HOLISTIC SHIP DESIGN – HOW TO UTILISE A DIGITAL TWIN IN CONCEPT DESIGN THROUGH BASIC AND DETAILED DESIGN

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SUMMARY

People have been designing and building ships successfully for hundreds of years – why change now?

There are many factors influencing the ship designers desire to find new processes and tools to drive their ship design forward. Initiatives like Industry 4.0 and the Digital Thread address the automation and utilization of robots. Other drivers are increased complexity and desire for sustainable solutions. Combined with the demand for higher innovation and focus on productivity and cost cutting, ship designers and yards must find new processes and systems in order to propel into the digital world.

This paper explains the advantages of holistic ship design compared to traditional design approaches and the significant potential of a Digital Twin in such a process.

NOMENCLATURE

[Symbol]	[Definition]
4GD	4th Generation Design
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CAx	Computer-Aided technologies
CFD	Computational Fluid Dynamics
ECR	Electronical Change Request
KBE	Knowledge Based Engineering
PLM	Product Lifecycle Management
PMI	Product and Manufacturing Information

1. INTRODUCTION: THE DIGITAL TWIN

The Digital Twin is a virtual image of an asset, maintained throughout the lifecycle and should be easily accessible at any time. It is a central part of our digital asset ecosystem and it will enable a new generation of advanced analytics and understanding of the product. A Digital Twin should be able to integrate data from many different software products and handle them in a managed environment throughout the whole lifecycle. The concept of the Digital Twin will potentially enhance information management, understanding and collaboration, to prevent costly mistakes and rework.

The combination of holistic design and Digital Twin has the potential to revolutionize the ship eco system from early design and planning to design and operation and demobilisation.

"The Digital Twin serves as a virtual replica of what is actually happening on the factory floor in near-real time" [5]. It gives the opportunity to make production related decisions early in the design process and during the full lifecycle of the asset.

Throughout the lifecycle [the asset] is going through different stages of development. It is important to define and maintain those stages to be able to enable good decisions. This traceability also enables better future products due to the captured knowledge in the existing Twins.

A Digital Twin should carry production and manufacturing information (PMI data). Such data is a facilitator for automatization and efficient use of robot and direct linking to different production assets like cutting- and nesting machinery. PMI is both readable by machines and it can be used for 2D prints or 3D visualisation for involved stakeholders.

A Digital Twin is more than just a rich 3D model, it may also include optimisation, simulations and –results and defining documents. Such an approach enables no double data description and provides a single definition source for the asset.

A Digital Twin is suitable to couple with sensors on the physical asset for capturing data that might be used in future designs, fatigue studies and different aspects of maintenance like scheduling replacement of components.

Autonomous vessels like the Norwegian "Yara Birkeland" - which will be world's first fully electric and autonomous container ship, with zero emissions – will ultimately require a Digital Twin approach for design and remote operation. [1]

Companies like Wilh. Wilhelmsen Holding ASA together with Ivaldi Group are currently developing methods to utilize 3D printers to manufacture spare parts for their ships. [6] Model information derived from a Digital Twin will take this one step further.

2. THE POTENTIAL OF THE DIGITAL TWIN

As mentioned earlier, many yards and ship designers are now challenging their way of doing ship design and are looking on new process and supporting systems. Legacy processes can involve as many as 15 to 25 different systems across the different design disciplines from early planning to fabrication. Data consistency and changes are hard to drive through and manage when the data definition and information is kept in so many different systems. To avoid failure, many costly efforts must be spent on non-value adding processes. It is also pricey to secure that relevant people can access the correct data in the required time span. In a demanding digital and disruptive world

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[with focus on cost cutting, improved innovation and fierce competition] yards and ship designers have, it needs to be challenged what has been and look for a novel approach for designing vessels for the next decades.
Legacy environments for ship design have been characterized by different specialized systems targeting a limited market. Other industries like Automotive, Aerospace and High-Tech are more or less sharing the same kind of product definition environments. The ongoing consolidation in PLM and CAx has, so far, had less impact to the marine industries. Enrolling such [PLM and CAx] environments to marine industries enables sharing of destiny with other industries, which means the development costs can be distributed on a large customer population.

3. INTRODUCTION HOLISTIC SHIP DESIGN

A holistic approach is dependent on a software platform that can handle the design from cradle to a ship in operation. It is a connected process with a master model guiding and maturing through the total design and life span of the asset. Reproducible scenarios and stages are used for optimization, simulation and understanding of the design.
Holistic design as a concept goes beyond problem solving. It incorporates all aspects of the ecosystem that a product will be subjected to. The concept is mainly focused around aesthetics, sustainability, spirituality and other aspects of "wants" rather than "needs". It is mostly employed in architecture but can be adapted to any form of product or service design. Ship design is especially suited for a holistic approach.
Using a holistic approach, helps to avoid scattered processes [as applied up to now], will result in a limited number of used systems and has a single backbone carrying the information through the various stages and disciplines.
Some key enablers in holistic design are:

