SHIP WORK BREAKDOWN STRUCTURES THROUGH DIFFERENT SHIP LIFECYCLE STAGES

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SUMMARY

Definition of complete and accurate work breakdown structures of a ship is an important and critical activity in every shipbuilding project. This is required in every stage of a ship project, right from the inquiry and concept design stage, to basic, detail and production design, and continues through definition of as-built structure, maintenance work breakdown structure, etc., right up to defining work breakdown structures for decommissioning (for ship and offshore structures).

While the need is well understood, many shipyards and ship design organizations find it challenging to define these work breakdown structures across all stages of a project, and to understand the linkages between these work breakdown structures through the various phases of a design and build project. Things become more difficult when the ship or offshore structure enters its service life, when the maintenance (and later the decommissioning) organizations are different.

One key challenge in the definition of ship work breakdown structures is how to represent the same entity in different structures as it moves through its lifecycle, e.g., from concept design to basic design to detail design to production design. A new component based approach based on 4th generation of design (4GD) technology built into a PLM system to manage ship data allows for the definition of different but linked work breakdown structures of a ship through its different lifecycle stages.

This paper explains in detail the different work breakdown structures in shipbuilding and how 4GD technology can be used to define and manage the same.

NOMENCLATURE

4GD	4th Generation Design
AWBS	Area Work Breakdown Structure
BOP	Bill of Process
BOR	Bill of Resources
CWBS	Contract Work Breakdown Structure
ESWBS	Expanded Ship Work Breakdown Structure
HBCM	Hull Block Construction Method
LRW	Liquid Radioactive Waste
MRV	Multi Role Vessel
O&M	Operation and Maintenance
PLM	Product Lifecycle Management
PWBS	Product Work Breakdown Structure
RFP	Request for Proposal
SFI	Senter for Forskningsdrevet Innovasjon
SNF	Spent Nuclear Fuel
SOW	Statement of Work
SRW	Solid Radioactive Waste
SWBS	Ship or System Work Breakdown Structure
WBS	Work Breakdown Structure
ZOFM	Zone Outfitting Method
ZPTM	Zone Painting Method
ZWBS	Zone Work Breakdown Structure

1. INTRODUCTION

A complex project like shipbuilding is made manageable by breaking it down into individual components in a hierarchical structure, known as the work breakdown structure, or the WBS. Such a structure defines tasks that can be completed independently of other tasks, facilitating resource allocation, assignment of responsibilities, and measurement and control of the project. An effective WBS plays a key role in the implementation of a shipbuilding project.

Definition of complete and accurate work breakdown structures is required in every stage of a ship project through its acquisition, deployment, and decommissioning and disposal phases. While the need is well understood, many shipyards and ship design organizations find it challenging to define these work breakdown structures across all stages of a project, and to understand the linkages between them.

This paper explains the different work breakdown structures in shipbuilding and how a new component based approach based on 4th generation of design (4GD) technology built into a PLM system can be used to define and manage the same.

This paper discusses the topic using examples of naval and other government ships, but the principles are equally applicable to commercial ships, offshore platforms and luxury yachts.

2. WORK BREAKDOWN STRUCTURE

A Work Breakdown Structure (WBS) breaks down the work of a project into a hierarchical structure of elements, in order to manage and control the scope. This allows good definition of the work, and allows discrete, coherent packages of work to be estimated and then delegated. A typical example can be Figure 1, which shows a basic WBS for the construction of a nuclear submarine. Generically, a work breakdown structure is defining the solution to a problem in terms of a product.

A work breakdown structure serves as a coordinating medium. For each work breakdown structure element, the detailed technical objectives are defined and specified work tasks are assigned to each contractor's organization elements, and assigned for the resources, materials, and processes required to attain the objectives. The linkage between the specification requirements, the work breakdown structure, the statement of work, and the master and detailed schedules provides specific insights into the relationship between cost, schedule, and performance. This relationship allows all items to be tracked to the same work breakdown structure element.

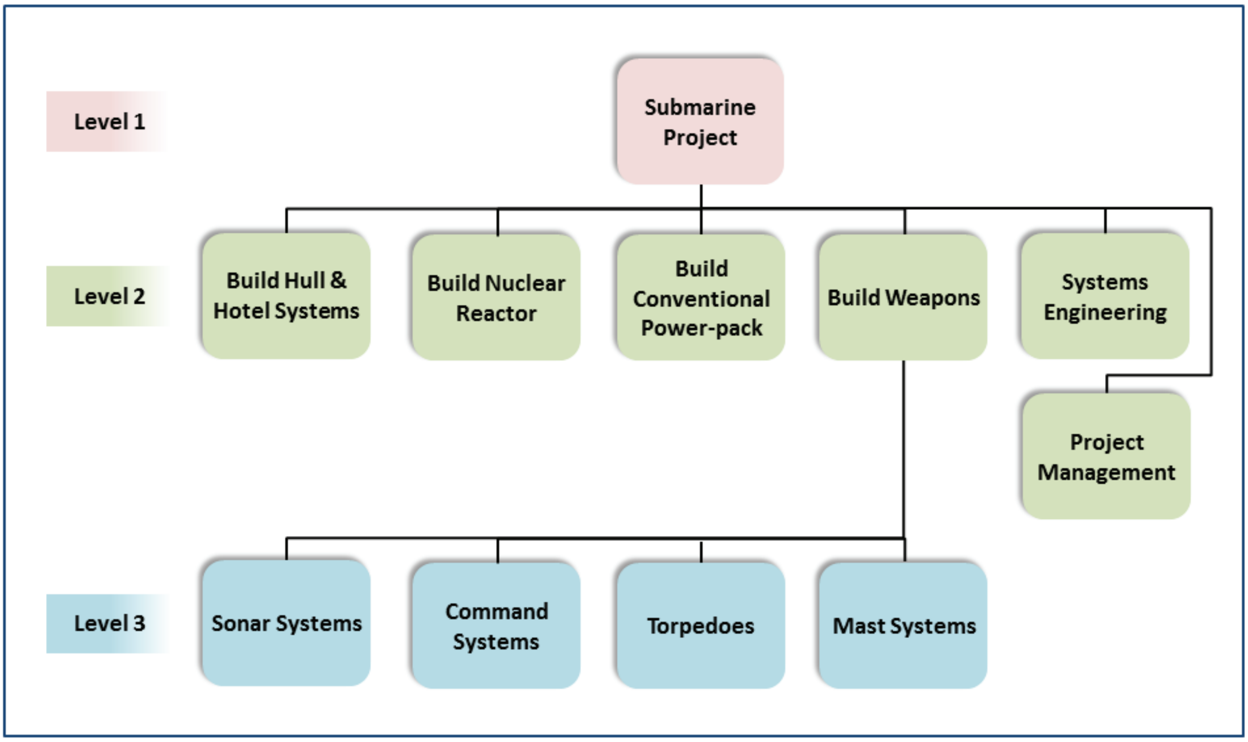


Fig. 1 : A Work Breakdown Structure for Construction of a Nuclear Submarine

Work breakdown structures commonly used in shipbuilding are either systems- or product-oriented.

3. PROGRAM WORK BREAKDOWN STRUCTURE

The Program Work Breakdown Structure provides a framework for specifying the objectives of the program. It defines the program in terms of hierarchically related product-oriented elements. Each element provides logical summary points for assessing technical accomplishments and for measuring cost and schedule performance.

The Program WBS is developed early in the conceptual stages of a program through systems engineering and management planning processes. It evolves through iterative analysis of the program objective, functional design criteria, program scope, technical performance requirements, acquisition strategy, and other technical documentation.

Early in the concept exploration phase, the systems engineering efforts are aimed at trying to establish the user's need. Prior to system design and development, system requirements must be established. For naval ships, these requirements flow down from high-level program documents, class and other regulations, and establish allocated mission functions assigned to specific ships.

In Requirements Analysis, the systems engineer identifies and documents the customer's requirements and translates them into a set of technical requirements for the system. The requirements analysis should cover the whole scope of the project, i.e., ship performance, software, logistics, project management, safety, environment, human resources, test and acceptance, etc.

It is essential to have a management system for user requirements and the linkages to system requirements, and then through to the eventual design specifications through to the formal acceptance activities. The user (or customer) requirements form the basis of the contract and its acceptance, and they can then be used to manage support of the ships through life.

Functional Analysis begins with separating an entity (e.g., ship, system) into high-level functional categories.

During Functional Analysis/Allocation, the systems engineer translates the requirements identified in Requirements Analysis into a functional decomposition that describes the product in terms of an assembly of configuration items where each configuration item is defined by what it must do, its required performance, and its interfaces. Configuration items can be hardware, software, or manpower. Functional allocation is the process that assigns systems, subsystems, and components to perform each function.

Functional Analysis translates the ship's missions, performance, goals, and other requirements into discrete and well-defined functions. The aim of functional analysis is to identify all of the activities that the system is required to perform, and each of these functions should represent what must be done, not how to do it. Functions are broken down to the appropriate level, often to sub-functions and functional elements, depending on the range of functions addressed by the entity (refer Requirements and Functional Breakdown Structures in Figure 3). Functional elements contain detailed descriptions of a system's functions at a level which allows the allocation of system components (i.e., equipment) to these individual elements. The Program WBS is developed at this point and precedes issue of a formal request for proposal (RFP).

The Program WBS is included as part of the solicitation (RFP) and used by the successful contractor to develop a more detailed Contract Work Breakdown Structure (CWBS) which includes all product elements (hardware, software, data, or services) for which the contractor is responsible.

4. CONTRACT WORK BREAKDOWN STRUCTURE (CWBS)

The Contract Work Breakdown Structure (CWBS) is the complete WBS for a specific contract. It is developed by the contractor in accordance with the contract statement of work (SOW). It includes the Program WBS elements for the products (hardware, software, data, or services) which are to be furnished by the contractor. Contractors extend the Contract WBS included in the RFP and submit the complete Contract WBS with their proposal.

A CWBS provides a consistent and visible framework that facilitates uniform planning, assignment of responsibilities, and status reporting.

