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International Journal of Maritime Engineering

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PAPERS

MOVING TOWARDS MODEL BASED APPROVAL – THE OPEN CLASS 3D EXCHANGE (OCX) STANDARD

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SUMMARY

Shipyards and classification societies must modify the traditional design documentation and review process and enable a direct 3D digital classification process to improve the exchange of information between the different stakeholders and ultimately accelerate the classification process. The Open Class 3D Exchange (OCX) standard represents a step-change in this context. The OCX is a vessel-specific standard addressing the information needs of the classification society and is a key enabler to replace traditional 2D class drawings with a 3D model. The successful and seamless exchange of the design models exported from 4 independent 3D CAD systems to the classification society's rule calculation tool has been demonstrated. The application of the OCX models for the prescriptive rule calculations demonstrates that the OCX model can carry all the information required by the classification society's Rules for this purpose. The possibility to also display the detailed features of the design model in a neutral web-based viewer provides the necessary capability for full visual verification of the design models.

NOMENCLATURE

A	*Cross-section area*
APPROVED	*APProval of Engineering Designs - Joint industry project*
CAD	*Computer-Aided Design*
COG	*Cross-section centre of gravity*
DW_{origin}	*Deadweight in the originating application*
DW_{new}	*Deadweight in receiving application*
IoT	*Internet of Things*
I_y	*Cross-section horizontal moment of inertia*
I_z	*Cross-section vertical moment of inertia*
OCX	*Open Class 3D Exchange*
PLM	*Product Lifecycle Management*
VLCC	*Very Large Crude-oil Carrier*

1. INTRODUCTION

Information technology, now increasingly leveraging the Cloud and global 24x7 access via mobile devices, is enabling the digital description and management of everything companies make and do, from the largest global organizations to small, start-up enterprises.

While much of the digital product definition focus for the past 30 years has been on the development of detailed 3D CAD models for mechanical and electrical design and manufacturing, the next 5 to 10 years will see an increased emphasis on digital modelling of all key aspects of the product lifecycle (user needs, functional requirements, system architecture and interfaces, physical design, etc.) spanning all relevant domains making up the product (e.g., embedded software, hardware, electronics, controls, optics, chemical formulations, etc.). The use of robust digital models at the systems level and in all aspects of product development (i.e., model-based systems engineering) is creating a new paradigm for how manufacturing organizations and their global extended ecosystems must interact and collaborate to bring innovative products to market, as well as support them throughout their lifecycles.

Increased digitalisation and automation within the shipbuilding industry have the potential to leverage the competition between high-cost and low-cost countries. Simulation, virtual prototyping, and virtual testing combined with the introduction of advanced production and manufacturing robots are enabling technologies important also to the shipbuilding industry (Schjølberg *et al.*, 2016). Robotization and automation will be instrumental in increasing production efficiency and lowering production costs. Future yards will be based on a digital thread intervening in all processes from design to production. In the future, a digital product definition from the design will be used in fully automated production processes (Schjølberg *et al.*, 2016). Internet of Things (IoT) will introduce capabilities to instrument the complete value chain in a cost-efficient way. It will be possible to quickly introduce design changes and simulate the impact on production. The production process can quickly be adapted and changed to reflect design changes. During the production, vital production parameters can be monitored in real-time and modified to meet quality requirements. Companies mastering this shift into the age of Industry 4.0 will be the winners.

Within the shipbuilding community, Product Lifecycle Management (PLM) – the management of product data across the enterprise – has become increasingly important over the last decade or so. There are several reasons for this development. The first is an increase in the globalisation of markets, resulting in collaborative practices in which product development, manufacture and maintenance occur in a geographically distributed and networked environment, with the result that much of the data relating to a product or artefact is dispersed over several organisations and locations. Secondly, there is an emerging economic and business paradigm shift in which companies that design and build products are increasingly being required to enter contracts to provide through-life support – that is, products are no longer being purchased as artefacts, but rather as services. Within the aerospace industry, for example, the concept of "power by the hour" has been introduced and is increasingly accepted. For products, such as cruise ships, offshore rigs, aircraft and rolling stock for railways, this could mean a commitment to providing support if the product is in service, extending to 30-50 years or in some cases even longer. Consequently, PLM has gained prominence in the engineering, manufacturing, contracting and service sectors amongst others; it requires the efficient capture, representation, organisation, retrieval and reuse of product data over its entire life.