- Front Loading
- Backbone
- Knowledge Based Engineering

3.1 FRONT LOADING

Front Loading challenges the traditional way of ship design specifically when it comes to the ability to able to order the steel as early as possible. The legacy processes are primarily 2D based and dependent on skilled workers leaving less opening for automation and robotization. With Front Loading, more emphasis is put on early design phases by building up a digital representation for decision making, simulation and testing. Typically, models are "matured" and populated with more and more detailed information as the design moves along from concept design, to basic design and detailed design. A rich 3D model with BREP definitions and PMI carries the machinery information to different production equipment like nesting systems, cutting machines and different kind of robots. (Compare figures 1 and 2)

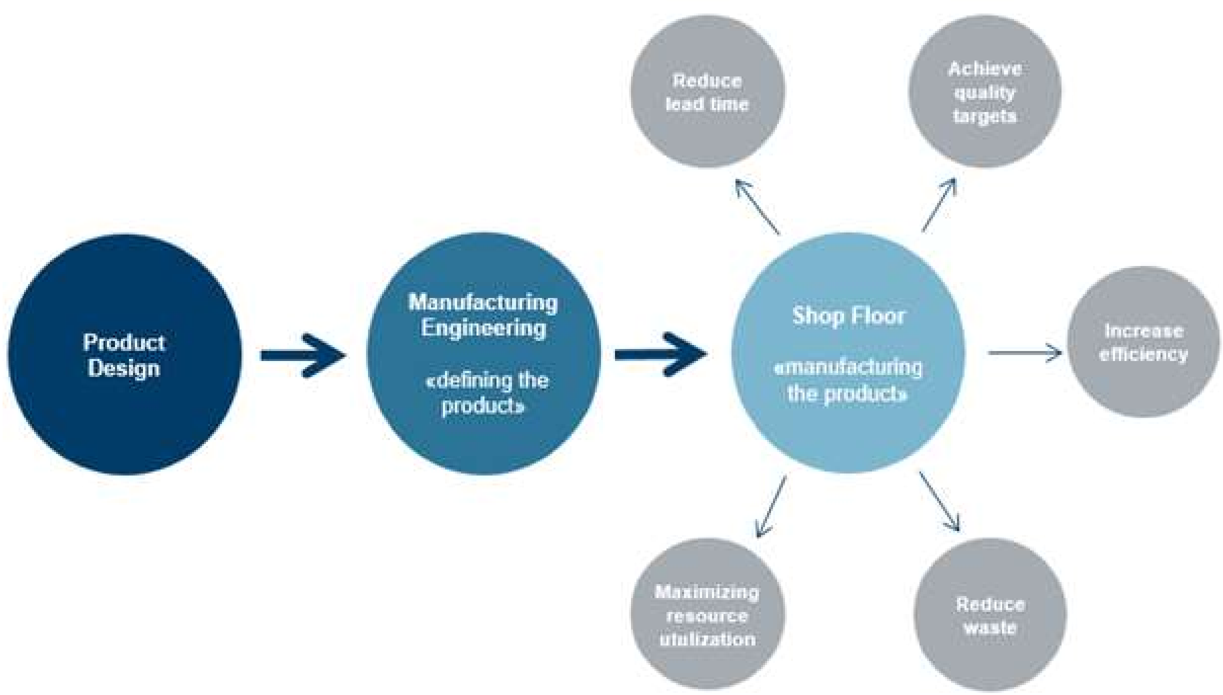

Figure 1: Traditional approach dependent on skilled workers

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3.2 BACKBONE

A Backbone system is handling all relevant product information through all stages in a managed way. Such systems often called Product Lifecycle Management (PLM) systems. The Backbone is able to handle information from different systems spanning from office programs to CAD, CAM and CAE. It is independent of geography and disciplines and displays all managed information in a user-friendly fashion independent of devices or location.
The Backbone is managing the content, user access, revisions and versions of all data. It should be key to support a Digital Twin approach. (Compare figure 3)

3.3 KNOWLEDGE BASED ENGINEERING (KBE)

In this context, we refer to Knowledge Based Engineering (KBE) as parametric models that incorporate/capsulate knowledge and handles specific tasks and/or processes. Use of KBE is often motivated by a desire to secure a certain process, a way of conducting design, or to speed up the process for cumbersome and time-consuming designs.
Some examples can be KBE parts for railing, ladders, doors, bathrooms, anchor pockets or even complete hull designs. A KBE solution often includes optimization, simulation as well as documentation.

