineering registers and "non-intelligent" 2D CAD
- Stress analysis
- Material administration tools

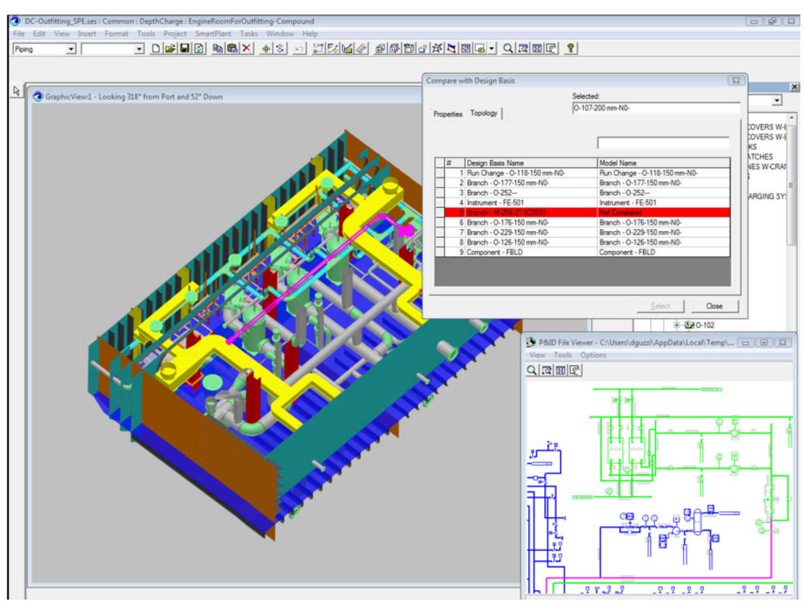


Figure 7: Integration between P&ID and 3D model, with automatic correlation as indicated by colors

Benefits during the build phase of the ship lifecycle

When the project is executed by a contractor using Octave Forte 3D (formerly Smart 3D), Facets P&ID (formerly Smart P&ID), Facets Instrumentation (formerly Smart Instrumentation), and/or other Octave solutions, the owner can have access to the project status at any time using HxGN LiveView. This enables the owner to view the 3D model, navigate to the P&ID and do design reviews to ensure it complies with the project and company standards and practices.

Octave Forte Interop (formerly Smart Interop Publisher) capabilities provide unique and very powerful means of bringing 3D model data from various sources/formats together, without the need for costly and time-consuming conversions. This allows for new/alternative work processes related to review and checking of data from various contractors in a project. The key is to create a uniform platform to access the ship data that may come from different data sources.

The importance of coordination of key project execution processes increases with the growing size and complexity of projects. When the owner chooses to deploy Octave InConcert Core (formerly HxGN SDx), many processes can all be supported by 3D visualization, including:

- Management of project change
- Managing the interfaces between project stakeholders
- Non-conformity management
- Technical query management (also known as Requests for Information)

This enables faster and better decision-making by the owner operator related to these project-critical processes. For example, the ship components involved in an interface item can be highlighted in the model to identify the consequences of delay in resolving the issue. The 3D model can also be used to help the user quickly and reliably identify all tags involved in a change, non-conformity, or interface issue.

A key activity of the owner operator during CAPEX projects is to ensure operational readiness. This includes:

- Familiarization of operations staff with the new facility
- Preparation of training materials
- Maintenance and inspection planning
- Hazops and pre-startup reviews

Having access to a visualization-enabled engineering design basis is an important aid for these processes. It provides a simple and intuitive way of accessing key information. Users can easily access the information they require by navigating and using the 3D model to access other needed information.

Training materials can use the 3D model to illustrate necessary information. For example, animated sequences can depict escape routes and critical Ship operations.

For inspection and maintenance planning, the 3D-enabled engineering design basis can assist maintenance and inspection planners in localizing equipment and inspection points. Planners can see whether there is a need for ladders or scaffolding to be erected to undertake work, what other work can be undertaken at the same time, and more.

2.2. Fabrication

The 3D model is an important tool in fabrication process since it should accommodate the imperfections of the fabrication and construction process (margins, shrinkage, etc.), in such a way that fabrication process "absorbs" these imperfections to get a 1:1 ship as it was originally designed. During this process changes required to support the machinery to make these parts often impose certain limitations (length of a pipe that needs to be bent, or the length of plate that is too large for the cutting machine used), these changes do not have an impact on the engineering side, but have an impact on the as-built situation and therefore need to be recorded into the model as well.

Forte 3D includes tools that can provide significant savings during the construction phase, such as structural detailing and manufacturing capabilities, including interfaces to Octave OnSite Production (formerly Smart Production) (nesting and cutting machines and robots), output of fabrication drawings and reports, weld and beveling data, etc.

2.3. Construction

The 3D model is an important tool in constructability planning, ensuring that there is enough space for heavy-lift equipment and to plan lifting and erection activities in the confines of the ship. The 3D graphical interface can also provide an intuitive drag-and-drop user interface to assist in the creation of construction work packages and to verify that all affected items have been included in a package.

A planning module, with module/block definitions, assembly creation that form the basis for the work-packs at the construction stage, Onsite Construction Planning (formerly Smart Construction) utilizes the 3D model in the visualization and reporting of the construction readiness and progress of a project. It highlights parts of the project that are already constructed or under construction, along with the locations and availability of materials for construction. The 3D model can also be used when preparing construction packages by identifying equipment to be included.