At the same time, there are a much greater reliance on Computer-Aided Design (CAD) models which have now displaced paper-based technical drawings and documentation as the main carriers of definitive product shape data in several major industries. Within the last ten years or so, the engineering industry in automotive, aerospace and construction has gradually converted to using CAD models as the main source for communicating designs to manufacturers, builders, maintenance crews and regulators. This switch to creating the engineering record digitally, however, presents problems not only for its long-term maintenance and accessibility – due in part to the rapid obsolescence of the hardware, software and file formats involved – but also for recording the evolution of design, artefacts and products.

2. A DIGITAL WORKFLOW

2.1 WHAT IS A MODEL?

A model is a representation or idealization of the structure, behaviour, operation, or other characteristics of a real-world system. A model is used to convey design information, simulate real-world behaviour, or specify a process. ASME (ASME/Y14.41, 2019) and ISO (ISO, 2015) give the following definition of the term model (see Figure 1):

Model: A combination of the design model, annotation and attributes that describes a product.

Engineers use models to convey product definition or otherwise define a product's form, fit and function. According to the *Model-Based Enterprise* (MBE, 2021), models can apply to a wide range of domains (systems, software, electronics, mechanics, human behaviour, logistics, and manufacturing). Models can be either computational or descriptive. Computational models are meant for computer interpretation and have a machine-readable format and syntax. Descriptive models are human interpretable and meant for human consumption (symbolic representation and presentation). Core to MBE is the *integration* of descriptive models with computational models. Computer-aided design (CAD) models used in manufacturing are good examples. Early CAD models were meant only for human viewing. Today, CAD models can be directly interpreted by other engineering software applications. A variety of standard interchange formats now exist to enable application-to-application transfer of engineering data.

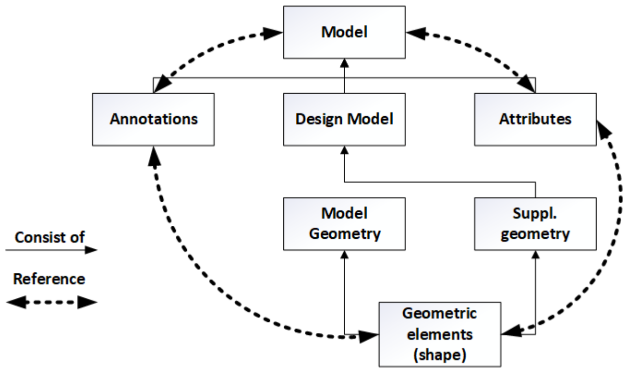


Figure 1. Model data elements, ASME (ASME/Y14.41, 2019)

2.2 FROM DRAWINGS TO MODELS

CAD models have traditionally been used in the design, evaluation, and manufacturing phases; up until the turn of the millennium, engineering software was used to support a paper-based workflow – CAD packages were used to create virtual models of designs, from which drawings and other design documentation could be produced. The manufacture or construction process was based on the resulting documentation. However, current digital environments necessitate an electronic flow of information between heterogeneous systems for Computer-Aided Design (CAD), Computer-Aided Engineering (CAE) and Computer-Aided Manufacture (CAM) as well as Enterprise Resource Planning (ERP), Customer Relationship Management (CRM) and Supply Chain Management (SCM). Thus, there is an increasingly greater reliance on CAD models which are now being used as the method for recording definitive product data.

Traditionally, drawings are used for communication in the industry because they are the clearest way to tell someone what to make and how to make it. They are considered a graphic universal language. The fundamental purpose of an engineering drawing is to carry, control and maintain a product's definition in a precise and clear way with no risk of misinterpretation or assumption. Technical drawings provide a means to communicate product complexity in a comprehensible and effective manner thanks to visual abstraction.

Many in the industry have moved away from a reliance on drawings to computer-based technology to design, price, and manufacture items in a world where digital information is king. Engineering drawings are no longer considered primary product definition sources or master representations of products as the integration of CAD systems within the product development process has become the standard. Both the aviation and automotive industries are moving towards a drawing free product lifecycle. We can see several drivers in this development (Quintana *et al.*, 2010):

- One master product definition
- Virtual prototyping and simulation
- Computer-aided manufacturing (CAM)
- Assembly automation
- Production of maintenance documentation

The above list is not exhaustive, but some common denominators are reduced time to market, reduced rework, reduced cost, and improved transparency for stakeholders throughout the product lifecycle.