4. DIGITAL TWIN IN CONCEPT PHASE

In this phase the designer/yard is bidding to get the contract, traditionally it has been done in 2D AutoCAD and the handover is a 2D GA drawing. Many ship designers are in addition to this using systems such as Rhinoceros or 3D Studio Max to create a visual presentation of the concept. Simulations and calculations are done by hand or in separate systems for each design discipline.
In conventional design methodologies, unconnected data sets are generated, often by copying data from previous projects with little adjustment to meet the requirements of the new project. The experienced Naval Architect manages to find various data from a number of suitable projects and adjust them to the needs of the new project.
This process is driven by getting concept design data as fast as possible. It is not very transparent and therefore creates a risk of failure. In addition, unconnected data sets have no proof of compatibility to each other. The design team, collaborating in the concept phase, can work out machinery schematics, general arrangements or hull lines which will not may not fit together. Every involved designer is focusing on the optimal result within his or her own design discipline in the new project, failing to focus on the broader picture.
With a holistic approach, ship designers will utilize a Master Model: building a 3D general arrangement with a linked 2D drawing, aesthetic views and different models suited for analysis and simulation. The Master Model holds both solid and surface representations which are

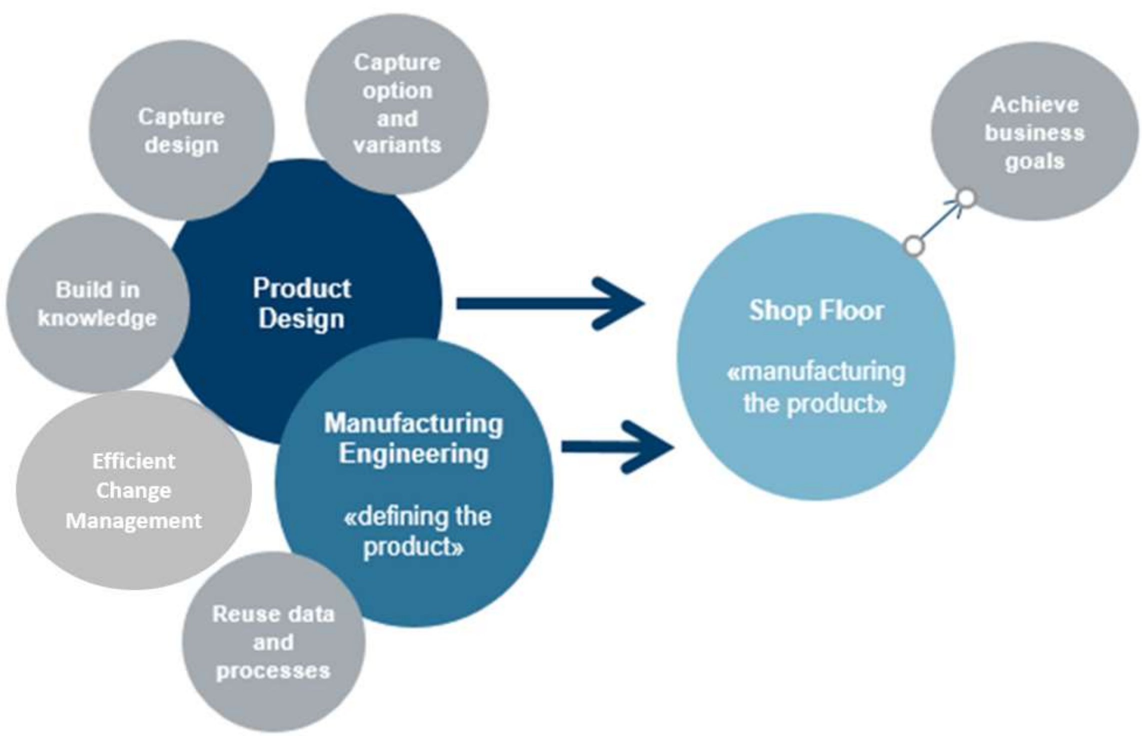

Figure 2: Front loaded process

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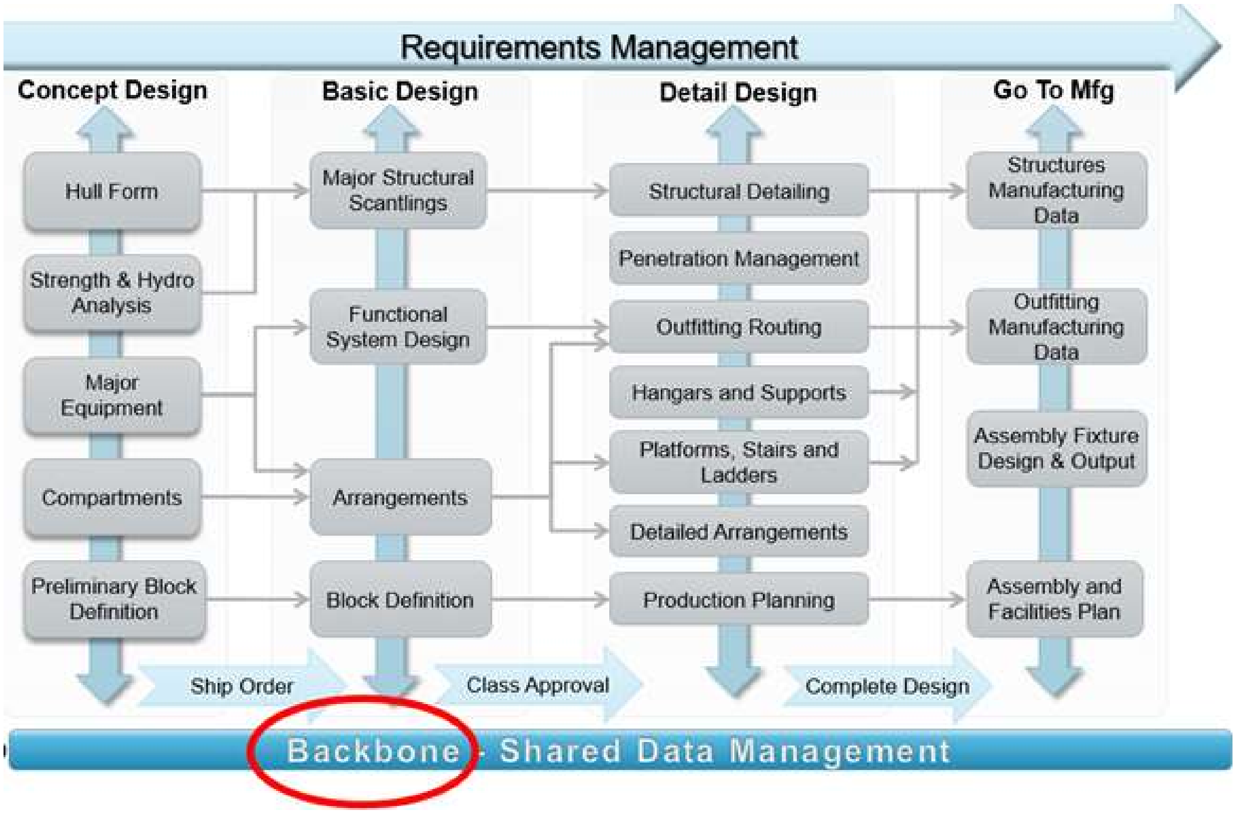

Figure 3: Example of a Process scheme included Backbone for shared data Management

available for different use cases and decision making. In this stage, the number of details are limited to what is necessary for the given purpose.

When defining the objective of the concept design phase, to arrive a signed contract for building the asset, a number of needs are identifiable among the created data. The feasibility, costs and risks are much more predictable when the design is carried out with a high level of detail and precision. However, there is no guarantee that the time invested in creating the concept will pay off, before the contract is signed. This results in the need to reduce the required time for creating sufficient set of data to what is necessary win a contract. As a result, it is vital to reduce the time required to generate sufficient sets of data to win a contract.