5. SHIP WORK BREAKDOWN STRUCTURE (SWBS)

The U. S. Navy currently uses a systems-oriented breakdown called the Expanded Ship Work Breakdown Structure (ESWBS). It is used throughout the entire ship life cycle to organize and correlate elements for cost, weight, specifications, system function and effectiveness, design, production, and maintenance studies. Numbering systems for ship's drawings and related documents, general and contract specifications, ship's weight groups, technical manuals, etc. are based on the ESWBS.

The US Navy's Systems Work Breakdown Structure was originally issued in March 1973 as a structured system (3-digit numbers providing 5 levels of breakdown) which was intended for use in specification preparation, cost estimating, cost progressing, management, weight control, drawing numbering, shipyard job order coding, and similar purposes. ESWBS provides two additional levels of breakdown of functional systems so that ESWBS can be used for logistic support, maintenance, and life cycle support purposes. So ESWBS is a five digit functional classification system, with the fourth and fifth single digit classification levels used to incorporate the functions that support maintenance and repair needs. For example, for weight reporting purposes, only the first three digits of this system apply.

SWBS groups are defined by basic function. The functional segments of a ship, as represented by a ship's structure, systems, machinery, armament, outfitting, etc., are classified by a system of 3-digit numeric groups. The major functional groups are :

ESWBS Group	Description
000	General Guidance and Administration
100	Hull Structure
200	Propulsion Plant
300	Electric Plant
400	Command and Surveillance
500	Auxiliary Systems
600	Outfit and Furnishings
700	Armament
800	Integration/Engineering
900	Ship Assembly and Support Services

Table 1 : ESWBS Groups (first three digits)

ESWBS Groups 800 and 900 (refer Table 1) although a part of the of the work breakdown structure, deal with engineering and design support. Therefore, these items are not required to physically describe the technical aspects of the ship.

The ESWBS classification system allows the ship to be specified at any of three levels : one-, two-, and three digits. Each higher level indicates a higher degree of technical definition, as can be seen from the examples in Table 2 below.

(Group)	100 - Hull Structure
(Element)	101 - General Arrangement-Structural Drawings
(Subgroup)	110 - Shell and Supporting Structure
(Element)	111 - Shell Plating, Surface Ship and Submarine Pressure Hull
(Element)	112 - Shell Plating, Submarine Nonpressure Hull
(Subgroup)	120 - Hull Structural Bulkheads
(Element)	121 - Longitudinal Structural Bulkheads
(Element)	122 - Transverse Structural Bulkheads

Table 2 : An Example of the ESWBS Organisation

6. SFI GROUP SYSTEM

The SFI group system was developed at the Norwegian Ship Research Institute (Senter for Forskningsdrevet Innovasjon - SFI), now known as MARINTEK. The SFI group system is an international standard which is used for a functional breakdown of technical and economic information of ships and offshore structures. It structures and systemizes all the ship's different systems and components through a 3-digit coding structure. Through the ships' lifetime, the SFI coding system is used for different purposes, like control of shipping, offshore or shipbuilding operations. In cost management, this structure works as a cost work breakdown structure.

The ship is divided into 10 main groups from 0 to 9, but often only main group 1-8 are used (refer Table 3). Main group 0 and 9 are extra posts where the user can address costs related to the ship that does not fit into the other main groups. The main groups are divided into 2-digit groups which are again divided into 3-digit subgroups.

SFI Group	Description
0	(reserved)
1	Ship General
2	Hull
3	Equipment for Cargo
4	Ship Equipment
5	Equipment for Crew and Passengers
6	Machinery Main Components
7	Systems for Machinery Main Components
8	Ship Common Systems
9	(reserved)

Table 3 : SFI Groups

7. PRODUCT WORK BREAKDOWN STRUCTURE (PWBS)

Product Work Breakdown Structure (PWBS) was developed to support group technology shipbuilding. PWBS subdivides work in accordance with an interim product view. Parts and sub-assemblies are grouped by common permanent characteristics, and classified by both design and manufacturing attributes. The classification system typically specifies parameters, such as form, dimensions, tolerances, material, and types and complexity of production machinery operations. Classification by product aspects relates a part or sub-assembly to a zone of a ship and also to work processes by problem area and by work stage.

A shipbuilder's PWBS is hardware or product oriented, and is consistent with the methods of planning, scheduling, and construction actually being used by the shipbuilder. The PWBS used on a particular shipbuilding program is based on the products produced and on the coding system used by the shipbuilder. PWBS provides a natural breakdown for schedule reporting and for collection of financial data.

First, PWBS divides the shipbuilding process into three basic types of work : hull construction, outfitting, and painting, because each imposes its own unique set of manufacturing problems. These types of work are further subdivided into fabrication and assembly classifications. Within the painting classification, fabrication applies to the manufacture of paint, and assembly refers to its application. The assembly subdivisions are naturally linked to zones (see next section "Zone Work Breakdown Structure" and Figure 3).

Second, PWBS classifies interim products in accordance with their resource needs :

- Material : e.g., steel plate, machinery, cable, etc.
- Manpower : e.g., welder, fitter, rigger, transporter, etc.
- Facilities : e.g., buildings, docks, machinery, tools, etc.
- Expenses : e.g., designing, transportation, sea trials, etc.

Third, PWBS classifies interim products by the four product aspects needed for control of production processes. Two of these, system and zone, are related to the ship design function while the other two, area and stage, are related to the production function. These four terms many be defined as follows :

- System - A structural or an operational characteristic of a product, e.g., longitudinal or transverse bulkhead, fuel-oil service system, deck lighting system, etc.

- Zone - An objective of production which is any geographical division of a product, e.g., engine room, cargo hold, operations room, etc., and their sub-divisions, or combinations (e.g., a structural block or outfit unit, a subassembly of either and ultimately, a part or component).
- Area - A division of the production process into similar types of work problems which can be
  - by feature (e.g., curved vs. flat panel, small diameter vs. large diameter pipe, etc.)
  - by quantity (e.g., job-by-job vs. flow lane, etc.)
  - by quality (e.g., grade of workers or facilities required, etc.)
  - by work type (e.g., marking, cutting, bending, welding, painting, testing, etc.), and
  - by anything else that creates a manifestly different work problem.
- Stage – Various sequences in the production cycle, e.g., preparation, fabrication, assembly, etc.

8. ZONE WORK BREAKDOWN STRUCTURE (ZWBS)

A zone is defined as a volume of the seaframe that provides space, structural support, and services required to perform a function, or a group of similar interchangeable functions located therein. Zones share the following :

- Similar Environment
- Similar Functions
- Bundled Services

Examples of zones defined in ships to address particular functions or services are Fire zone, Collision zone, Electronics zone, Weapons zone, Underwater Sensor zone, etc. Each zone has unique features and characteristics that help define and distinguish it from other types of zones.

A ship is also divided into design zones for easier management of the ship's design and construction, and to aid design review. This is a spatial or geographical division of the ship. Each zone is designed with all piping, wiring, outfitting, machinery, and furniture to be contained within that zone. During design review, the reviewers can "see" all of the ship, including its interior structure and all items to be included in the finished ship for the zones being reviewed.

Zone Work Breakdown Structure (ZWBS) can also be defined based on a spatial breakdown of the ship (more from the way a ship is constructed), and is sometimes used interchangeably with Area Work Breakdown Structure (AWBS) - both show spatial breakdown of the ship. In some shipyards, the AWBS is defined for Design Zones, which are again spatial. AWBS is also defined for a shipyard (not ship) based on segregation of work (e.g., by feature, by work type, etc.) as explained in the previous section.

Zone logic significantly enhances the efficiency and productivity of design and production work by taking advantage of the underlying similarities in the products or subassemblies, those common characteristics classified by both design and production attributes.

Zone logic technology concepts dictate that work be planned and executed under a priority scheme :

1. Divide work into geographical zones carefully considering the nature of the problems that are involved,
2. Develop a zone oriented product and interim product work breakdown structure,
3. Properly sequence the work to be accomplished by stage and area,
4. Plan final systems tests as necessary.

Shipbuilding methods have consistently become more productive during the last few decades mainly because of the change from traditional system-oriented processes to the following zone-oriented processes :

- Hull Block Construction Method (HBCM),
- Zone Outfitting Method (ZOFM), and
- Zone Painting Method (ZPTM).

HBCM planners define interim products starting with a hull as a zone, thence subdividing it into block zones which in turn are divided into sub-block zones and so on. The process is completed when zones are defined that cannot be further subdivided, i.e., zones which correspond to parts. The nature of any of these zones associates it with a specific manufacturing level. This regimentation is natural for hull construction but not so for outfitting.

The Zone Outfitting Method (ZOFM) is a natural consequence of HBCM because both employ the same logic. Shipyards which employ ZOFM assemble most outfit components independent of or on hull blocks.

The Zone Painting Method (ZPTM) is a natural extension of the logic employed in both HBCM and ZOFM. It transfers much painting work, traditionally performed in a building dock or at an outfit pier, to preceding manufacturing levels (on-block) by integrating painting with hull construction and outfitting processes.

In ZPTM, a zone is not only defined by compartments such as decks, cargo holds, engine room, etc., but also by hull blocks, sub-blocks and components. The defined hull blocks of ZPTM are identical to the hull blocks defined for HBCM and ZOFM.

9. LIFECYCLE PHASES AFTER SHIP DELIVERY

Before analysing information requirements of ship product structure in the lifecycle phases after ship delivery, it is worth comparing abstraction level of product structure data used in the design/manufacturing phases with that of product structure data in the operations and maintenance (O&M) phases. Objects represented in product structure in the design phase are classes, abstract objects which do not exist in the real world. They specify shape, physical characteristics, and functional characteristics that members (or individuals) of a class must have, e.g., centrifugal pump type A. On the other hand, individuals which exist at specific time-space in the real world should be managed in product structure in the O&M phase in addition to classes. For example, it is required to monitor and trace installation time, repair history, and current status of a real pump with tag number 0000001.

In the O&M phase, after O&M master plan is first established from design and manufacturing data of a product, O&M works are performed according to this master plan, of which history is also managed. The O&M master plan links to class-level product structure while the O&M history connects to individual-level product structure. Therefore, information model of ship product structure should support both class- and individual- level product structures and couple them together.

Information model for supporting ship product structures is discussed in section 11.