From a business perspective, companies will benefit from reduced investment in piecemeal integration projects. The corresponding increase in data quality, based on data transfer versus data re-creation, will lower the cost resulting from rework. Ultimately, companies should see a significant reduction in application integration costs, as downstream processes and successive programs reuse the existing interoperability framework.

From a technical perspective, the standards-based approach can greatly simplify integration complexity, by largely eliminating the need to develop and maintain point-to-point integration solutions. The simpler integration model will make it feasible to add new applications as demands arise for new capabilities. The time required to deploy new applications and processes that are integrated with existing capabilities will be greatly reduced.

These benefits are predicated on several factors. The standards used must be comprehensive enough to support a complete business scenario, such as engineering design. They must be robust enough that they can support exchange between a wide variety of data models and applications. They must be feasible to implement, and the implementation itself should follow certain established patterns to derive maximum benefit, see (AIA, 2013; Astrup, 2017).

2.3 STANDARDISATION

Considerable effort has been spent in developing standard protocols for product definitions both in shipbuilding and other industries (Bronsart *et al.*, 2005).

Product data models meant to support the data exchange have been developed in earlier times and led to e.g., ISO standards (STEP series) have led to the shipbuilding specific STEP protocols: ISO 10303-215, ISO 10303-216, ISO 10303-218 (ISO-AP216, 2003; ISO-AP215, 2004; ISO-AP218, 2004) which cover a broad range of different, sometimes overlapping scopes. Even though the implementation of these standards was supported by many development projects in the international community over the past 20 years, today there are only very few systems capable of exporting their internal data structures according to the standard definitions.

Due to its broad scope, the application protocol AP218 is principally capable to support the need for data exchange during the early stages of the design in a consistent manner. Due to the generally limited support by the software vendors, the shipbuilding protocols are not used in actual commercial ship design projects today.

The lack of a ship-specific standard is a major problem for the shipbuilding industry. This has left a void that needed to be filled and resulted in a continuation of the development of “point-to-point” solutions based on a variety of ad hoc application programming interfaces (APIs) and XML-based interfaces. While these have been effective in terms of achieving the result, they have not been cost-effective from an industry perspective as the number of interfaces grows at a combinatorial rate as the numbers of applications increase, (Polini, 2011).

2.4 A SHIPBUILDING SOLUTION

The role of the classification society during the new-building phase is to verify and approve that the design fulfils class and Statutory requirements (i.e. the Rules) (IACS, 2011). The society carries out a technical review of the design plans and related documents for a new vessel to verify compliance with the applicable rules and regulations. Today, the review process is purely document-based. The current practice in ship classification is to base the verification job on documents prepared and submitted by the designer/yard. Documents may consist of drawings, descriptions, calculations, reports, procedures, certificates and similar information describing e.g. the design, installation, testing, operation, maintenance or status of an object (DNV, 2021). For the hull design verification, 2D drawings have been the single most important design document exchanged between the yard/designer and the classification society. The classification society must manually build up its verification and calculation models based on the submitted documents if independent calculations are required. This process is time-consuming and error-prone. For every design revision, the classification society may need to do a re-verification. The final design approved by the classification society is marked by a set of approved “stamped” drawings.

Computer-Aided Design (CAD) models are now displacing technical drawings and documentation as the main product definition in several major industries. Within the last ten years or so, the engineering industry in automotive, aerospace and construction has gradually converted to using CAD models directly for communicating designs to manufacturers, builders, maintenance crews, and regulators. The shipbuilding industry is also gradually switching to creating engineering records in digital models.

Shipyards and classification societies must modify the traditional design documentation and review process and enable a direct 3D digital classification process to improve the exchange of information between the different stakeholders and ultimately accelerate the classification process, see Figure 2. Compared to traditional drawing approval, the advantages include:

- reducing shipyard workload with fewer drawings to create,
- improving quality and a common understanding of design and class comments by using a 3D design representation directly,
- optimizing the calculation process by directly interfacing the 3D design model with all calculation software such as structural and stability software,
- improved transparency and support for automation and increased self-service.