In the Digital Twin concept, a team of technical specialists will need to work and collaborate at the same time. Non-technical personnel will need access to information to pursue the project on the administrative- and business side. This requires a platform for collaboration and data access - which state of the art PLM systems can provide. A user-friendly interface with configurable access to data that meets the requirements of both technical and non-technical personnel is essential. Good search capabilities, using indexing technology, ensures that every person can find the data they needs when they needs it.

A Digital Twin in the concept phase, is different from the legacy processes by the fact that all the data is connected. The advantage is that conflicts in compatibility will be identified earlier and can be completely avoided which subsequently will lead to better decision procedures.

To address time efficiency, it is essential to organise the creation of the Digital Twin, as lean and effective as possible. Re-Use of existing data for the Digital Twin is key in order to save time. Re-used data might be a library of standard parts or other project neutral components. Those components can come from another Digital Twin. The ability to clone existing Digital Twins and change it to new requirements enables the use of existing project data to be the foundation for a new design. Therefore, it is important to be able to identify the concept phase of a more matured Twin. In a PLM system, this may be addressed by using revision and status management. State of the art product definition platforms support the reuse of data with sophisticated search functionality which is accessing both lifecycle and CAx data from a single and easily accessible user interface.

The Digital Twin in concept design [due to its connected product architecture] is providing a better baseline for CAE analysis. This enables more and better simulations earlier in the design process. Performing simulations and optimization earlier in the product design process will get more important as Industry 4.0 thinking will spread into the maritime industries. [3]

Capturing knowledge [rather than just documenting a product] is the required thinking to generate a Digital Twin, which will helps the concept design team to create a better ship design in the future.