10. DECOMMISSIONING

Decommissioning and disposal activities present their own unique set of challenges, and the legal obligations required of operators and those contracted with the work are demanding and detailed. Maintaining complete compliance and operational best practices is fundamental to the success of the entire decommissioning process, which means operators and the contractors assigned need to carefully plan, execute and follow-up the decommissioning work.

Decommissioning is also very important in offshore and for nuclear powered ships/submarines. To keep the length of this paper within reasonable limits, this topic is not discussed further. Only an example of the work breakdown structure for dismantling of a nuclear submarine is given below (Figure 2) :

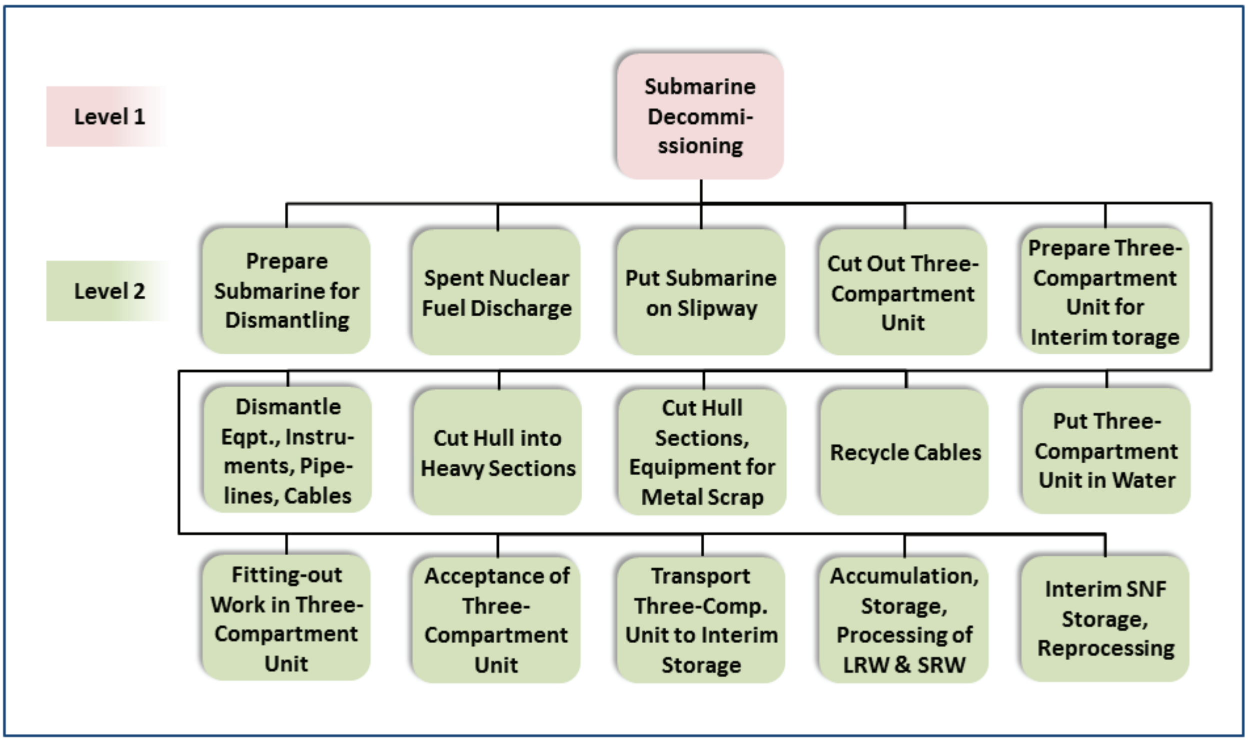


Fig. 2 : A Work Breakdown Structure for Dismantling of a Nuclear Submarine (LRW : Liquid Radioactive Waste, SRW : Solid Radioactive Waste)

11. INFORMATION REQUIREMENTS OF SHIP PRODUCT STRUCTURES

Definition of complete and accurate work breakdown structures of a ship is an important and critical activity in every shipbuilding project. This is required in every stage of a ship project, right from the inquiry and concept design stage, to basic, detail and production design, and continues through definition of as-built structure, maintenance work breakdown structure, etc., right up to defining work breakdown structures for decommissioning.

Views on the same product are different from each other depending on lifecycle phases or application purposes, which lead to different product structures for the same product. Ship product structure evolves from a rough structure to more detailed structures during the course of a project – from system-oriented product views in the conceptual and basic design phases to block-oriented product views in the detailed design phase, to zone-oriented product views in the manufacturing design phase. Later, near the end of the contract, the transformation back to a system orientation occurs to permit overall ship evaluation, in terms of both systems performance and cost performance. The information model of ship product structures should be able to support these multiple product views.

In pre-design (initial/contract) design, basic design and detail design phase, the product tree for outfitting is defined based upon the SWBS (System Work Breakdown Structure) which is composed of the functional unit of the outfitting equipment. The early stage of ship design is the basis for developing the product structure and SWBS since the ship consists only of systems. A hull block tree, outfitting equipment, building specification, and schematic P&ID, for example, are linked to the product structure represented by SWBS.

During production design phase, the product is designed based on the hull block structure on which units or parts of outfitting equipment are installed, which depends on block division planning. During this phase, production information such as process (stage), workplace and production schedule is determined. This stage of design is used to define the actual geometry of interim products that capture the joining of blocks, the mounting of outfit and equipment items, the process plan, and production schedule.

The design phase which expresses the system structure to the block and zone of the hull structure in the 3D geometry is also called transition design phase. Transition design starts part way through functional design (under initial and basic design phases) and is characterized by the layout of major distributive systems into 3D and the arrangement of key compartments or areas , e.g., the machinery spaces.

In systems trees (like Ship or Systems Work Breakdown Structures in Figure 3), each parent product or component part is associated with its system. In block tree (Product Work Breakdown Structure in Figure 3), each parent product or component part is associated with its block. For outfitting work, each outfitting parent product or component part is associated with a virtual Zone Work Breakdown Structure which is a zone tree (refer Figure 3).

In outfitting work, usually different types of equipment, i.e., a mechanical part, electrical part and piping part, are assigned to the same zone since all the installation/assembly operations are associated with the same zone. When the work breakdown structure of a hull block and zone is generated in process planning, the outfitting system is divided into manufacturing parts and installation parts that are connected to the block and zone structures.

In addition to supporting multiple product views, the information model for defining ship work breakdown structures should associate the product structure with the product data. The product data includes not only information of Product, Process, Resource, and Production schedule but also 2D drawing, document, production method and the attributes of each component. Specifying the sequence of processes required to obtain the product as well as the materials and resources (work centers) required for each process would lead to the development of Bill of Process (BOP) and Bill of Resources (BOR). So the generic work breakdown structure diagram shown in Figure 3 can be expanded further (to the right) to add trees for Bill of Process and Bill of Resources. However, this is not elaborated further in this paper because of the limitations in showing a very big diagram. The information model should allow components of each product structure to be linked together as the ship project progresses so that their evolution can be traced (the blue arrows in Figure 3 show this link or associativity), and should allow full traceability at any point in time.

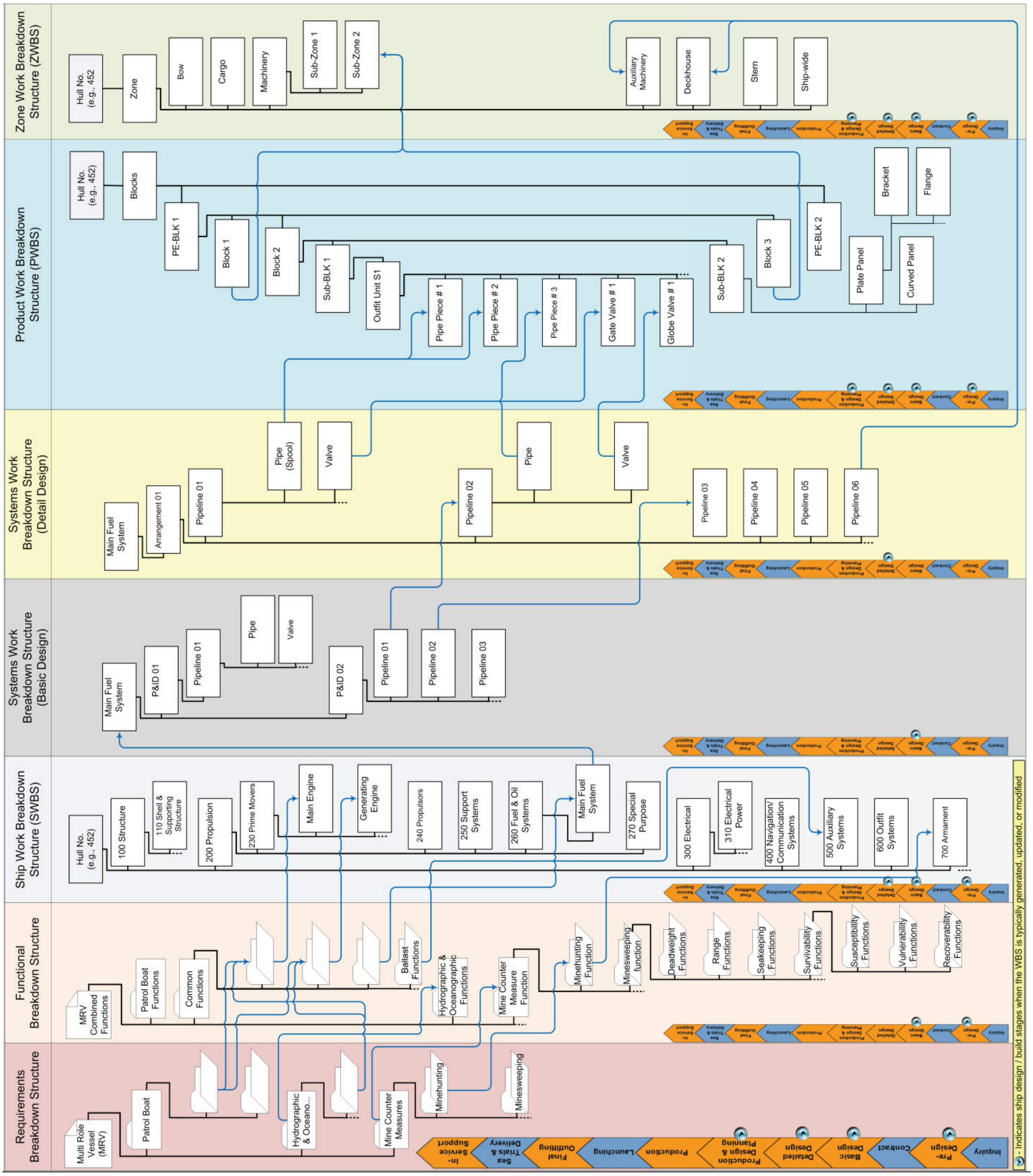


Fig. 3 : Generic Ship Work Breakdown Structures (blue arrows indicate associativity between items as the design evolves)

12. COMPONENT BASED DESIGN (4GD)

A new Component-Based approach based on 4th generation of design (4GD) technology built into a PLM system to manage ship data allows for the definition of different but linked work breakdown structures of a ship through its different lifecycle stages. Siemens PLM has implemented a Component Based Design solution for marine/shipbuilding with the release of Teamcenter 10.1 and NX 9.0. The underlying component-based design technology is called 4th Generation Design, or 4GD.