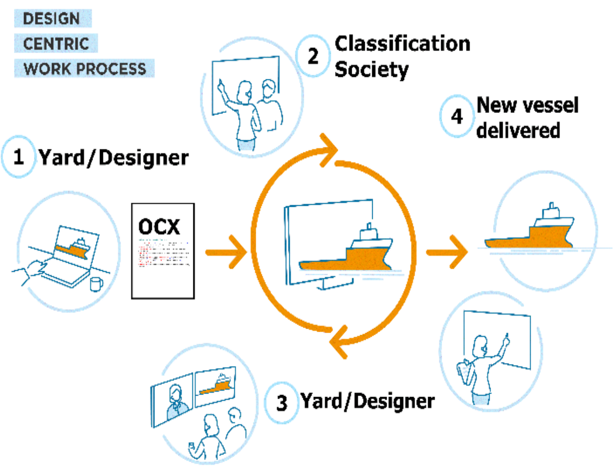


Figure 2. A digital information flow between yard/designer and the classification society

Sharing a common 3D model enables a fully digital design-centric and iterative work process (the numbers refer to the steps displayed in Figure 2:

1: The Yard/Designer uploads the 3D design model to the classification society.

2: The classification society reviews the 3D model, performs rule calculations and provides comments and red marking directly on the design model giving immediate feedback to the designer.

3: The Yard/Designer makes the required design changes and engages in a model-centric dialogue with the classification society. A new design revision is uploaded documenting the changes.

4: At the end of the process, a new vessel is delivered with a shorter time to market, and improved traceability, and quality.

The APPROVED project (Halfhide, 2019) has for the first time brought together expertise from CAD/CAM software providers Aveva, Hexagon (formerly Intergraph) and Siemens; along with ship designers and builders Kongsberg Maritime (formerly Rolls-Royce Marine), Ulstein and Chantiers de l'Atlantique; as well as 3D and PLM implementation specialists Digitread. During the project period, NAPA joined to fully support the OCX standard development.

The result of the combined efforts is the development of an interoperability specification that the partners hope will allow for shipbuilders and class societies to engage in complete sharing of the digital workflow using a common specification for 3D models: Open Class 3D Exchange standard. Uniquely, OCX addresses the needs of the classification society and shipbuilders for fully digital information exchange. Effectively, OCX acts as a conduit between the design tools and class confirmation tools, highlighting the structural information the class society requires and idealizing and formatting it in an efficient way that can be easily processed. The APPROVED JIP has demonstrated the capabilities of the OCX providing seamless information exchange between the designer/yard and the classification society covering the hull structure definition of the design. The OCX Consortium (3docx.org, 2021b) was established in 2021 to maintain, evolve and promote the OCX standard to the benefit of the shipbuilding industry. This was a major milestone in the development of the standard and fulfils the JIP members' original intention. At the time of writing, 27 members have joined the consortium. The members comprise the major classification societies, the major vendors providing design systems to the shipbuilding industry and several designers/yards (3docx.org, 2021a). The uptake of the OCX by the industry is gradually expanding as classification societies are building on the OCX capabilities and changing the way they can interact with designers and shipyards (Habibic, 2022; Astrup, 2022; Seppälä, 2022).

3. OPEN CLASS 3D EXCHANGE (OCX)

3.1 INTRODUCTION

A vessel-specific standard addressing the information needs of the classification society is a key enabler to replace traditional 2D class drawings with a 3D model. This is the purpose of the "***Open Class 3D Model Exchange (OCX)***" neutral format. The goal of the standard is to replace traditional 2D class drawings with a 3D model as the design documentation submitted to the classification society. The OCX standard (Astrup and Cabos, 2017; O. Astrup, 2019; O. C. Astrup, 2019; 3docx.org, 2021b) is unique in the sense that it specifically addresses the needs of the classification society and shipbuilders addressing a fully digital information exchange.

3.2 WHAT DISTINGUISHES THE OCX STANDARD FROM OTHER SHIPBUILDING STANDARDS?

PROSTEP, a PLM consultancy company with more than 25 years of experience in the maritime industry, has analyzed the OCX standard and compared it with the current standards in use by the maritime shipbuilding industry (3docx.org, 2021c). The main takeaways are summarised in Figure 3 and emphasize three unique aspects of the OCX standard:

- A topological model
- Shipbuilding semantics and features
- The spatial and logical structure of compartments and tanks

Quote: *"OCX is a format to support topological and feature-based (shipbuilding design) semantics not found in existing exchange formats (such as IGES, STEP, JT) for class approval related data exchange scenarios to complement (and eventually replace) (paper-) drawings."*