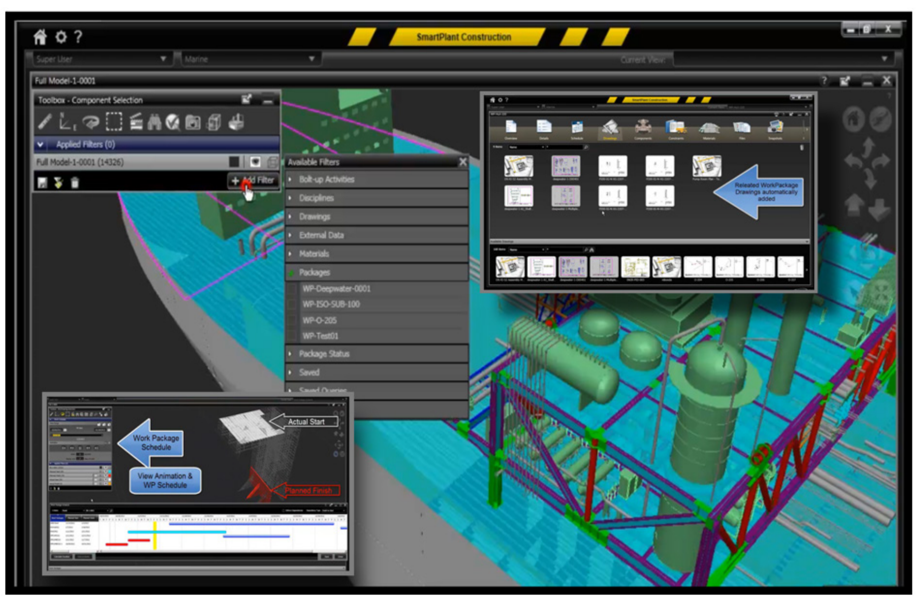


Figure 8: Smart Construction

2.4. Systems completion

3D visualization can be an important aid during completions. It can help familiarize the completions team with the ship during the planning phase, including the identification of escape routes to improve ship safety. By highlighting non-conformities (deviations and waivers) in the ship, the commissioning team is familiar with these and can take account of them. This also promotes ship safety during the completions process. By integrating the engineering design basis with scheduling information, it is possible to highlight in the 3D model where work is to be undertaken and when to detect and avoid potential conflict of activities.

The 3D-based planning and visualization of temporary installations reduces hardware cost and shortens build-up and tear-down cycles.

The 3D graphical interface can also provide an intuitive drag-and-drop user interface to assist in the creation of completions work packages and to verify that all affected items have been included in a package. The 3D model can be used to highlight which tagged equipment is included within a specific work pack or commissioning subsystem to verify all relevant equipment has been identified and improve the quality of completions planning. By highlighting the completions status of equipment (including outstanding punch-list items) in the 3D model, it is possible to intuitively show the status of completions for management reporting.

Not only can we streamline and shorten the commissioning with Smart Completions but as we start early planning for commissioning we can impact construction to make sure we more efficiently complete systems versus pieces of systems and with that delay the commissioning and handover to the owners.

2.5. Simulation and analysis capabilities

Through the use of a digital twin and the cognitive power of Artificial Intelligence, the subsequent spread of fire from an ignition can be predicted. This simulation is not just based on the physical layout of the ship but also on a number of other factors such as compartment materials, flammable substances, ventilation, installed fire suppression systems. Physical and behavioral attributes are tagged to the twin so the AI layer can determine factors such as how long it will take to burn through different materials. At the bottom of figure 9 you can see that the application has determined there are eight walls that are vulnerable to fire and should be further insulated. It has also determined that there are four zones that are not protected by fire suppression (sprinklers) that should also be addressed.

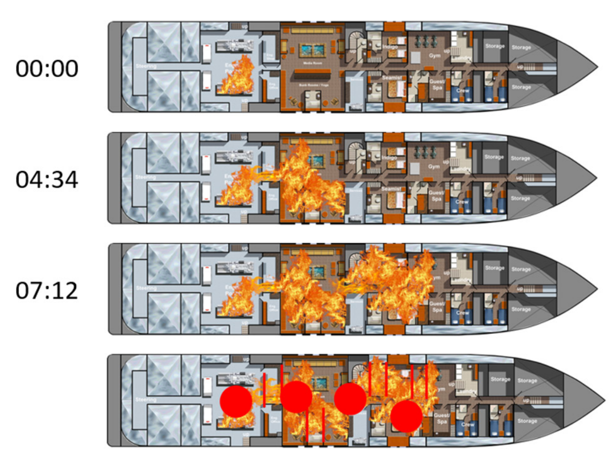


Figure 9: Simulation of fire spread and identification of weak points using digital twin and AI

Benefits during the build phase of the ship lifecycle

The 3D digital twin views can also provide significant value by visually representing the potential impact of heat within a ship. Figure 10 shows a color-coded view inside a ship compartment and represents anything that has potential to get hot in red. This can give a valuable visual on two things, first a view on where insulation might need to be added and second, a view on how heating in a ship might impact the health and safety of crew.

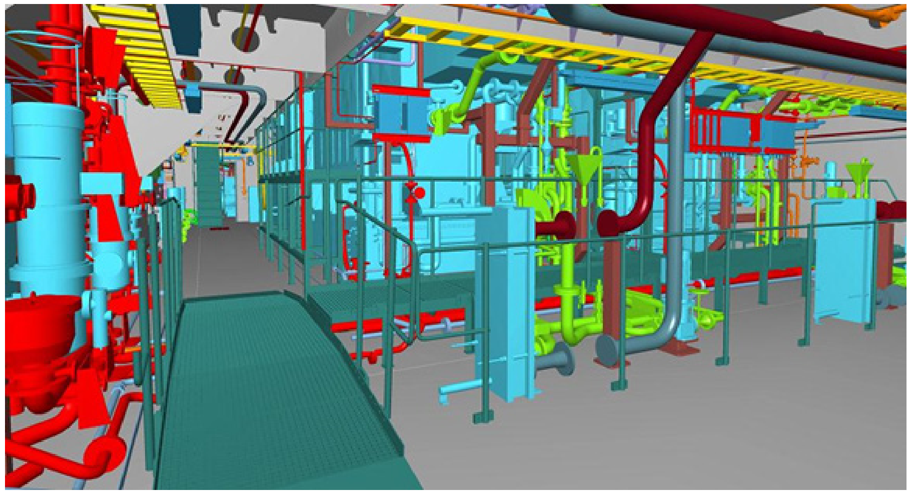
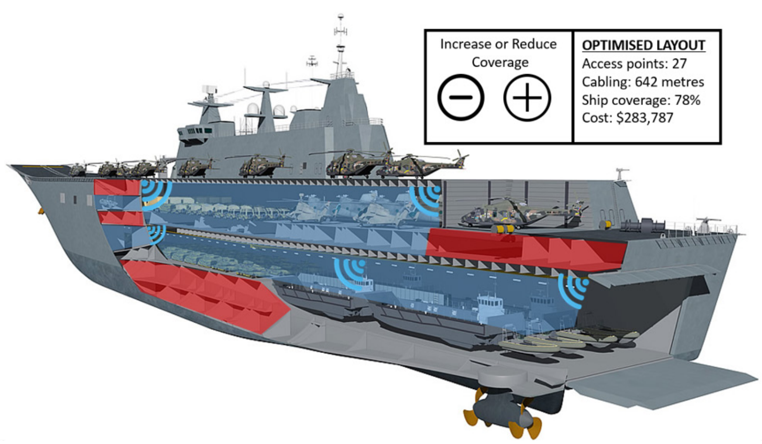