A ship or a submarine has millions of parts, and in the 4GD solution, these are represented by Design Elements. A Design Element can be a structural steel member (like a stiffener or a bracket), a pipe piece, a weld, an instance of a standard part (e.g., flange), an individual length of HVAC duct, or a specific cable hanger.

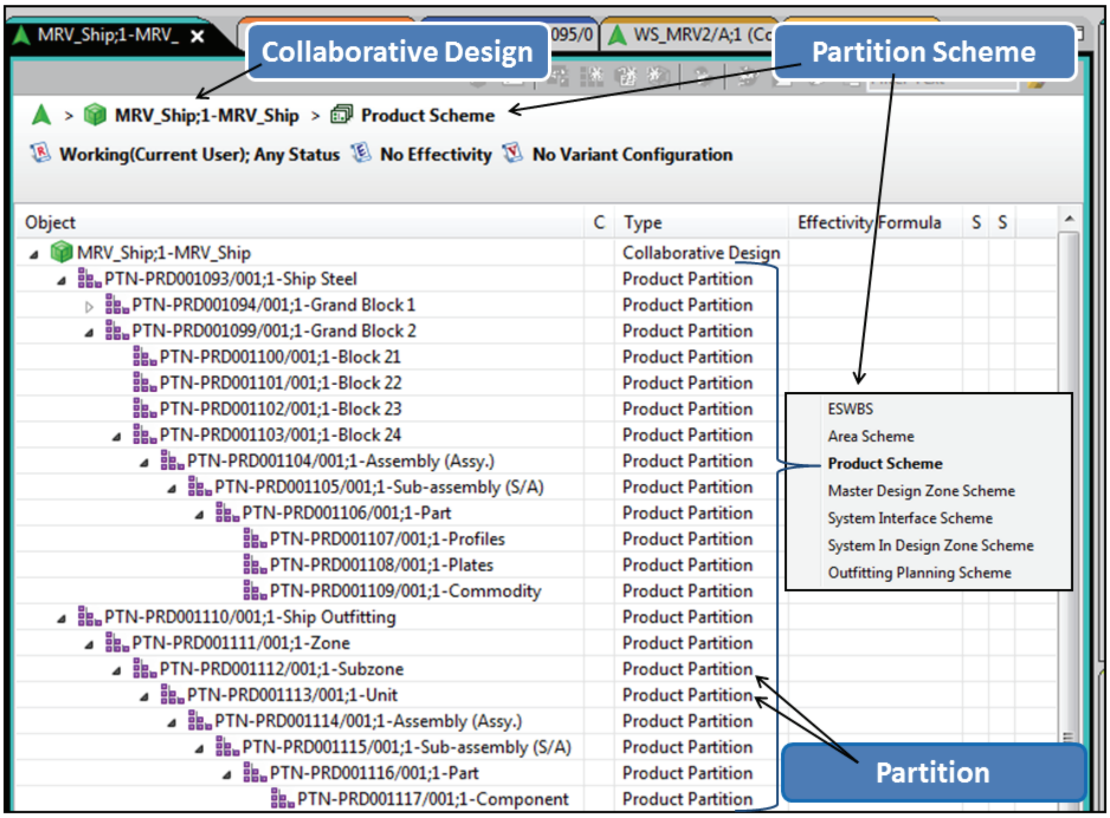
A Collaborative Design is an overall collection of Design Elements. It is a single container for all the design data that comprises a ship or a class of ships. A Design Element is an independently managed occurrence of design data within a Collaborative Design. The design data is authored and modified by a multi-disciplinary team of contributors, and is available for downstream use, e.g., manufacturing.

Each Design Element has a specific business purpose and is managed independently in the following ways :

- Has its own access privileges (i.e., read/write)
- Has its own maturity status (i.e., in work, being checked, released)
- Has its own position in ship coordinates
- Has its own set of attributes (e.g., pump operating pressure for each pump instance)
- Has its own revision history
- Has its own unit effectivity
- Has its own locking status (checked out / checked in)

In Component-Based Design, there is no product-level assembly structure. A Design Element is a declared member of a Collaborative Design – it is not a child of a Collaborative Design. So the millions of Design Elements that comprise the members of a Collaborative Design are essentially a large flat collection of design data.

Partitions provide a way for a user to organize product data (Design Elements) in a traditional hierarchical manner as per the requirement. As explained earlier, in shipbuilding different product views are required as ship design proceeds, so there are multiple work breakdown structures like ESWBS, PWBS, AWBS, ZWBS, etc. So each of these different product views or work breakdown structures are defined as different Partition Schemes. Partition Scheme hierarchies provide a logical way to organize the millions of Design Elements in multiple ways. A Collaborative Design can have one or more Partition Schemes for organizing data. This is explained in Figure 4 below. There is no limit to the number of Partition Schemes which can be defined for a Collaborative Design, which means any number of work breakdown structures or views of a ship can be generated. Figures 5 to 7 show different Partition Schemes representing ESWBS, AWBS and PWBS for a Multi Role Vessel (MRV).

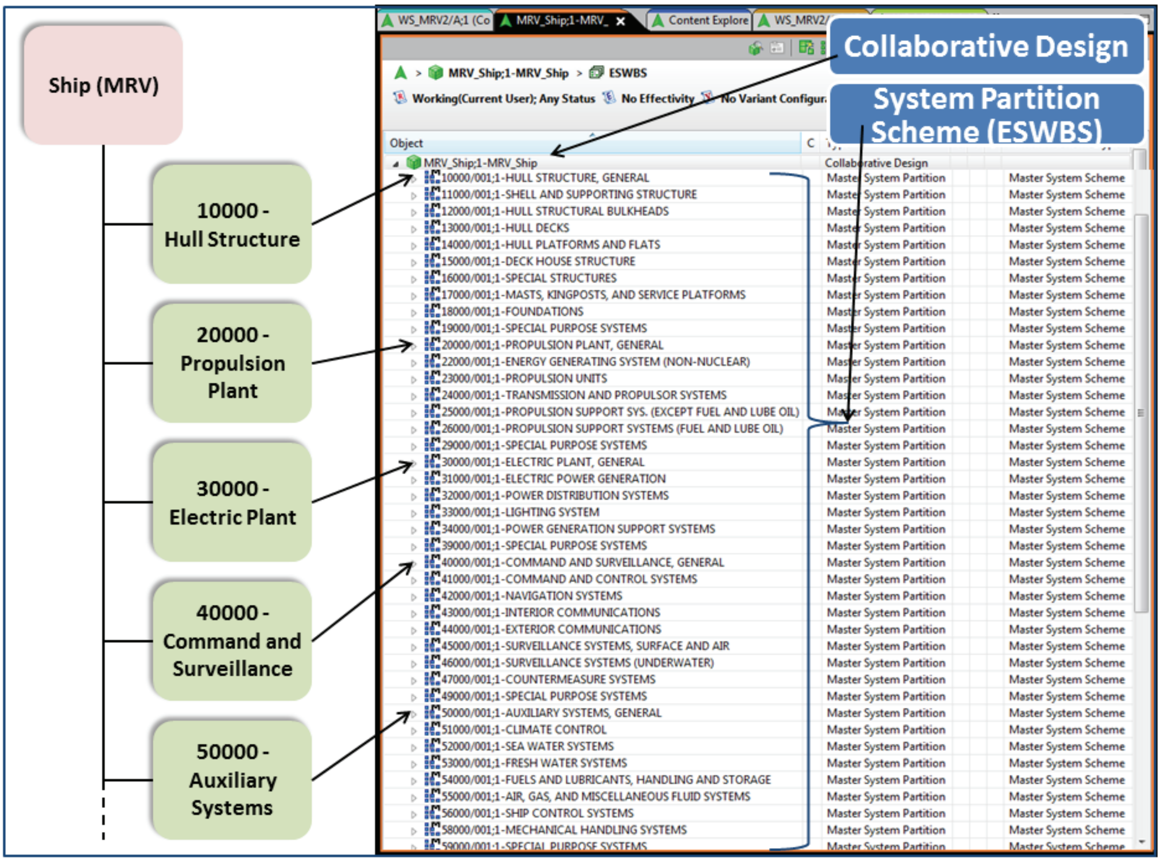


> MRV_Ship;1-MRV_Ship > Product Scheme

Working(Current User); Any Status No Effectivity No Variant Configuration

Object	C	Type	Effectivity Formula	S	S
MRV_Ship;1-MRV_Ship		Collaborative Design			
PTN-PRD001093/001;1-Ship Steel		Product Partition			
PTN-PRD001094/001;1-Grand Block 1		Product Partition			
PTN-PRD001099/001;1-Grand Block 2		Product Partition			
PTN-PRD001100/001;1-Block 21		Product Partition			
PTN-PRD001101/001;1-Block 22		Product Partition			
PTN-PRD001102/001;1-Block 23		Product Partition			
PTN-PRD001103/001;1-Block 24		Product Partition			
PTN-PRD001104/001;1-Assembly (Assy.)		Product Partition			
PTN-PRD001105/001;1-Sub-assembly (S/A)		Product Partition			
PTN-PRD001106/001;1-Part		Product Partition			
PTN-PRD001107/001;1-Profiles		Product Partition			
PTN-PRD001108/001;1-Plates		Product Partition			
PTN-PRD001109/001;1-Commodity		Product Partition			
PTN-PRD001110/001;1-Ship Outfitting		Product Partition			
PTN-PRD001111/001;1-Zone		Product Partition			
PTN-PRD001112/001;1-Subzone		Product Partition			
PTN-PRD001113/001;1-Unit		Product Partition			
PTN-PRD001114/001;1-Assembly (Assy.)		Product Partition			
PTN-PRD001115/001;1-Sub-assembly (S/A)		Product Partition			
PTN-PRD001116/001;1-Part		Product Partition			
PTN-PRD001117/001;1-Component		Product Partition			