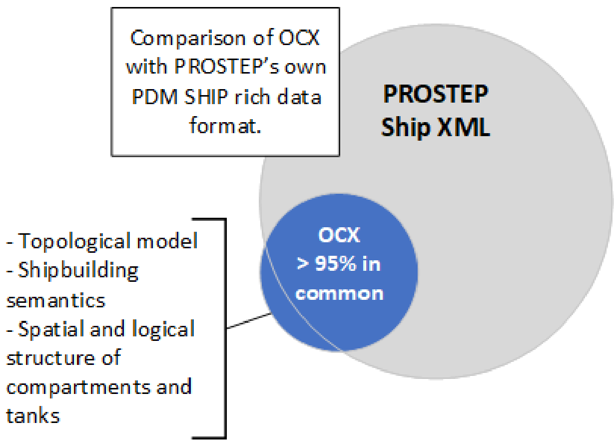


Figure 3. Analysis of the OCX by PROSTEP (3docx.org, 2021c). Graphics reproduced from the original by courtesy of PROSTEP.

PROSTEP also places the OCX format in a process context, see Figure 4. Based on their analysis of the schema, PROSTEP identify the following improvement areas:

- outbound/inbound data transfer needs including visual representation,
- archiving of approval process data,
- comment exchange,
- and IP protection.

The format was developed with a process context in mind and the aim is that an OCX model can replace current 2D classification drawings as design documentation. The unique OCX features and some of the identified improvement areas will be addressed in the subsequent sections.

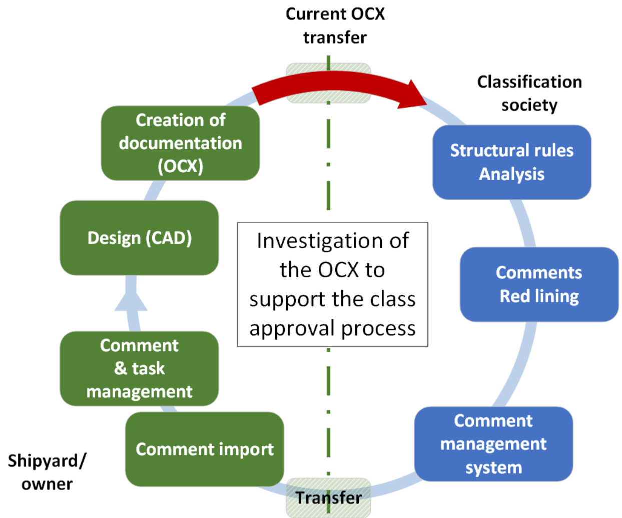


Figure 4. Analysis of the OCX by PROSTEP (3docx.org, 2021c). Graphics reproduced from the original by courtesy of PROSTEP.

3.3 DESIGN CRITERIA

The main design objective of the OCX has been to address the information needed by the classification society to verify the design. The goal is to replace today's 2D drawings as design documentation with a digital 3D data model. The OCX serves two purposes to fulfil the verification needs of the classification society:

- The OCX can be used to derive the calculation models for the societies Rule calculation tools.
- The OCX must contain the necessary information to provide visual verification of the design by the classification society.

The OCX contains all the information needed by a receiving application to fully reconstruct an idealised model representation of the original CAD model. The OCX is designed so a model includes the information required to fulfil the calculation scope given by the classification society's Rules. Besides, the OCX is designed so a model will also contain the detailed geometry provided by the authoring application. This description represents the sheet geometry as provided by the authoring CAD system. This additional level of detail serves two purposes: 1) it enables the authoring application to qualify the geometry of the idealised model with the source model and 2) the 3D rendering of the detailed geometry model supports the visual verification of the design model. This last item is important for the verification by the classification society as it will ultimately allow the replacement of today's 2D drawings with a 3D visual model.

The OCX structure adapts concepts used by Product Lifecycle Management (PLM) and organises the information content into three major categories similar to Rachuri (Rachuri *et al.*, 2008), see Figure 5.

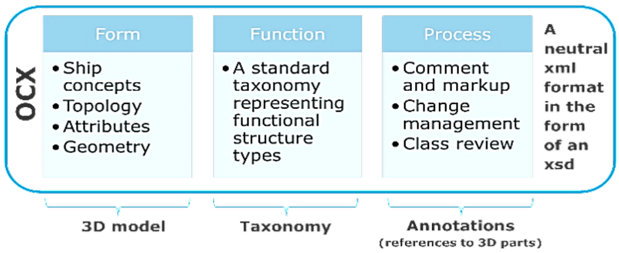


Figure 5. OCX information structure

What: The vessel hull form is described by its geometry, features, materials, topology etc.