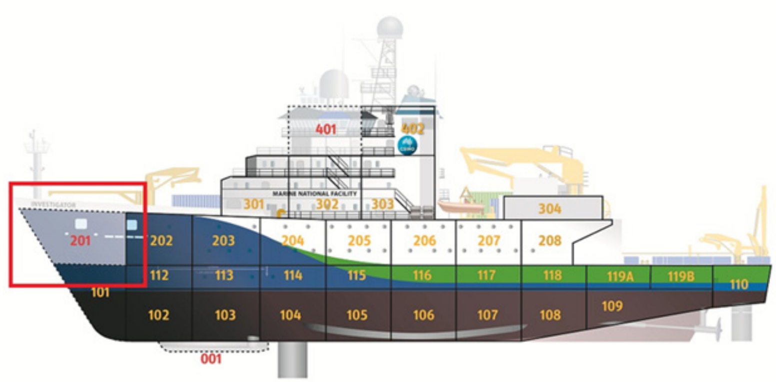
Figure 8: Smart Construction

These are a couple of examples of how digital twin can help in the design/prototyping phase of a ship build. But there are many other valuable applications of digital twin in this phase and like other capabilities such as Augmented and Virtual Reality. In below examples represented in 3D pictures, some potential applications that would be possible:

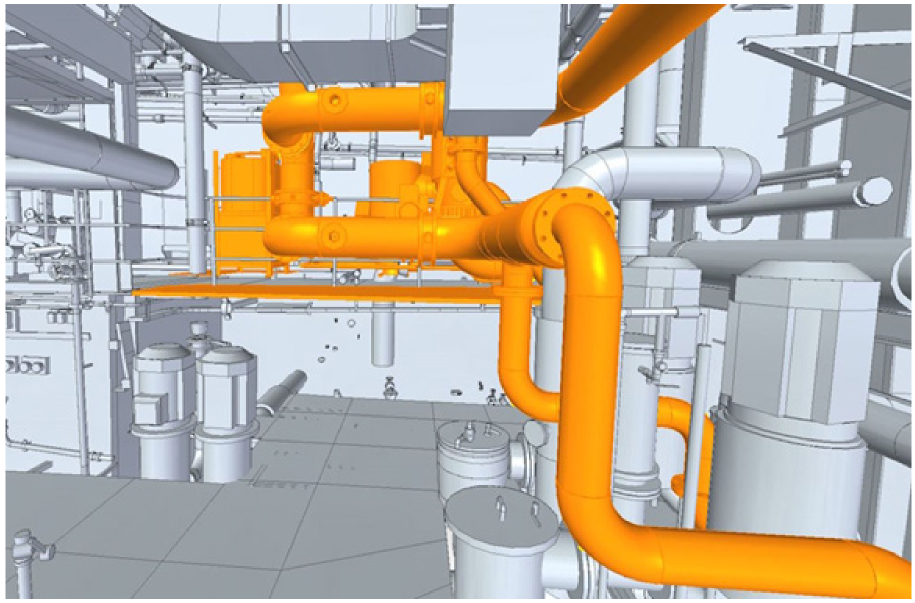


Example 1: Ship wi-fi modeling with the ability to increase and decrease coverage to control cost

Example 2: Block division optimization to minimize the amount of work to consolidate and maximize hull integrity

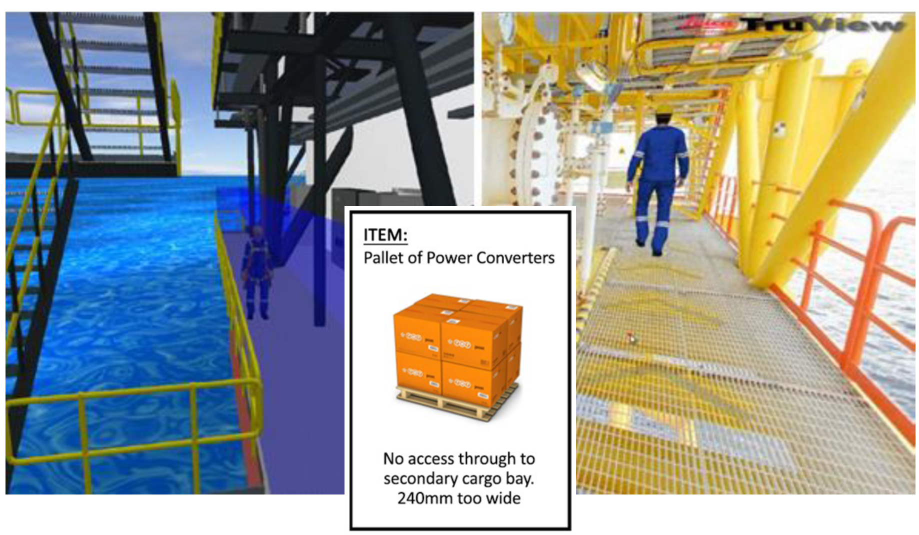


Benefits during the build phase of the ship lifecycle



Example 3: Optimizing piping routes

Example 4: Analyzing buoyancy and ship dynamics in different sea conditions



Example 5: Determining access size limitations for equipment to be stored in cargo areas

3. Benefits during the operational phase of the ship lifecycle

While the owner operator can gain considerable benefits during the build phase of the ship lifecycle, the benefits during the operations phase can be even greater. Change is the only constant when we talk about maintaining a fleet of ships, often each ship is specifically fitted for certain missions or has during the build process already incorporated changes compared to the first in class due to lessons learned or availability of components. Another important aspect in the lifecycle of a ship is that these modifications often require detailed study and planning to determine the true impact of these modifications that are executed during the operational phase of the ship.