Fig. 4 : Collaborative Design, Partitions and Partition Schemes



Object		
MRV_Ship;1-MRV_Ship	Collaborative Design	
10000/001;1-HULL STRUCTURE, GENERAL	Master System Partition	Master System Scheme
11000/001;1-SHELL AND SUPPORTING STRUCTURE	Master System Partition	Master System Scheme
12000/001;1-HULL STRUCTURAL BULKHEADS	Master System Partition	Master System Scheme
13000/001;1-HULL DECKS	Master System Partition	Master System Scheme
14000/001;1-HULL PLATFORMS AND FLATS	Master System Partition	Master System Scheme
15000/001;1-DECK HOUSE STRUCTURE	Master System Partition	Master System Scheme
16000/001;1-SPECIAL STRUCTURES	Master System Partition	Master System Scheme
17000/001;1-MASTS, KINGPOSTS, AND SERVICE PLATFORMS	Master System Partition	Master System Scheme
18000/001;1-FOUNDATIONS	Master System Partition	Master System Scheme
19000/001;1-SPECIAL PURPOSE SYSTEMS	Master System Partition	Master System Scheme
20000/001;1-PROPULSION PLANT, GENERAL	Master System Partition	Master System Scheme
22000/001;1-ENERGY GENERATING SYSTEM (NON-NUCLEAR)	Master System Partition	Master System Scheme
23000/001;1-PROPULSION UNITS	Master System Partition	Master System Scheme
24000/001;1-TRANSMISSION AND PROPULSOR SYSTEMS	Master System Partition	Master System Scheme
25000/001;1-PROPULSION SUPPORT SYS. (EXCEPT FUEL AND LUBE OIL)	Master System Partition	Master System Scheme
26000/001;1-PROPULSION SUPPORT SYSTEMS (FUEL AND LUBE OIL)	Master System Partition	Master System Scheme
29000/001;1-SPECIAL PURPOSE SYSTEMS	Master System Partition	Master System Scheme
30000/001;1-ELECTRIC PLANT, GENERAL	Master System Partition	Master System Scheme
31000/001;1-ELECTRIC POWER GENERATION	Master System Partition	Master System Scheme
32000/001;1-POWER DISTRIBUTION SYSTEMS	Master System Partition	Master System Scheme
33000/001;1-LIGHTING SYSTEM	Master System Partition	Master System Scheme
34000/001;1-POWER GENERATION SUPPORT SYSTEMS	Master System Partition	Master System Scheme
39000/001;1-SPECIAL PURPOSE SYSTEMS	Master System Partition	Master System Scheme
40000/001;1-COMMAND AND SURVEILLANCE, GENERAL	Master System Partition	Master System Scheme
41000/001;1-COMMAND AND CONTROL SYSTEMS	Master System Partition	Master System Scheme
42000/001;1-NAVIGATION SYSTEMS	Master System Partition	Master System Scheme
43000/001;1-INTERIOR COMMUNICATIONS	Master System Partition	Master System Scheme
44000/001;1-EXTERIOR COMMUNICATIONS	Master System Partition	Master System Scheme
45000/001;1-SURVEILLANCE SYSTEMS, SURFACE AND AIR	Master System Partition	Master System Scheme
46000/001;1-SURVEILLANCE SYSTEMS (UNDERWATER)	Master System Partition	Master System Scheme
47000/001;1-COUNTERMEASURE SYSTEMS	Master System Partition	Master System Scheme
49000/001;1-SPECIAL PURPOSE SYSTEMS	Master System Partition	Master System Scheme
50000/001;1-AUXILIARY SYSTEMS, GENERAL	Master System Partition	Master System Scheme
51000/001;1-CLIMATE CONTROL	Master System Partition	Master System Scheme
52000/001;1-SEA WATER SYSTEMS	Master System Partition	Master System Scheme
53000/001;1-FRESH WATER SYSTEMS	Master System Partition	Master System Scheme
54000/001;1-FUELS AND LUBRICANTS, HANDLING AND STORAGE	Master System Partition	Master System Scheme
55000/001;1-AIR, GAS, AND MISCELLANEOUS FLUID SYSTEMS	Master System Partition	Master System Scheme
56000/001;1-SHIP CONTROL SYSTEMS	Master System Partition	Master System Scheme
58000/001;1-MECHANICAL HANDLING SYSTEMS	Master System Partition	Master System Scheme
59000/001;1-SPECIAL PURPOSE SYSTEMS	Master System Partition	Master System Scheme

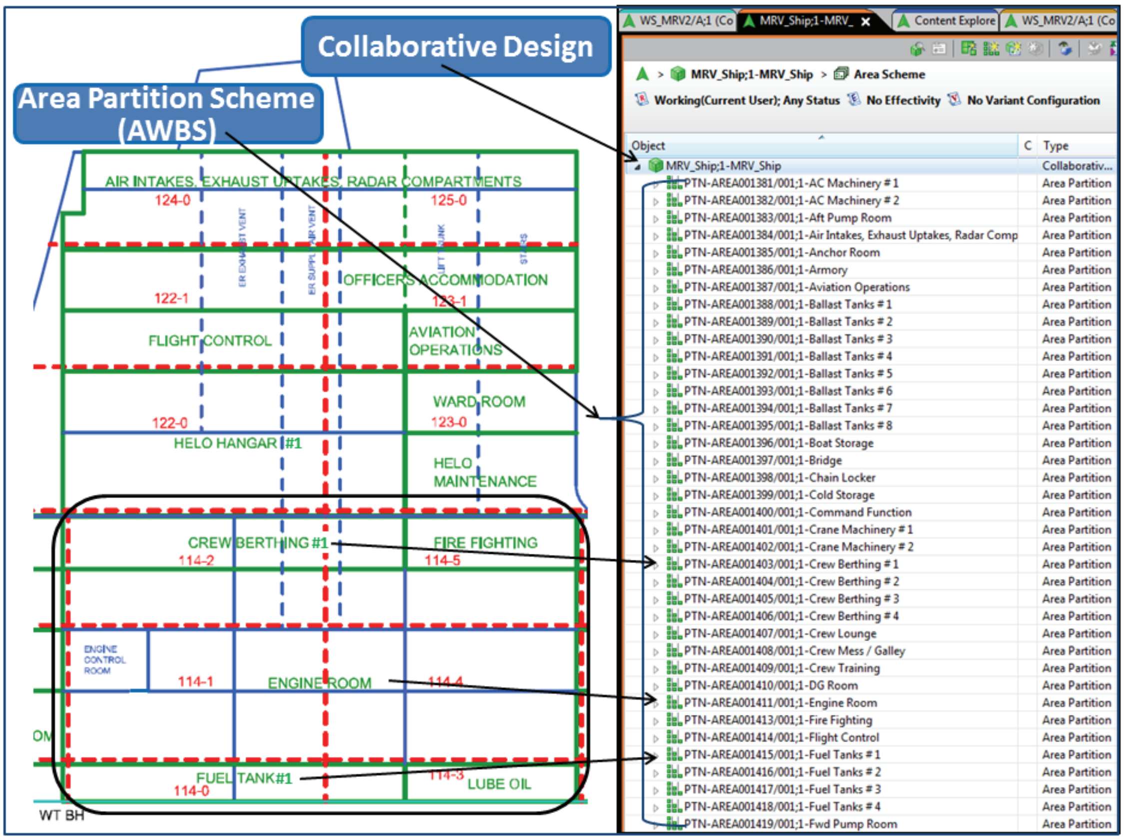
Fig. 5 : System Partition Scheme (ESWBS) for a Multi Role Vessel (MRV)

A Design Element may be a member of multiple partition hierarchies, and may also appear in more than one partition node within a single partition hierarchy. For example, in a system-based partition hierarchy (like ESWBS), a generator is part of an electrical power system, generator cooling system, and the fuel system. The same generator is also in the engine compartment zone in a zone-based partition hierarchy (like ZWBS).

The design data does not change while creating and modifying the partition hierarchies. Partitions are used only to organize the Design Elements into multiple views. In addition, Partitions can be populated manually (i.e., user assigns a Design Element as a member of a specific Partition), or Partitions can be populated dynamically (i.e., a Partition declares a Design Element to be its member because the Design Element lies within a specified volume area, or the Design Element has a certain attribute value defined).