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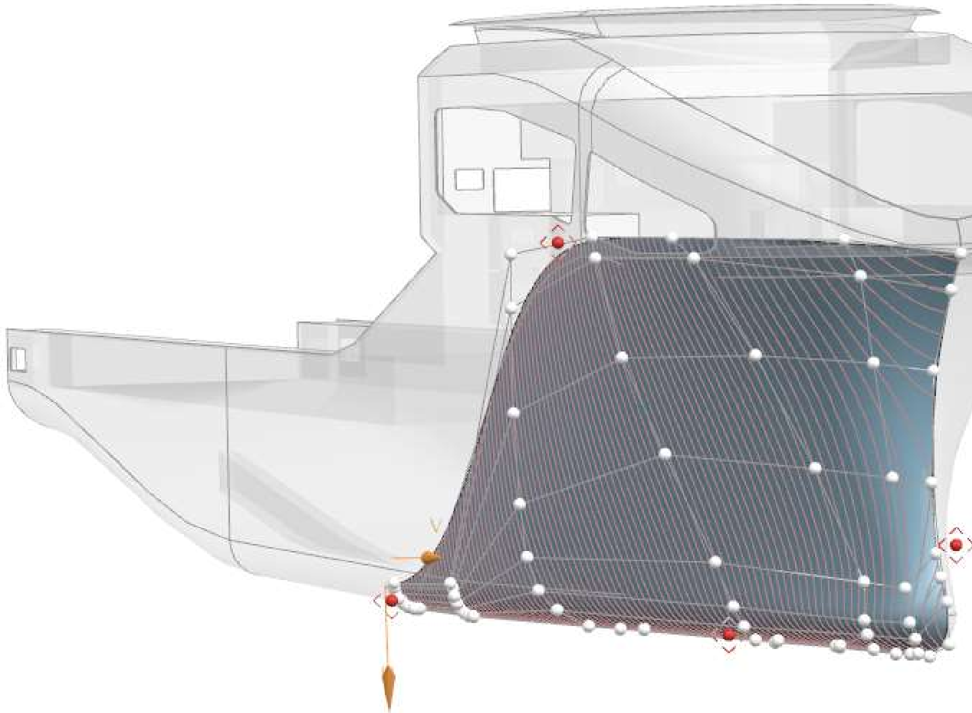

Figure 4: hull fairing on the Digital Twin

Connected visualisation and Virtual Reality applied to the Digital Twin will give better support to the required sales processes reducing the gap between the different parties involved in winning a new contract.
Hull shape design of the Digital Twin is an integrated process [shown in figure 4], this will enable changes to be made rapidly in the different downstream processes. The defined Hull Shape model usually is the first geometrical definition defined for a Digital Twin. The design impact of the Hull Shape in a ship design usually is considerable in most downstream design processes. At the same time downstream processes defining requirements against the Hull Shape definition. Therefore, Hull Shape definition needs to be centric in the early concept phase of a Digital Twin. Processes analysing the hull shape and providing feedback for changes of the hull shape may be secondary and give change requests towards the hull design.
Using state of the art 3D systems gives the ship designer the opportunity to work on faired Hull Shapes from the very start of the design phase. Such a Hull Shape is parametric and very suitable for CFD calculation early in the design process. These calculations are imperative for achieving more efficient and sustainable hull designs.
While the hull is being analysed and optimised towards stability, seakeeping and resistance the hull is already used in the space subdivision of the vessel for applying functional design and risk analysis. The hull definition has an associative relationship to this subdivision. Any change applied to the hull can immediately be distributed towards the spatial subdivision. This may be managed by automated processes or user interaction.

Knowledge about required outfitting will be collected with traditional schematic sketches. Utilising systems engineering approaches throughout the product definition [the software] will provide part lists and interactive requirements between representations of the early 3D Model, the required functional space and the schematic drawings.
The functional space layout, the hull and interactive part lists [of the schematics] will lead to associative definitions of a three-dimensional General Arrangement model. (As illustrated in figure 5) This creates a comprehensive view of the Digital Twin in the concept phase.
The entire CAD process is supported by a lightweight viewing format, ISO 13406 (JT) which enables all Non-CAD users to display the current status of the geometrical model. The lightweight geometry is embedded in the data Backbone and it is therefore always in sync with the latest version of the Digital Twin. Status and access control gives a whole new level of opportunities for interaction with the classification society, yard and the customer of the ship design team.

5. DIGITAL TWIN IN BASIC DESIGN PHASE

This design phase addresses the need for class information. Classification documents are created together with information for any other authority. This information must be in line with the latest rules and regulations.
Historically customers using drawing automations to generate classification drawings to formally collaborate with the classification society. If those drawings have been

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generated from a 2.5D or 3D model manual tracking and mapping of changes is required from the communication on the drawing to its model definition.
In the basic design process of the Digital Twin, collaboration with the ship owner and the classification society is enabled and controlled by the Backbone. HTML 5-based technology helps to access Twin's data without complex installation processes. It is platform independent and works on multiple devices and sites. Status and rights management ensures that the related parties will only have access to the relevant data, in its matured state, for their role and project privileges.
During the basic design phase, multiple product views will show the relevant subset of the Digital Twin to the viewing user. [4] The product definition platform is assisting the different groups in providing and generating the required product views dynamically.
The ship structure process is supported by a managed library for standard parts and structural elements. The structural design in basic design is challenged in flexibility, as radical changes may occur. The ship design company can address radical changes quickly based on reasonable technical and economical data and this will give them a competitive edge. To address this a structural systems approach is used. A structural system might be a deck, bulkhead or structural hull definition represented by a sheet body. Seam curves subdivides a system into subsystems. This might be performed based on intersections with other systems, different thickness areas, structure block boundaries and/or manufacturable parts. In this phase Stiffener, Edge Reinforcements and Pillars are defined as curves, they can be displayed as solid body for better usability. This topology architecture provides the ship designer the flexibility he/she needs.
The sheet and curve based architecture of the ship structural definition enables an efficient interface for ship structural CAE calculations. The derived CAE model is associatively connected with the ship structural definition, so CAE results are traceable to the structural definition. Changes can be tracked and coordinated transparently across multiple disciplines and sites. Interactive collaboration with the classification society on the Digital Twin [not on documentation of the Digital Twin!] is possible and the way to go forward.
In the future, a model based classification process will improve the collaboration and communication on the relevant Digital Twin data. [2] Certificates and approved structures will be managed and connected directly to the Digital Twins data within the Backbone.
The structure designer is working in context of the 3D conceptual data, such as the General Arrangement assembly. The designer can address required changes while displaying the structural view in context. (Illustrated in figure 6) The ship structure basic design view will be transitioned, with an automated process, into the ship structure detailed design view. This transition is supporting later changes on the basic design view.