3.1. Providing a front-end to a ship informational portal

Integrated with SmartPlant Foundation or InConcert Core, the 3D model provides a simple, intuitive front-end to a ship information portal. The user can rapidly navigate through the ship from a simple right-hand menu option to access other information in the engineering design basis, such as:

- P&IDs
- Single line diagrams
- Loop diagrams
- Vendor maintenance instructions
- Spare parts lists
- Equipment certificates
- Fabrication records

Using Forte 3D integrated with Facets P&ID and Facets Instrumentation, enables navigation across deliverables also on a non-tagged object basis, as the system will recognize the same objects across the different design tools.

Where the engineering design basis has been integrated with external third-party operations systems, it is possible to provide menu options from the 3D visualization model to access a wide range of information, including:

- Real-time information from DCS, continuous vibration monitoring, thermodynamic condition monitoring systems, and trend data from the ship historian
- Ship asset records and maintenance history from the CMMS
- Inspection records and status from the ship inspection system
- Failure records and history from the reliability system
- Correspondence from a third-party content management system, such as Microsoft SharePoint®

Benefits during the operational phase of the ship lifecycle

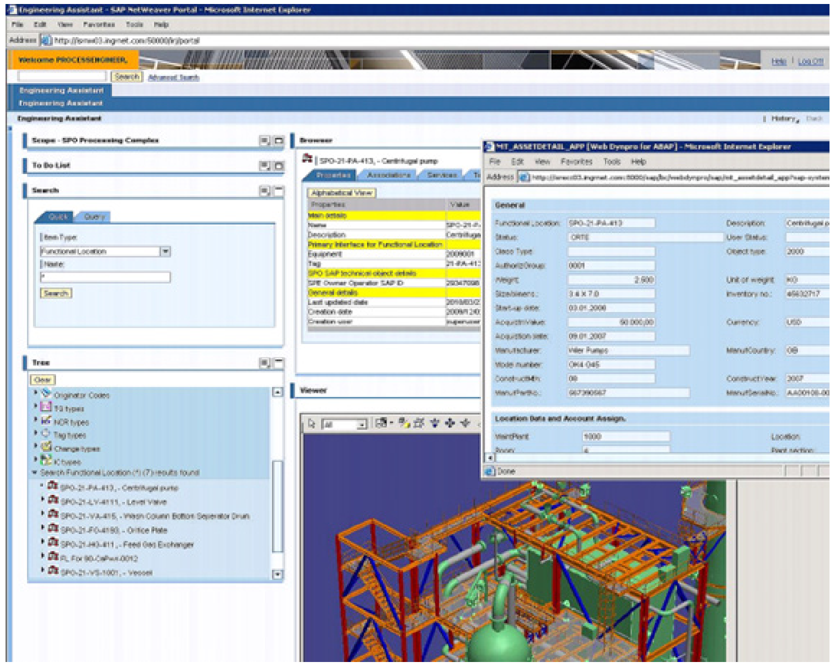


Figure 11: The SDx web portal shows data from the engineering design basis and CMMS

The 3D model can also be used as a flexible graphical reporting engine where information from the engineering design basis or third-party systems can be used to highlight parts of the model, including:

- Inspection locations that are overdue for inspection
- Equipment that is failing more often than planned according to the reliability system
- Safety-critical equipment where maintenance is overdue

Providing rapid and intuitive access to ship data and documentation reduces OPEX costs, improves ship safety and reliability, and enhances personnel safety by enabling better decisions to be made faster than would be possible otherwise. The availability of an "As-Built" 3D ship model reduces:

- Ship walk-downs to verify the true state of the physical ship design for the planning of turnarounds or other ship modifications, today this is a lot of time spend when the ship is put into dry dock for maintenance
- Helicopter trips to ship to investigate the actual situation
- Time spent on-ship and the inherent risk of trips, slips, and falls
- Unproductive travel time
- Travel costs

3.2. Existing ship data capture and verification

The use of laser-scanning technologies to capture the "As-Built" state of a ship is becoming more common as technologies improve and costs fall. Ship owners are using laser scanning where updated 3D models of their ships are not available in advance of undertaking modifications, turnarounds, and ship life extensions, as well as part of overall ship asset data integrity programs.

There are different approaches to capturing the "As-Built" ship geometry. The most common approach involves capturing a 3D image of the ship as a point cloud followed by post-processing to model the ship objects and manually add data such as tag numbers.

Forte 3D includes capabilities to perform clash checks against the point clouds, as well as using the point-cloud for exact positioning of new objects in the model relative to existing objects.

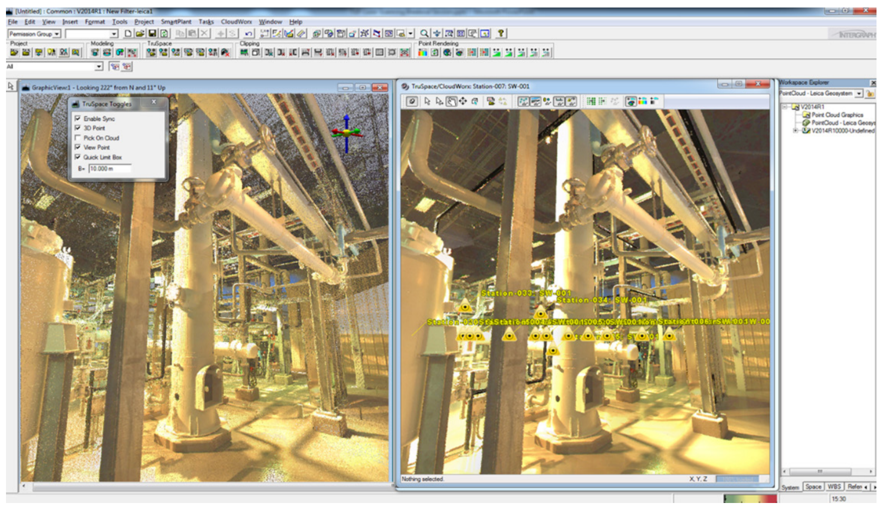


Figure 12: Laser scans and TrueView images inside Smart 3D

Once the piping topology has been captured in a 3D model, this can be verified against the rest of the engineering design basis, such as schematics and engineering registers, and may be used to assist in navigating the ship asset data and documentation.