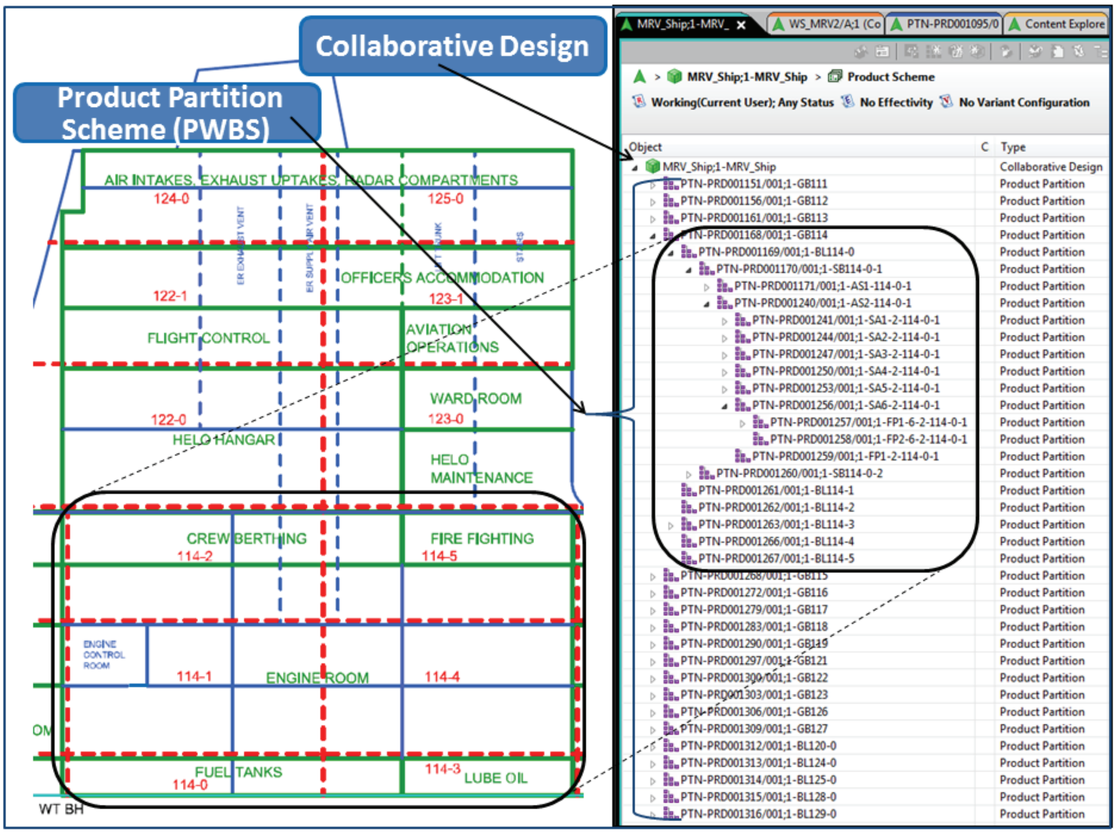
Partitions hierarchies are navigated as an indented tree, which provides a convenient and natural way to browse and navigate product data.

The Design Element is also a versatile object where the business decides the level of detail needed for each type of design data in the overall ship design. For example, each pump assembly unit placed on different ship decks can be its own Design Element, all steel plates throughout the entire ship can each be a Design Element, each Weld can be a Design Element, and even the hull surface definition can be managed as a Design Element. The shipbuilder has the option to decide the level of granularity for independently managed critical design data, and defines these as the Design Elements in the ship Collaborative Design.



Object	C	Type
MRV_Ship;1-MRV_Ship		Collaborativ...
PTN-AREA001381/001;1-AC Machinery # 1		Area Partition
PTN-AREA001382/001;1-AC Machinery # 2		Area Partition
PTN-AREA001383/001;1-Aft Pump Room		Area Partition
PTN-AREA001384/001;1-Air Intakes, Exhaust Uptakes, Radar Comp		Area Partition
PTN-AREA001385/001;1-Anchor Room		Area Partition
PTN-AREA001386/001;1-Armory		Area Partition
PTN-AREA001387/001;1-Aviation Operations		Area Partition
PTN-AREA001388/001;1-Ballast Tanks # 1		Area Partition
PTN-AREA001389/001;1-Ballast Tanks # 2		Area Partition
PTN-AREA001390/001;1-Ballast Tanks # 3		Area Partition
PTN-AREA001391/001;1-Ballast Tanks # 4		Area Partition
PTN-AREA001392/001;1-Ballast Tanks # 5		Area Partition
PTN-AREA001393/001;1-Ballast Tanks # 6		Area Partition
PTN-AREA001394/001;1-Ballast Tanks # 7		Area Partition
PTN-AREA001395/001;1-Ballast Tanks # 8		Area Partition
PTN-AREA001396/001;1-Boat Storage		Area Partition
PTN-AREA001397/001;1-Bridge		Area Partition
PTN-AREA001398/001;1-Chain Locker		Area Partition
PTN-AREA001399/001;1-Cold Storage		Area Partition
PTN-AREA001400/001;1-Command Function		Area Partition
PTN-AREA001401/001;1-Crane Machinery # 1		Area Partition
PTN-AREA001402/001;1-Crane Machinery # 2		Area Partition
PTN-AREA001403/001;1-Crew Berthing # 1		Area Partition
PTN-AREA001404/001;1-Crew Berthing # 2		Area Partition
PTN-AREA001405/001;1-Crew Berthing # 3		Area Partition
PTN-AREA001406/001;1-Crew Berthing # 4		Area Partition
PTN-AREA001407/001;1-Crew Lounge		Area Partition
PTN-AREA001408/001;1-Crew Mess / Galley		Area Partition
PTN-AREA001409/001;1-Crew Training		Area Partition
PTN-AREA001410/001;1-DG Room		Area Partition
PTN-AREA001411/001;1-Engine Room		Area Partition
PTN-AREA001413/001;1-Fire Fighting		Area Partition
PTN-AREA001414/001;1-Flight Control		Area Partition
PTN-AREA001415/001;1-Fuel Tanks # 1		Area Partition
PTN-AREA001416/001;1-Fuel Tanks # 2		Area Partition
PTN-AREA001417/001;1-Fuel Tanks # 3		Area Partition
PTN-AREA001418/001;1-Fuel Tanks # 4		Area Partition
PTN-AREA001419/001;1-Fwd Pump Room		Area Partition

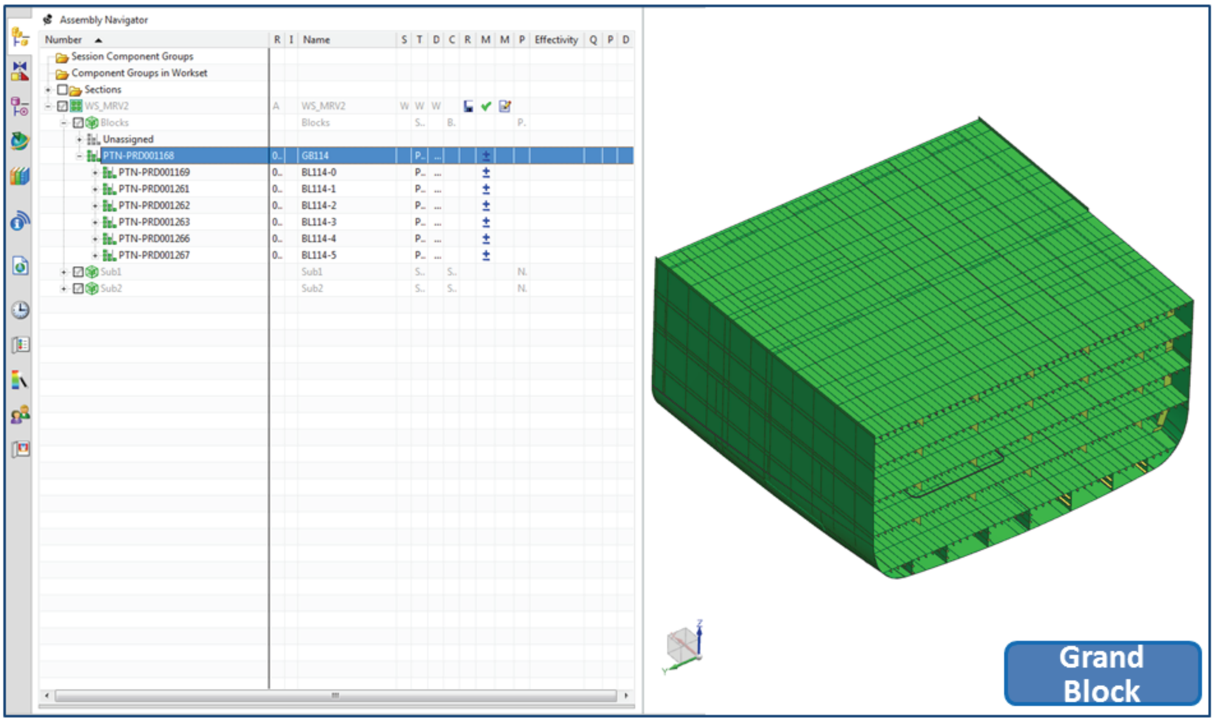
Fig. 6 : Area Partition Scheme (AWBS) for the MRV (Green lines show Area Boundaries in Drawing)



Object	C	Type
MRV_Ship;1-MRV_Ship		Collaborative Design
PTN-PRD001151/001;1-GB111		Product Partition
PTN-PRD001156/001;1-GB112		Product Partition
PTN-PRD001161/001;1-GB113		Product Partition
PTN-PRD001168/001;1-GB114		Product Partition
PTN-PRD001169/001;1-BL114-0		Product Partition
PTN-PRD001170/001;1-SB114-0-1		Product Partition
PTN-PRD001171/001;1-AS1-114-0-1		Product Partition
PTN-PRD001240/001;1-AS2-114-0-1		Product Partition
PTN-PRD001241/001;1-SA1-2-114-0-1		Product Partition
PTN-PRD001244/001;1-SA2-2-114-0-1		Product Partition
PTN-PRD001247/001;1-SA3-2-114-0-1		Product Partition
PTN-PRD001250/001;1-SA4-2-114-0-1		Product Partition
PTN-PRD001253/001;1-SA5-2-114-0-1		Product Partition
PTN-PRD001256/001;1-SA6-2-114-0-1		Product Partition
PTN-PRD001257/001;1-FP1-6-2-114-0-1		Product Partition
PTN-PRD001258/001;1-FP2-6-2-114-0-1		Product Partition
PTN-PRD001259/001;1-FP1-2-114-0-1		Product Partition
PTN-PRD001260/001;1-SB114-0-2		Product Partition
PTN-PRD001261/001;1-BL114-1		Product Partition
PTN-PRD001262/001;1-BL114-2		Product Partition
PTN-PRD001263/001;1-BL114-3		Product Partition
PTN-PRD001266/001;1-BL114-4		Product Partition
PTN-PRD001267/001;1-BL114-5		Product Partition
PTN-PRD001268/001;1-GB115		Product Partition
PTN-PRD001272/001;1-GB116		Product Partition
PTN-PRD001279/001;1-GB117		Product Partition
PTN-PRD001283/001;1-GB118		Product Partition
PTN-PRD001290/001;1-GB119		Product Partition
PTN-PRD001297/001;1-GB121		Product Partition
PTN-PRD001300/001;1-GB122		Product Partition
PTN-PRD001303/001;1-GB123		Product Partition
PTN-PRD001306/001;1-GB126		Product Partition
PTN-PRD001309/001;1-GB127		Product Partition
PTN-PRD001312/001;1-BL120-0		Product Partition
PTN-PRD001313/001;1-BL124-0		Product Partition
PTN-PRD001314/001;1-BL125-0		Product Partition
PTN-PRD001315/001;1-BL128-0		Product Partition
PTN-PRD001316/001;1-BL129-0		Product Partition