6. DIGITAL TWIN IN DETAILED DESIGN PHASE

In the detail design phase, the Digital Twin will be shown in ship structure detail design views in a subdivision of structural blocks. Design features such as end cuts, cutouts, slots, etc. are created. Detail Design can make use of KBE capabilities to implement connections and create design features.
Fourth Generation Design (4GD) in NX/Teamcenter enables the display of the relevant ship structural subsets

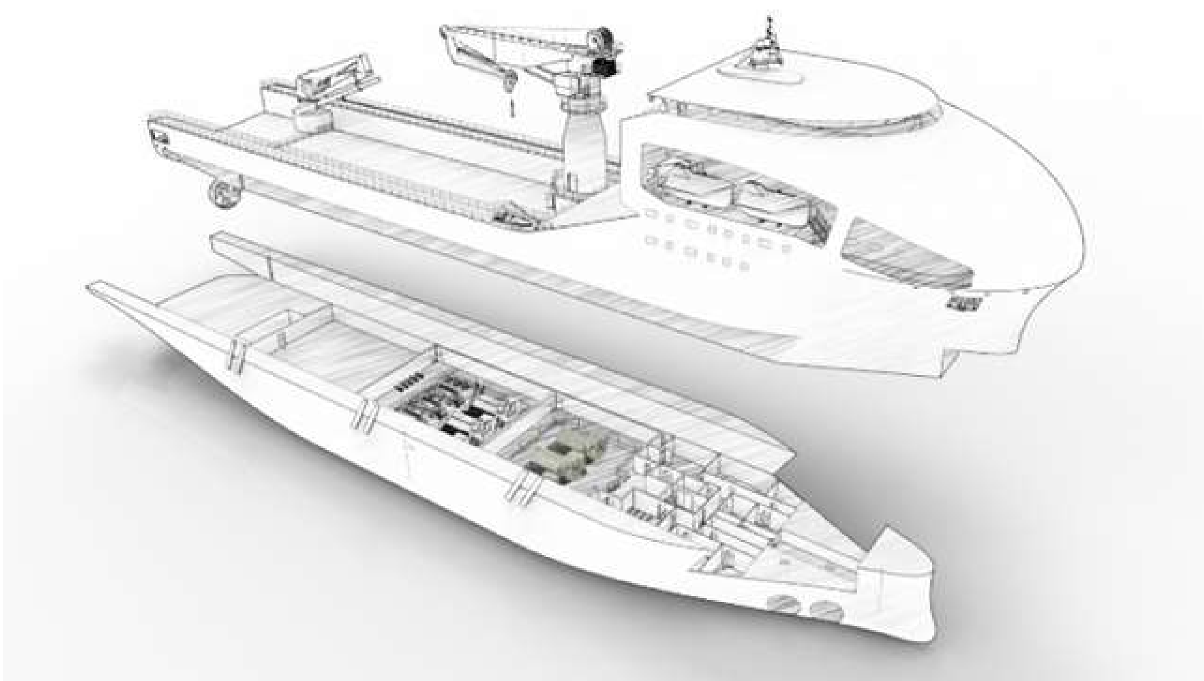

Figure 5: spatial subdivision connected with general arrangement and associative Hull Shape definition

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of the Digital Twin for other design disciplines. [4] Piping and Outfitting, Interior Design and design of specific mission equipment are handled in the context of each other. (see figure 7)

As on the physical building berth the process in a digital yard is applied to a single product – the Digital Twin of the asset. Different people have the opportunity to collaborate their design expertise into a good product. In digital processes around the concept of a Digital Twin it is the Backbone which is supporting and managing this cooperation.

Penetration management is embedded and helps the piping engineer to collaborate with the ship structural engineer. The piping engineer can design his pipes in a ship structural context. He will route his pipes interactively through the defined structural arrangement. This enables him consider i.e. girder or profiles while planning his piping routes. When the engineer intends to have his/her pipe to penetrate a bulkhead or plate, he/she can choose sufficient cutouts from a managed library. Together with remarks of the piping engineer an electronic change request (ECR) will be generated and provided in a task pool. Tasks from this pool are distributed based on organisational rules to the structural engineer in question. The structural engineer can either approve the ECR [which will lead him to the software to create the cutout] or come back with a new suggestion of cutout or position to take the structural design in consideration.