An important capability is to verify topology in the intelligent 3D model developed from the scanning process against the schematic process topology in the P&ID diagram. Discrepancies can be highlighted, enabling the owner to bring the 3D model and P&ID, two critical sources of data for ship asset data integrity, into alignment.

Octave Forte Isometrics (formerly Smart Isometrics) provides a simple end-user tool to maintain the As-Built piping geometry and can be used as a basis for maintaining the 3D ship model.

Benefits during the operational phase of the ship lifecycle

3.3. The digital twin and the birth of the virtual maintenance engineer

As we can see, the Digital Prototype can accelerate the Design Phase of a ship-build by dramatically reducing rework and manual simulation. The digital twin on the other hand can be even more valuable as simulation based on predicted data and AI is no longer required as sensors are capturing real data from the physical platform. The entire digital twin can be lit up with information being collected across thousands of sensors on-board the platform. This can create a three-dimensional dashboard of information and identify a vast number of events, interactions and issues happening on-board the physical vessel in real time. So, in theory a user could wear a Virtual Reality headset and walk around the digital twin of that vessel and view the exact same events, interactions and issues virtually as they are happening in the physical world. That is extremely powerful as it can provide visual and dimensional context to a mechanical issue. If we wanted to simplify that result, we could just provide collected sensor data in the form of a dashboard on a PC. An individual could then drill down through sensor information from a web application. However, in order to expedite root cause analysis, we could overlay that sensor data onto the digital twin and through the use of VR provide a view that has the added benefit of visual context giving rise to the birth of the "Virtual Maintenance Engineer."

Putting on a Virtual Reality headset and walk around the digital twin of that vessel and view the exact same events, interactions and issues virtually as they are happening in the physical world.

As you can see in Figure 13, a Virtual Maintenance Engineer can use a VR headset to navigate the digital twin, in this case a 3D scan of a compartment, and view real-time data being collected from the Physical Twin. This can provide the engineer with visual context to understand what the issue might be, in this case a coolant flow issue raising the temperature of a diesel generator. Although there would most likely be an engineer attending to the issue on the Physical Twin, a virtual engineer who may have subject matter expertise could be in another location viewing the same interaction within the digital twin. Not only can the view provide key sensor data from systems and equipment within the compartment, but the virtual engineer can also pull in sensor data from other parts of the ship as required.

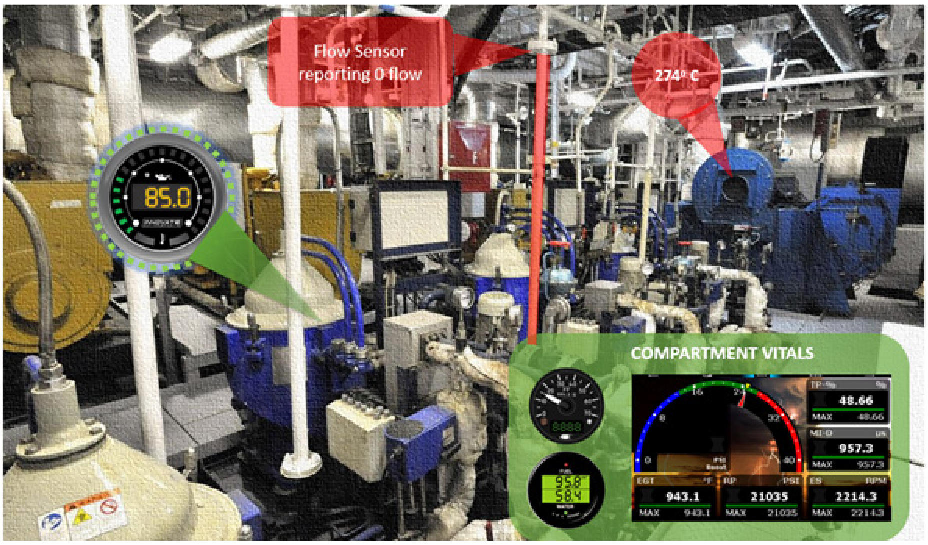


Figure 13: VR view (3D scan) of a ship compartment within the digital twin showing real-time sensor data overlay collected from the physical platform

Benefits during the operational phase of the ship lifecycle

Similar to the Digital Prototype, the use cases for digital twin are vast. To take that use case one step further, inspection data including Objective Quality Evidence (OQE) such as photos, videos and inspection reports, can be attached to the specific locations on the digital twin. That way an individual using an AR device such as a headset can walk into a ship compartment on the Physical Twin and instantly view locations of where OQE has been previously attached to the digital twin (seen as red dots in Figure 14). That way they can view the various OQE and results of quality inspections as they view the physical system it relates to. Dots could be turned green when the issue has been addressed allowing for engineers to walk around the ship fixing red dot issues and making them green. Talk about gamification!

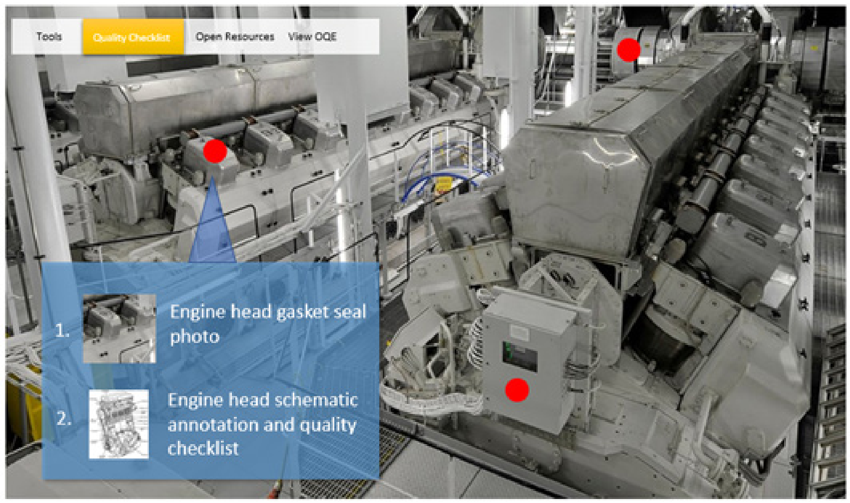


Figure 14: View of the physical twin through an AR device
showing locations of OQE attached to the digital twin

Digital twin is so much more than a collage of pretty pictures. Digital twins could be the most powerful assets an organization owns, but there are challenges to overcome in order to get it right. As you can see in Figure 15, there is so much valuable data that can be captured in a digital twin. Operational history alone could quickly fill your IT department's servers. In fact when an F35 flies for one hour it can produce two terabytes of flight information. That's enough to fill the average home backup drive.