Fig. 7 : Product Partition Scheme (PWBS) for the MRV (Red dotted lines show Block Boundaries in Drawing)

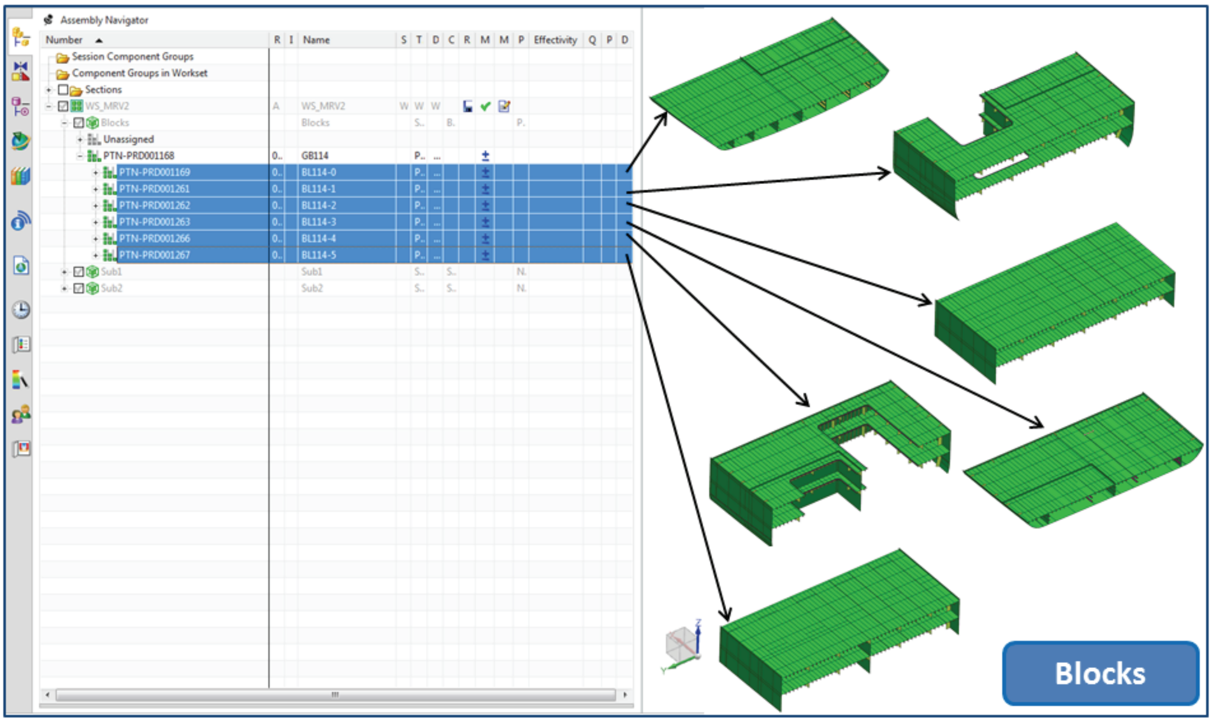
Taking the example of the Product Partition Scheme (PWBS) of the Multi Role Vessel shown in Fig. 7 above further, we can expand the PWBS to lower levels for definition of the interim products right up to the individual part level. The individual part is a Design Element as explained at the beginning of this section. This is shown in Figures 8 to 11 below.



Assembly Navigator

Number	R	I	Name	S	T	D	C	R	M	M	P	Effectivity	Q	P	D
Session Component Groups															
Component Groups in Workset															
+ ☐ Sections															
− ☑ WS_MRV2	A		WS_MRV2	W	W	W			✓						
− ☑ Blocks			Blocks		S..		B.				P.				
+ Unassigned															
− PTN-PRD001168	0..		GB114		P..	...			±						
+ PTN-PRD001169	0..		BL114-0		P..	...			±						
+ PTN-PRD001261	0..		BL114-1		P..	...			±						
+ PTN-PRD001262	0..		BL114-2		P..	...			±						
+ PTN-PRD001263	0..		BL114-3		P..	...			±						
+ PTN-PRD001266	0..		BL114-4		P..	...			±						
+ PTN-PRD001267	0..		BL114-5		P..	...			±						
+ ☑ Sub1			Sub1		S..		S..				N.				
+ ☑ Sub2			Sub2		S..		S..				N.				

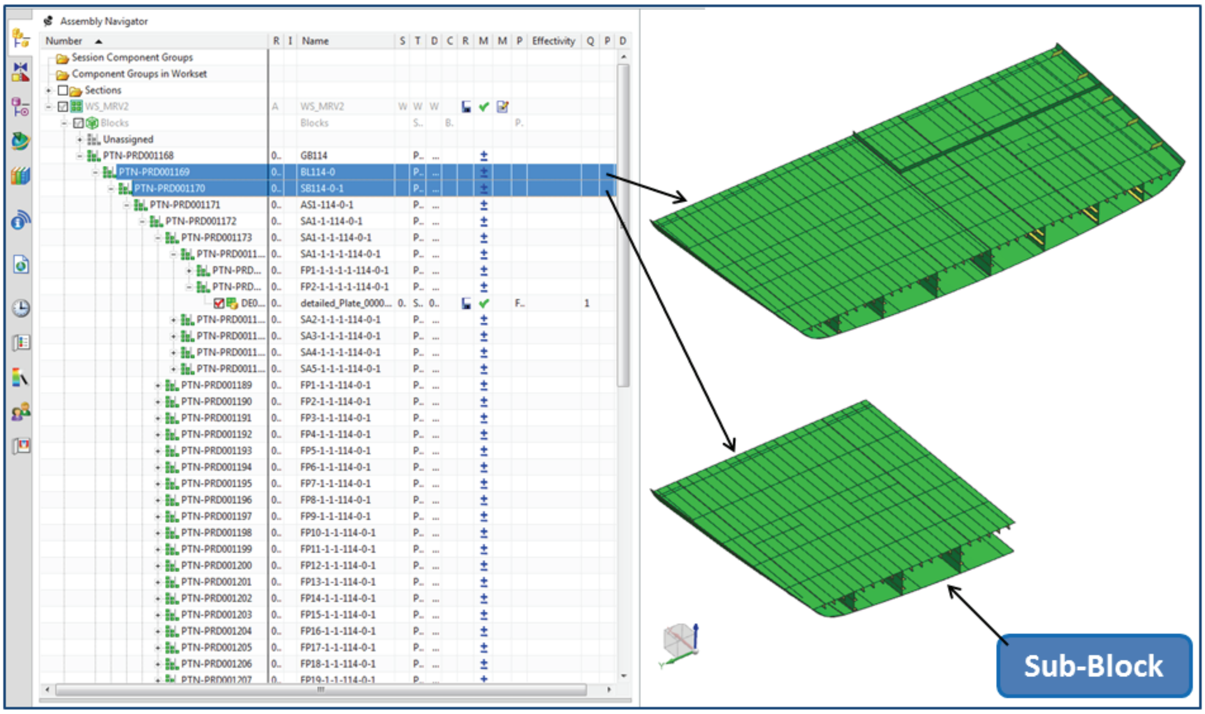
Fig. 8 : PWBS for the MRV showing one Grand Block



Assembly Navigator

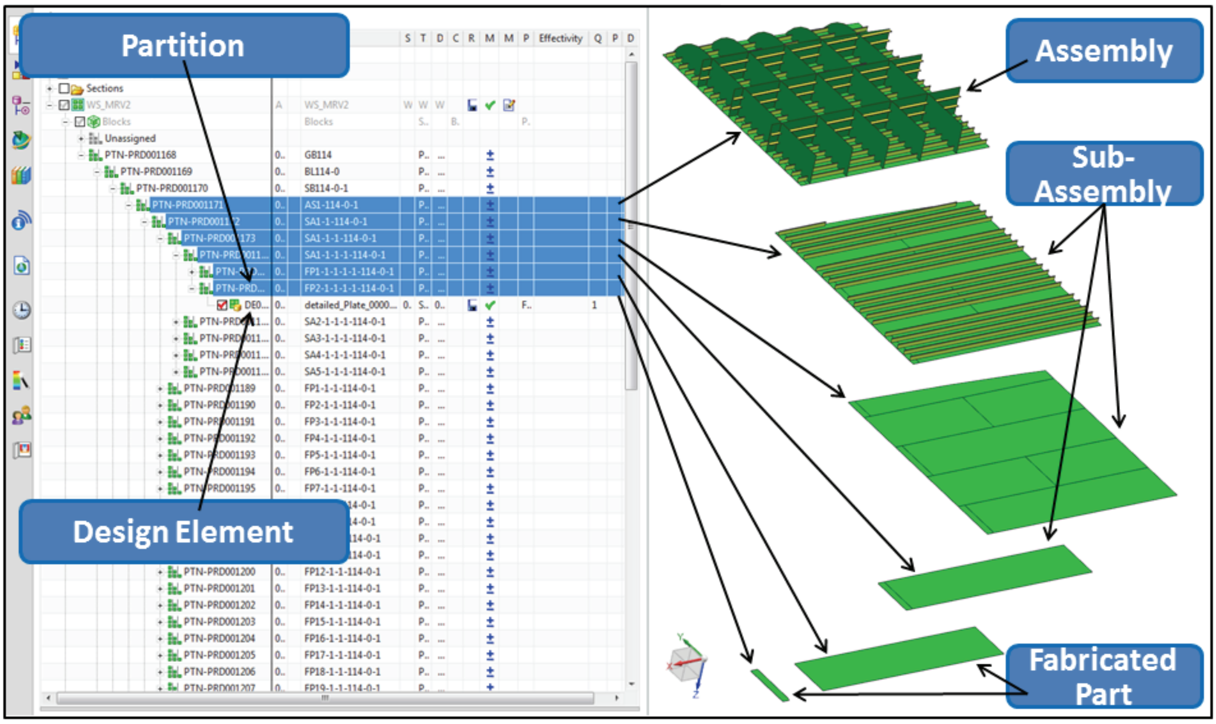
Number	R	I	Name	S	T	D	C	R	M	M	P	Effectivity	Q	P	D
Session Component Groups															
Component Groups in Workset															
+ ☐ Sections															
− ☑ WS_MRV2	A		WS_MRV2	W	W	W			✓						
− ☑ Blocks			Blocks		S..		B.				P.				
+ Unassigned															
− PTN-PRD001168	0..		GB114		P..	...			±						
+ PTN-PRD001169	0..		BL114-0		P..	...			±						
+ PTN-PRD001261	0..		BL114-1		P..	...			±						
+ PTN-PRD001262	0..		BL114-2		P..	...			±						
+ PTN-PRD001263	0..		BL114-3		P..	...			±						
+ PTN-PRD001266	0..		BL114-4		P..	...			±						
+ PTN-PRD001267	0..		BL114-5		P..	...			±						
+ ☑ Sub1			Sub1		S..		S..				N.				
+ ☑ Sub2			Sub2		S..		S..				N.				