The Backbone with embedded reporting tools enables a light and straight forward communication on the assets definition, without the need [or delay] of an extracted representation such as a drawing. However, if drawings and PDFs are needed they are easily available on demand. They should not be used as information carrier but rather handled as “snap shots”.

The ability to have subset views of the Digital Twin for designing in context also connects interior design and further outfitting close to the structural and piping design of the vessel. The rich definition of Digital Twins gives a foundation to utilise capabilities of virtual reality [and augmented reality in later processes]. This creates a new experiences and opportunities for collaboration with both suppliers, clients and internally at the yard for better designs.

In collaboration with our ship building and design customers worldwide, the different requirements of the ship structural definition in the different design processes have been identified. To support the detailed design phases for ship structure design in the best way, a new ship structural breakdown of the Digital Twin will automatically be transitioned by the system. This transition creates a more production- and detailed design focussed view of the ship structural definition. The ship structure detailed design model is built in a component based design architecture.

In the finalised ship structural detailed design definition, the Digital Twin will have a component item for each physical component for optimal support of the Lifecycle Management requirements during detailed planning, production and maintenance of the asset.

7. ENABLING TECHNOLOGY

Our background and experience comes from working with Siemens PLM Software. As a provider, Siemens PLM Software differs from its competition in its openness and a devoted alignment to its customers. Unlike its major competitors, Siemens PLM Software has shared its technology and promoted openness. Good examples are JT that has become an ISO standard (14306) and Parasolid

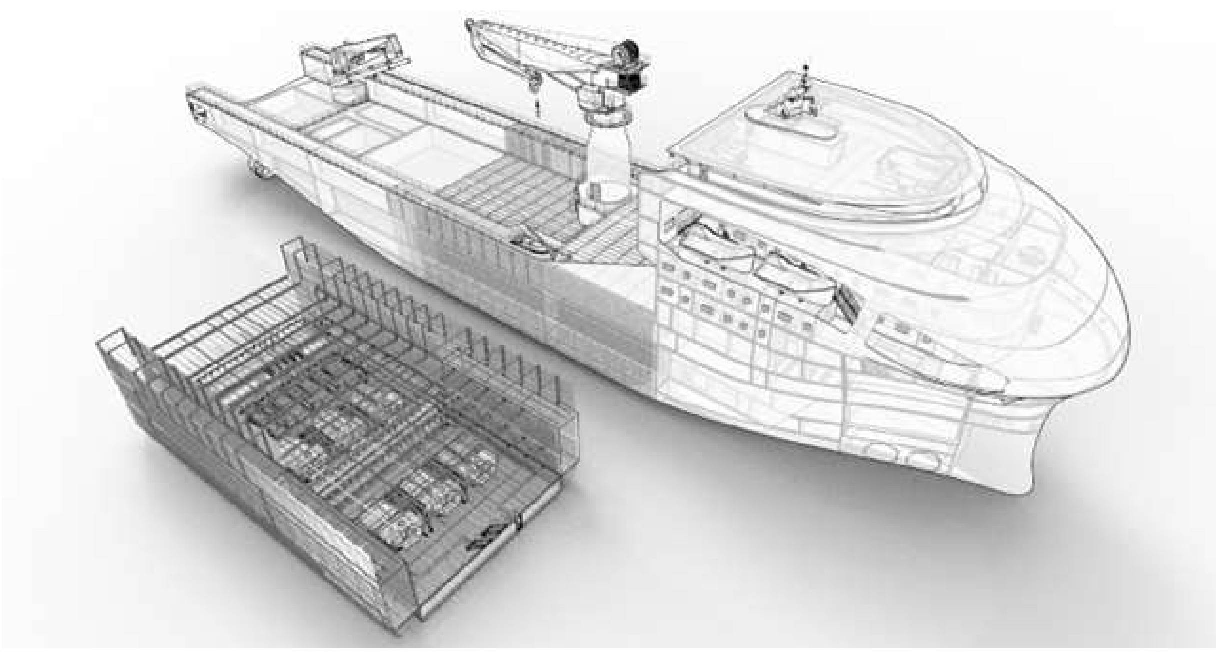

Figure 6: Utilizing concept data of the Digital Twin for the ship structural basic design in context