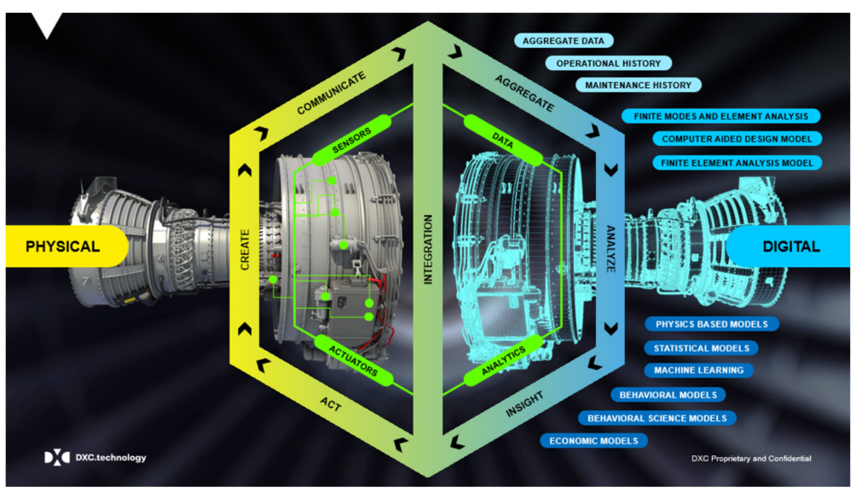
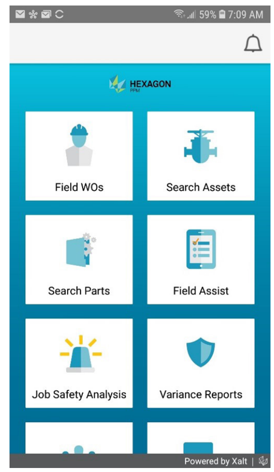
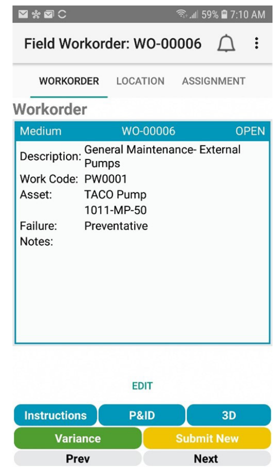


Figure 15: Information that can be captured in a digital twin

The biggest challenge with a digital twin is extracting the important information from that data before loading into the digital twin. Data by itself is quite useless. However, when data is processed, interpreted, organized, structured or presented to make it meaningful or useful, it becomes information. For the F35 example that means converting two terabytes of data into two megabytes of information. That would either mean manually looking through approximately 150 million pages of data to get the information required or using advanced technologies such as High-Performance Computing, AI, Big Data and Analytics to extract it.

3.4. Maintenance, inspection and mission planning





The benefits to maintenance, inspection, and mission planners of having access to an As-Built 3D ship model include the ability to identify the objects quickly and easily for inspection or equipment to be maintained or identification of work applicable to the ship's mission. The 3D model in combination with the consolidated engineering and design data in InConcert Core helps you plan with higher quality information and makes creating the work packages faster for inspection and maintenance. The ability to navigate between engineering data, vendor documentation, intelligent schematics, and the 3D model speeds up accessing the necessary information required in the building of inspection and maintenance plans. The 3D graphical interface can also provide an intuitive drag-and-drop user interface to assist in the creation of the ship asset hierarchy, defining maintenance and inspection packages and verifying that all affected items have been included.

Forte 3D includes the capability to generate inspection isometrics and other inspection drawings. By including inspection point location data in the 3D model, the 3D model can be integrated with inspection systems and provide significant benefits in the process of maintaining inspection documentation and perform inspection planning.

For maintenance or inspection planners, being able to see the location where work is to be undertaken also makes it easy to:

- Plan if there is a need to erect scaffolding or take step ladders in order to perform an activity
- Assess if the required space to perform maintenance is available
- Improve the quality of Job Safety Analysis and emergency preparedness
- Identify the applicable changes in order to make the ship ready for the next mission

Presenting the inspection and maintenance status of the disciplines in the 3D model can also assist in highlighting deviations to established plans and drawing attention to areas where inspections or maintenance have not been performed according to schedule. This can aid ship management in risk identification and mitigation following inspection and maintenance work. In addition, it enables prioritization of work to avoid potential unplanned shutdowns.

Benefits during the operational phase of the ship lifecycle

The 3D model can be used to identify and visualize corrosion/erosion loops. This is an important concept to identify parts of the ship subject to similar corrosion conditions and the same materials. The identification and application of corrosion loops in the inspection process reduces the effort required in inspection planning, increases inspection efficiency, and simplifies the location of inspection locations.

Linking of thickness measurement locations (TMLs) to physical locations and inspection results held in an inspection management system enables fast and simple access to view trend data or comparisons with other TMLs in the same system.

3.5. Maintenance and inspection execution

The 3D model can also help in planning activities so that work can be rationalized by undertaking all activities located physically in the same location. Using a 3D model to rationalize inspections, one operator has reported reduced costs of 30 percent and reduced time spent on the ship. Maintenance modifications can be similarly planned so that location-based sequencing can optimize the work undertaken to increase wrench time.