Why: The functions of the vessel are represented by a taxonomy describing requirements, and the function to be performed.

How: Process and business-related life-cycle data represented by layered annotations describing process information e.g. approval, change management, inspection, testing etc.

The main design considerations have been to incorporate:

- A concept-rich and vessel-specific domain model.
- A lightweight and CAD-neutral representation of the 3D geometry.
- The ability to grow the product definition information throughout the design lifecycle.
- The ability to describe the function and process-related information.
- The ability to reference function and process information to the 3D model using multi-layered annotations.
- A referencing scheme or mechanism which is robust to 3D model design changes.
- An easily extendable scheme to cater for new functions and process-related data.

The intended use scenario for the OCX is shown in Figure 6. The scenario represents the retrieval of the design information required by the classification society directly from the yard's design model utilizing a neutral exchange format. The advantage of having a standard and common neutral exchange format advocates information sharing and re-use and avoids the current practice in maritime using cumbersome point-to-point interfaces (Polini, 2011).

The overall intention of the developers of the OCX is to have the exchange format accepted by the maritime industry at large as a neutral exchange format. We believe that a vessel-specific standard addressing the information needs of the classification society is a key enabler to replace traditional 2D drawings with a 3D model as design documentation submitted for verification.

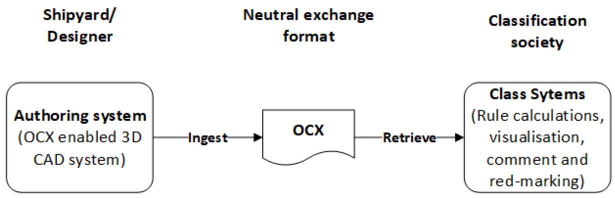


Figure 6. Intended OCX use scenario

3.4 SCHEMA, MODEL AND ANNOTATION

A **schema** is a collection of entities (or classes), attributes, and relationships between entities. It defines the patterns or templates by which populations of these entities and relationships shall be represented. Such a schema is often called a Product (Data) Model (as opposed to a populated data model). The OCX specification is a schema.

A **model** is a population of a schema, following the patterns, templates and constraints stipulated by the schema. It contains the actual instances of the entities (or classes). Such a model is often called a populated data model, a project data model, or a building information model (if the content is construction industry-specific). An OCX exchange file is a population of the OCX schema and represents a ship structure information model. The purpose of an OCX model is to form the basis for a model-based approval of the design by the Classification Society.

Annotation can be simply defined as adding any extra information for various purposes, such as further explanations, viewpoint interpretation, extra descriptions of or comments on an existing entity in the model.

3.5 MAIN CAPABILITIES OF THE OCX

The required information for the hull discipline has been the scope of the first implementation of the OCX schema.

The developed schema has the following main capabilities:

- The ability to describe a Vessel using typical shipbuilding concepts such as Panel, Plate, Stiffener, Pillar, Bracket, Lug, Cope, Cut-Outs, End Connections & Penetrations.
- Structure functions: Taxonomy for load-bearing structure functions (e.g. Deck, Girder, Bulkhead and sub-types).
- A unique identifier for each structure part.
- Physical spaces (compartments with content).
- All part geometry interrelationships (topology).
- A self-contained and parametric sheet geometry representation:

    a. 3D surface primitives (Plane, Cylinder, Cone, NURBS)
    b. 3D curve primitives (Line, CompositeCurve, Circle, Arc, NURBS).
- The ability to provide two different levels of details for the geometry representation:
    a. Gross geometry representation at the Panel level.
    b. Detailed geometry representations at the Plate and Bracket level for the true visual representation of the design model.
- All parameters required by the society's Rules.
- Catalogues: Cross sections, materials and openings.
- Metadata: Scantling attributes, vessel particulars.
- Design views (a user-defined part hierarchy).
- Full units support.