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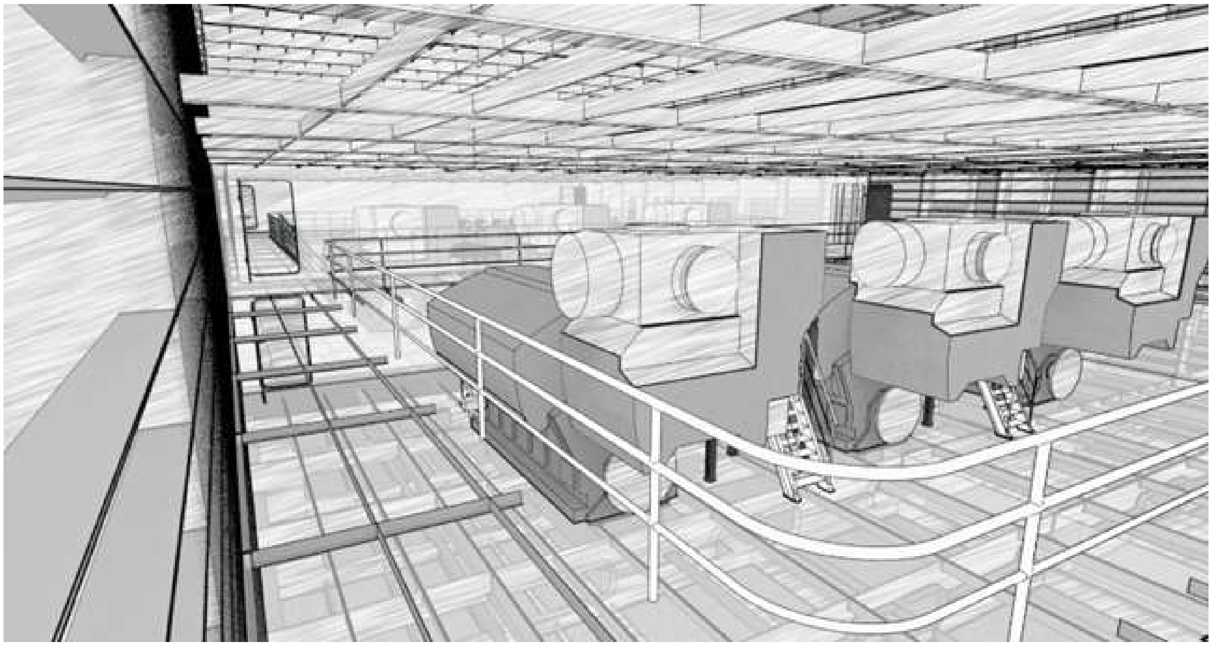

Figure 7: The Digital Twin enables Piping and Outfitting of an engine room in ship structural and general arrrangement views

that is used by several hundred competing companies in CAx.

Siemens PLM Software heritage from both CAE and CAM solutions being able to communicate with different systems. This heritage, Siemens builds on in both CAD and PLM.

Major customers such as Samsung, Daimler Benz and Rolls Royce are driving the technology forward together with our 90 000 other customers with more than 11 million seats. The basis of the technology is shared by different industries like Automotive, Defence and Aerospace, Machinery, Marine and High-Tech.

Ship design- and building solutions are built upon a shared technology base with other industries, meaning that Siemens PLM Software can share developing costs on diverse industries and a large number of users and offer the latest state of the art software in the various industries.

Ship design customers in Europe, USA and the Far East have been instrumental in developing the solution for commercial ship design into a leading-edge position. Because we share destiny with more than 11 million seats Siemens PLM Software is able to preserve its leading technology position in a world of accelerating technology and disruptive initiatives.

Ship design- and building is one of the most complex processes among the industries. Legacy vice it has also been a scattered process with many different systems and information silos. Like most other industries the product [the vessel] is becoming more and more complex. Customers have more sophisticated needs and green politics is driving the demands for efficient and innovative solutions. Digitalization will eventually transform the marine industry and create a new generation of Digital Shipyards. To meet these demands ship design customers need a good foundation and partnership [to their software providers] that can meet an ever more complex and compelling environment. Traditional providers of ships design software do not have either the muscles or the technology to fulfil these needs.

Siemens PLM Software with its openness and willingness to share and work together with customers contributes to competitiveness and secures an ongoing improvement. These customers can build upon Digital excellence and leverage the power of emerging technologies across organizations giving them ability to transform data into actionable insight and ultimately gaining business advantages. Those customers will be able to capitalize on digital disruption and make the right decisions going forward in a competitive digital world.

8. CONCLUSION

In a holistic design approach, the Digital Twin is holding all information of the asset. Starting with the definition of a Digital Twin already in concept design is helping the ship designer to have transparent processes and ultimately a better product.

Technology managing the Digital Twin and supporting a digital design processes will help ship design organisations to have a competitive edge in a digital world.

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10. AUTHORS BIOGRAPHY

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Helge Kjeilen is Chairman and owner in Digitread AS distributing and supporting Siemens PLM Software. During his career starting in 1981 he founded and co-found several Nordic IT companies. Helge has also worked as Country Manager in both Apollo Computer and Prime Computervision. For 25 years Helge has severed as board member in Wittusen & Jensen. Helge Kjeilen has a Master of Business and marketing (MBM), Field of study Business Administration and Royal Norwegian Naval Academy, OKA. Helge has for 7 years been sensor for Master thesis at Norwegian University of Science and Technology.

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