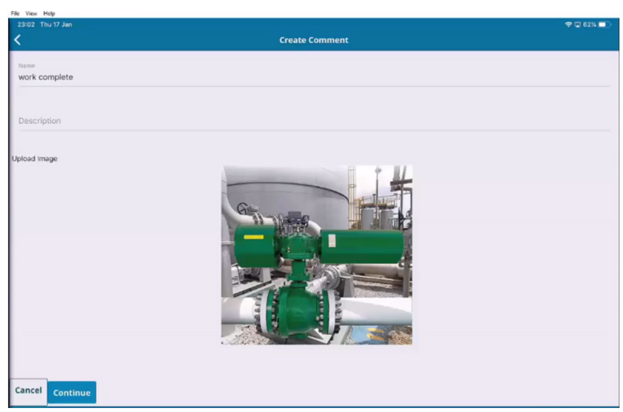


Figure 17: The possibility to take picture during a survey and have these automatically linked to the right tags in SDx when back to the office

The 3D model is now frequently used as the source for generating inspection drawings, such as inspection isometrics and inspection drawings. Generating these as graphical reports rather than traditional drawings saves time and effort and improves accuracy. Ultimately, traditional inspection drawings can be eliminated completely by taking the 3D model into the field with a portable device. The inspector can identify an inspection point on the laptop screen, then capture material thickness measurements via an ultrasonic inspection device. The result is held on the laptop for later upload to the ship inspection system.

The visualization of maintenance and inspection locations enables evaluation of maintenance clearances and can be used to determine current or future replacements needs of for instance the shell plates.

Benefits during the operational phase of the ship lifecycle

3.6. Mission planning and modifications

Mission specific or generic modifications planning typically takes six to 14 months of detailed effort to scope and prepare for a shortest possible dry dock time in order to undertake maintenance activities and modifications that cannot be done while the ship is operating. Each day the ship is in dry dock it impacts the readiness and the opportunities to perform missions, so it is important that plans are optimized. These modifications also pose an inherent safety issue: large numbers of staff not familiar with the ship are performing out-of-the-ordinary tasks under a heavy time pressure for completion to return the ship to an operational state.

The 3D model is an important visualization tool in the turnaround planning process. Alternative strategies to reduce downtime can be evaluated. The 3D model provides a good, accurate basis for contractors to do their work. The 3D graphical interface can also provide an intuitive drag-and-drop user interface to assist in the creation of work packages and to verify that all affected items have been included in a turnaround package.

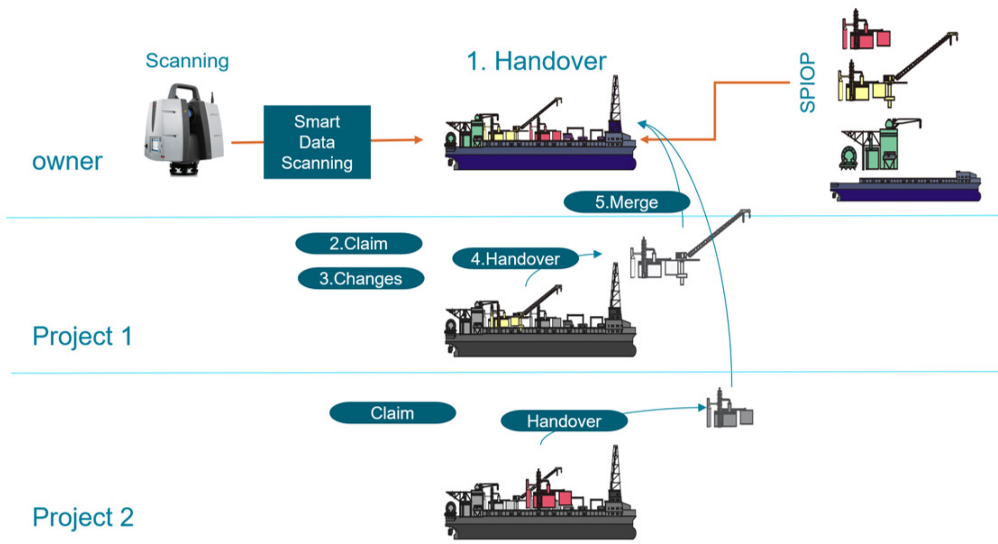


Figure 18: As-built process scenarios within Forte 3D

The availability of an accurate, "As-Built" 3D model reduces the need for onsite verification of modifications.

The 3D model can play an important role in the planning and simulation of modifications and turnarounds. Complex operations, such as the removal and replacement of major pieces of equipment or the dismantling and reassembly of major equipment, can be simulated. No other technique can offer the power to be able to identify whether there is adequate access for heavy lifting equipment or transportation equipment, detect potential clashes while moving equipment, and show this convincingly. Similarly, the 3D model can be used to verify whether there is adequate space for scaffolding or other temporary structures or equipment.

Planning in advance to prevent problems arising during turnaround execution will decrease the risk of undertaking complex operations, increase the scope of work that can be undertaken, and reduce the risk of delays.

Benefits during the operational phase of the ship lifecycle

The 3D model can also be used to highlight where work is scheduled to be performed day-by-day, hour-by-hour during the dry-dock period. This can increase turnaround efficiency and reduce associated safety risks. The 3D model helps users:

- Assess if there are too many people trying to work in the same area, resulting in congestion
- Determine if personnel will be welding or lifting operations will take place above other workers
- Ascertain if optimal use is being made of expensive temporary equipment, such as cranes
- Plan and optimize laydown areas needed to assemble materials and equipment for the turnaround

During maintenance execution, the 3D model can be color-coded to display the system status of work undertaken (blocked, flushed, purged, cleaned, opened, etc.) and tie-in locations and isolations with status.

The 3D model is important as a source for the automated generation of drawings such as isometrics to perform modifications and inspection. The intelligent 3D model also includes important materials information and catalogs that can be used when planning modifications and replacements to ensure that all changes comply with the original or intended future design standards.

With the arrival of Forte 3D, the opportunity to build intelligent rules into the 3D model can also ensure that planned modifications adhere to regulatory requirements.

3.7. Analysis and simulations

The 3D ship model is a prerequisite for performing advanced engineering and geotechnical analysis and simulations, such as the advanced computational fluid dynamic (CFD) modeling of ventilation, gas dispersion, prediction, and consequence analysis of vapor cloud explosions and blasts on ships.