4. THE SCHEMA DETAILS

4.1 INTRODUCTION

It will not be possible to cover all the details of the schema in this paper as the format describes more than 175 ship specific entities and captures several hundred design parameters. What will be provided is a high-level description of some of the key elements (objects) which differentiate the OCX from previous standards or neutral formats. The general OCX schema follows the W3C standards for XML (W3C, n.d.) and serialises only one root element: ocxXML. There must be one, and only one, ocxXML element in any OCX XML instance document (that is, an XML document containing OCX XML information) representing an OCX model.

4.2 EACH PHYSICAL PART HAS A UNIQUE ID

The ability to uniquely identify an object as well as preserve information about its ownership by the authoring system is fundamental to the OCX model. These concepts are required for all subtypes of ocx:EntityBase_T and are captured within the definitions resource schema of the OCX specification. For this purpose, a global element ocx:EntityBase is defined which takes the GUIDRef attribute. The GUIDRef uniquely identifies the parent object using a GUID which also exists in the sending application. This is the reference mechanism used by the OCX to uniquely refer to any entity carrying a GUIDRef and enables an unambiguous reference between applications independent of the application context. Once an OCX instance is created, the GUID provides traceability for its entire lifecycle. The ability to both exchange and trace model changes and document approval states is not possible without this capability.

4.3 UNIT SUPPORT

The OCX schema incorporates the UnitsML mark-up language initially developed by NIST and later taken over by the OASIS group (Celebi *et al.*, 2010). The UnitsML types allow for an unambiguous unit implementation in the OCX schema. All units of measures in the OCX schema must inherit from the abstract base class Quantity. The Quantity element carries two attributes:

- numericvalue
- unit

The unit is a reference to a unique identifier describing the unit according to the UnitsML type, see (OASIS, 2011) for a comprehensive description.

4.4 OCX REFERENCE MECHANISM

The ability to uniquely reference an object as well as preserve information about its ownership by the authoring system is fundamental to the OCX model. For example, if multiple software applications are used to annotate or refer to an instance of a structure item like e.g., a stiffener, having a unique identifier associated with each instance allows for exchange and storage in a common archive with the capability of tracking design changes between different model revisions. Many elements in the OCX XML schema define attributes that are intended to contain references to other elements, either through a unique identifier (i.e. by using the unique GUID of the referenced element) or by using a URI.

For this purpose, the OCX schema defines a generic type named OcxItemPtr. The definition in the OCX XML schema of these attributes includes a refType attribute that identifies the types of elements that can be referenced. It is possible to implement a consistency check based on this information. This is how OCX implements part relationships representing the model topology. The extensive use of references including a parametric model description makes OCX models very compact.

4.5 CATALOGUES

The OCX schema provides several catalogue definitions for standard items such as material definitions, bar section definitions and standard cut-outs (openings). This reduces the size of the OCX model itself by extensive use of references to the catalogue items. It is also easy for the schema users to map their project or yard-specific standards to the OCX catalogue definitions.

4.6 GEOMETRY REPRESENTATION

The implemented geometry model in the OCX is a sheet (moulded form) definition based on trimmed surfaces and parametric geometry constructs. The OCX can fully describe parametric geometry entities using native XML constructs. This makes the OCX fully self-contained without the need to depend on geometry representations in the form of STEP, JT, IGES or other commonly used exchange formats for geometry. The list of implemented

3D curve geometry entities ranges from plain straight lines to Non-Uniform Rational B-Splines (NURBS) definition. 3D surface definitions include native XML definitions of a plane, sphere, cone, cylinder and extruded surface definitions.

4.7 REPRESENTATION OF THE VESSEL

The Vessel entity represents the OCX definition of the asset subject to verification by the classification society. The Vessel object inherits from an abstract Form element intended to be used by all assets with geometry. The abstract FORM element enforces all exported asset elements to include information about the tolerances used to represent geometry entities in the authoring application. The element carries two Quantity elements, DistanceTolerance and AngleTolerance respectively. For geometric operations, it will be important for the receiving application to know the model tolerances in the authoring application.

The Vessel object specifies a comprehensive set of metadata about the vessel which are optional elements except for the vessel's principal particulars, such as moulded breadth and depth, block coefficient and length between perpendiculars. It is also possible to export the vessel arrangement in the form of either closed geometric volumes (compartments) or physical spaces (volumes defined by structural objects). The Arrangement definition in OCX can have either a set of Compartment definitions or a set of PhysicalSpace definitions or both.