Fig. 9 : PWBS for the MRV showing Blocks



Number	R	I	Name	S	T	D	C	R	M	M	P	Effectivity	Q	P	D
Session Component Groups															
Component Groups in Workset															
☐ Sections															
☑ WS_MRV2	A		WS_MRV2	W	W	W			✓						
☑ Blocks			Blocks		S..		B.				P.				
Unassigned															
PTN-PRD001168	0..		GB114		P..	...			±						
PTN-PRD001169	0..		BL114-0		P..	...			±						
PTN-PRD001170	0..		SB114-0-1		P..	...			±						
PTN-PRD001171	0..		AS1-114-0-1		P..	...			±						
PTN-PRD001172	0..		SA1-1-114-0-1		P..	...			±						
PTN-PRD001173	0..		SA1-1-1-114-0-1		P..	...			±						
PTN-PRD0011...	0..		SA1-1-1-1-114-0-1		P..	...			±						
PTN-PRD...	0..		FP1-1-1-1-1-114-0-1		P..	...			±						
PTN-PRD...	0..		FP2-1-1-1-1-114-0-1		P..	...			±						
☑ DE0...	0..		detailed_Plate_0000...	0.	S..	0..			✓		F..		1		
PTN-PRD0011...	0..		SA2-1-1-1-114-0-1		P..	...			±						
PTN-PRD0011...	0..		SA3-1-1-1-114-0-1		P..	...			±						
PTN-PRD0011...	0..		SA4-1-1-1-114-0-1		P..	...			±						
PTN-PRD0011...	0..		SA5-1-1-1-114-0-1		P..	...			±						
PTN-PRD001189	0..		FP1-1-1-114-0-1		P..	...			±						
PTN-PRD001190	0..		FP2-1-1-114-0-1		P..	...			±						
PTN-PRD001191	0..		FP3-1-1-114-0-1		P..	...			±						
PTN-PRD001192	0..		FP4-1-1-114-0-1		P..	...			±						
PTN-PRD001193	0..		FP5-1-1-114-0-1		P..	...			±						
PTN-PRD001194	0..		FP6-1-1-114-0-1		P..	...			±						
PTN-PRD001195	0..		FP7-1-1-114-0-1		P..	...			±						
PTN-PRD001196	0..		FP8-1-1-114-0-1		P..	...			±						
PTN-PRD001197	0..		FP9-1-1-114-0-1		P..	...			±						
PTN-PRD001198	0..		FP10-1-1-114-0-1		P..	...			±						
PTN-PRD001199	0..		FP11-1-1-114-0-1		P..	...			±						
PTN-PRD001200	0..		FP12-1-1-114-0-1		P..	...			±						
PTN-PRD001201	0..		FP13-1-1-114-0-1		P..	...			±						
PTN-PRD001202	0..		FP14-1-1-114-0-1		P..	...			±						
PTN-PRD001203	0..		FP15-1-1-114-0-1		P..	...			±						
PTN-PRD001204	0..		FP16-1-1-114-0-1		P..	...			±						
PTN-PRD001205	0..		FP17-1-1-114-0-1		P..	...			±						
PTN-PRD001206	0..		FP18-1-1-114-0-1		P..	...			±						
PTN-PRD001207	0..		FP19-1-1-114-0-1		P..	...			±						

Fig. 10 : PWBS for the MRV showing Sub-Block



				S	T	D	C	R	M	M	P	Effectivity	Q	P	D
☐ Sections															
☑ WS_MRV2	A		WS_MRV2	W	W	W			✓						
☑ Blocks			Blocks		S..		B.				P.				
Unassigned															
PTN-PRD001168	0..		GB114		P..	...			±						
PTN-PRD001169	0..		BL114-0		P..	...			±						
PTN-PRD001170	0..		SB114-0-1		P..	...			±						
PTN-PRD001171	0..		AS1-114-0-1		P..	...			±						
PTN-PRD001172	0..		SA1-1-114-0-1		P..	...			±						
PTN-PRD001173	0..		SA1-1-1-114-0-1		P..	...			±						
PTN-PRD0011...	0..		SA1-1-1-1-114-0-1		P..	...			±						
PTN-PRD...	0..		FP1-1-1-1-1-114-0-1		P..	...			±						
PTN-PRD...	0..		FP2-1-1-1-1-114-0-1		P..	...			±						
☑ DE0...	0..		detailed_Plate_0000...	0.	S..	0..			✓		F..		1		
PTN-PRD0011...	0..		SA2-1-1-1-114-0-1		P..	...			±						
PTN-PRD0011...	0..		SA3-1-1-1-114-0-1		P..	...			±						
PTN-PRD0011...	0..		SA4-1-1-1-114-0-1		P..	...			±						
PTN-PRD0011...	0..		SA5-1-1-1-114-0-1		P..	...			±						
PTN-PRD001189	0..		FP1-1-1-114-0-1		P..	...			±						
PTN-PRD001190	0..		FP2-1-1-114-0-1		P..	...			±						
PTN-PRD001191	0..		FP3-1-1-114-0-1		P..	...			±						
PTN-PRD001192	0..		FP4-1-1-114-0-1		P..	...			±						
PTN-PRD001193	0..		FP5-1-1-114-0-1		P..	...			±						
PTN-PRD001194	0..		FP6-1-1-114-0-1		P..	...			±						
PTN-PRD001195	0..		FP7-1-1-114-0-1		P..	...			±						
			14-0-1		P..	...			±						
			14-0-1		P..	...			±						
			114-0-1		P..	...			±						
			114-0-1		P..	...			±						
PTN-PRD001200	0..		FP12-1-1-114-0-1		P..	...			±						
PTN-PRD001201	0..		FP13-1-1-114-0-1		P..	...			±						
PTN-PRD001202	0..		FP14-1-1-114-0-1		P..	...			±						
PTN-PRD001203	0..		FP15-1-1-114-0-1		P..	...			±						
PTN-PRD001204	0..		FP16-1-1-114-0-1		P..	...			±						
PTN-PRD001205	0..		FP17-1-1-114-0-1		P..	...			±						
PTN-PRD001206	0..		FP18-1-1-114-0-1		P..	...			±						
PTN-PRD001207	0..		FP19-1-1-114-0-1		P..	...			±						

Fig. 11: PWBS for the MRV showing Assembly, Sub-Assemblies, and Fabricated Parts (up to the Design Element level)

A careful observation of the Partition Schemes shown in Figures 4 and 7 will show that they represent two different Product Work Breakdown Structure (PWBS) for the same ship (MRV). This in effect means the two PWBSs are for two different build strategies. So it is very easy to define and assess alternate build strategies in 4GD using Partition Schemes.

It is not necessary to define partition hierarchies prior to the start of a project or program. While some partition hierarchies may be fully understood at the start of a program, there is no penalty or design impact for defining a new partition while a program is already in progress, and no impact for extending and/or altering an existing partition hierarchy. Moreover, since Partitions are completely separate from the design data of the Design Elements, the partition assignment of Design Elements can be easily changed.

13. 4GD AND PLM

The Siemens PLM 4GD component-based design solution is fully immersed in the Teamcenter PLM backbone. This effectively integrates shipbuilding-capable design tools within a rich PLM backbone, and provides the ability to effectively manage not only the design information for a given ship, but the whole product development process, including the design itself and all related information across the lifecycle for families of ships as they evolve.

Apart from the ability to define different product views (or WBS) of a ship, submarine or offshore structure as it evolves through its lifecycle, there are several other advantages of the Siemens PLM 4GD component-based design solution as below :

- Management of End-to-End Product Data across the Product Lifecycle
- Workflow automation and Change Management
- Versioning and Controlled Evolution of Product Data
- Ship / Hull effectivity / Carry over within ship class or from sister ships
- Enable multiple users collaborating or working in parallel on alternative designs without duplication
- Capture of stable product baselines for certification of contract milestones and support for historical configuration
- Support for Multi-CAD design content and flexible round-trip supplier data exchange

14. CONCLUSION

Recent trends in the engineering information management technology of the shipbuilding industry are characterized by the spread of the product lifecycle management (PLM) concept and an increased demand on better use of ship engineering data after ship delivery. Product structure data, explicit hierarchical assembly structures representing assemblies and the constituents of those assemblies, form the backbone of all engineering data managed by PLM systems. Since core information managed by PLM systems is product structure, a suitable information model which can efficiently define and manage the various ship work breakdown structures through different ship life cycle stages is required. The new Component Based Design solution for marine/shipbuilding based on 4th generation of design (4GD) technology with Teamcenter PLM backbone addresses these requirements.

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