Forte 3D includes bi-directional interfaces to pipe stress analysis such as Octave Aspect Pipe Stress (formerly CAESAR II), and structural analysis tools such as Lloyds, Octave Aspect Structure (formerly GT STRUDL), Staad Pro and DNV-GL Sesam GeniE.

3.8. Staff training and retention

Attracting and retaining highly qualified employees is becoming more important. Industry demographics reveal that many of today's most experienced employees will retire over the next decade, leaving a "knowledge gap" for many ships. Newly qualified engineers and technicians who are used to playing advanced video games will expect and require modern, graphically-enabled IT tools to help them do their work. The 3D-enabled engineering design basis provides a simple, intuitive access point to ship information. This will be an important technology to help train new staff and bridge the "knowledge" gap when older employees retire. As costs decrease and 3D technologies advance to provide immersive environments, virtual reality, augmented reality, and more, the possibilities and capabilities for staff training will increase.

Benefits during the operational phase of the ship lifecycle

The 3D model can also be used to quickly and intuitively instruct new staff on evacuation routes, stair locations, firefighting equipment, and safety shower locations.

Advanced training simulation software such as Simgenics 3D Pact is also available, enabling realistic training of ship personnel. The software includes capabilities such as:

- Configure training scenarios and workflows without programming
- Create on-screen photo-realistic control panels
- Create action-points and operational behavior of buttons, levers, etc.
- Highlighting of objects/areas of special relevance for the training
- Create realistic looking events with full physics
- Create physics-aware and textured 3D graphics
- Create dynamic characters for realistic training

Figure 19: Example images from Simgenics 3D Pact training solution

Leading owner operators are already using 3D models as part of their computer-based training, both for familiarization and for testing operators regarding the operations sequence and emergency procedures. This can be used for worker certification and the qualification of staff for key activities and roles on the ship. In addition, 3D-enabled staff training can begin early, prior to new ships being commissioned.

Training of staff regarding operations that are potentially hazardous or undertaken in hazardous areas is especially important where training and incidents can be simulated without exposing staff to potential risks on-site.

3D-based computer training can also be used to simulate complex or infrequently performed activities so that staff is familiar with processes before they need to be undertaken during ship outages where errors can increase downtime and lost production.

4. Ship decommissioning

Owner are faced with increased legislation and regulations regarding the need to remove redundant ships in an environmentally responsible manner and restore the ship site after removal. The 3D ship model can be used as an important aid in planning decommissioning and dismantling.

Alternative dismantling strategies can be simulated and demonstrated to authorities and other stakeholders, such as the local population, to explain the approach chosen.

Tanks, equipment and pipelines that need special treatment because of toxic contaminants or radiation can be quickly identified, and quantities, weight, center of gravity, etc. can be reported. The removal and traceability of these equipment and pipelines can be captured to demonstrate compliance with appropriate regulations.

Complex and potentially hazardous operations can be simulated in advance to identify and mitigate risks.

5. Conclusion

Utilizing the engineering data developed during the CAPEX phase of the project and represent this in such a way that people can easily recognized and identify the objects and their related information will bring tremendous cost savings during the operational life span of a ship. It will also reduce the time in the dry dock since the preparations for the maintenance, mission updates and/or mid-life upgrades of the ship can be done in preparation of bringing the ship into the dry dock. This will greatly reduce the time that the ship is not available for missions and allow an increase of time at sea.

Combining the aspects in above paragraphs leads to unique ships within the fleet and they should from an engineering and data asset therefore managed as such; hence each ship should have its own unique 3D model. This largely contradicts the class of ships that are supposed to be identical; however, history has proven that this has never been realistic due to the technological and commercial factors that get built in the next vessels of the class. This does not, however, dismiss the need for tools across the fleet that will enable purchase and maintenance advantages.

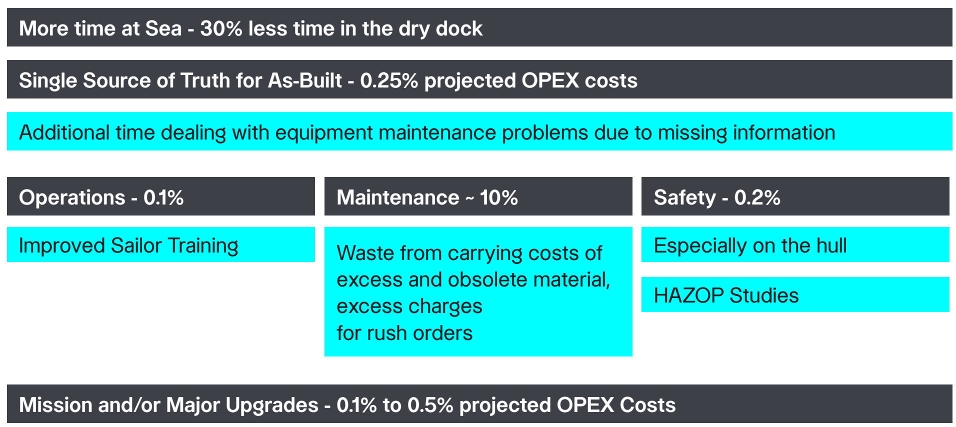


Figure 20: VROI example per area - based on projected OPEX costs

Using the as-built data configuration and showing this through 3D different scenarios for different usage can provide proven benefits for:

- Mission planning
- Inspection planning
- Maintenance including life extension programs

The design data can be merged back into the as-built model for future reference.

By using centralized catalog with project specifics added to it, economy of scale can still be achieved by combining the bill of materials within a single purchasing system based on article identifications.

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[2] Internal papers Octave, several authors

[3] Digital Twin, LinkedIn article by Bernard Ash, CTO - Aerospace and Defence (ANZ) at DXC

About Octave

Octave is a leader in enterprise software, turning data into decisive action and intelligence into your edge. Our software solves for and simplifies complexity, from the design and build to operations and protection of people, property, and assets– for any scope, at any scale. For decades, we've partnered with customers to sharpen performance, elevate efficiency, and amplify results. From factory floors to entire cities, our solutions are tuned to scale up what's possible from day one onward.

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