The Compartment definition in the OCX is a geometric volume definition. A Compartment represents the concept of a closed space part of the vessel capacity plan defined by the enclosing surface geometries given by the CompartmentFace objects, see Figure 7.

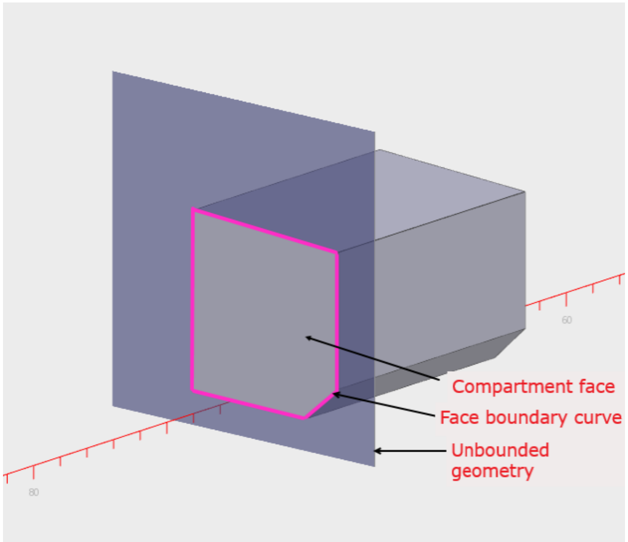


Figure 7. OCX Compartment definition

The CompartmentFace consists of an unbounded surface definition and a limiting trim curve in the form of a FaceBoundaryCurve as shown in Figure 7. The FaceBoundaryCurve must define a fully closed curve to be valid. The unbounded surface definition can either be given explicitly by one of the OCX Surface entities or implicitly by referencing the plane of a grid reference GridRef or by a reference to another instantiated surface.

A PhysicalSpace is a structural concept of a compartment representing a physical closed volume (space), see Figure 8. This subset of the schema defines the "spatial" subdivision of the vessel representing actual physical volumes. A PhysicalSpace is a closed volume consisting of one or more cells where boundaries cannot overlap. Physical space is represented by the existing physical structure panels in the model which forms the closed volume.

Both Compartment and PhysicalSpace carry properties (CompartmentProperties) and may carry one or more content specifications (dry or liquid). The centre of gravity, volume and air pipe heights are also required CompartmentProperties attributes.

During the basic design of the vessel, the structure will be detailed and eventually also create physical spaces or compartments. The OCX has a construct to also represent physical spaces using PhysicalSpace objects. It will then be possible to compare the initial compartment definition with the physical spaces defined by structural engineering. This is the intended use of the PhysicalSpace representation in the OCX. The arrangement defined by Compartment objects may originate from a different source than the PhysicalSpace representation. It will be important for the verification process that the OCX can carry both representations and trace the originating source. This will also enable a receiving application to compare the two representations.

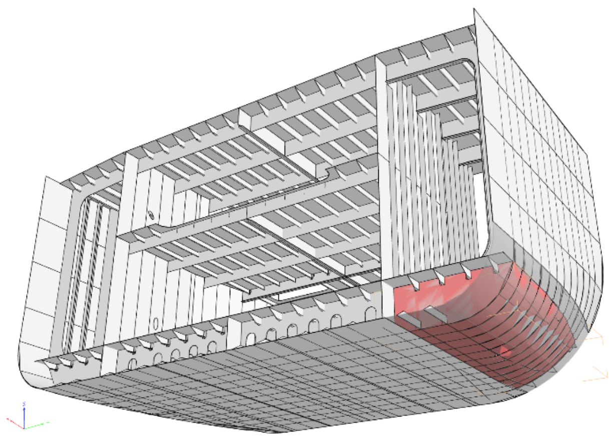


Figure 8. A PhysicalSpace compartment (the darker volume space in the figure) defined by physical structure panels forming an enclosed and watertight volume

A Vessel element may also specify its CoordinateSystem in the form of a local coordinate system definition and additional reference grids, typically the frame table for X spacings and additional Y and Z grid spacings. The OCX advocates the use of reference grids for limiting the exported structure objects. This follows established modelling practices by most marine CAD systems.

Also, a collection of reference surfaces may be exported. This design is intended to be used for the surfaces which will limit many instances in an OCX model. The surface definition of the hull form is encouraged to be exported as a ReferenceSurface since the hull form will naturally limit very many of the OCX structure panels as decks, transverse bulkheads and longitudinal elements. Using the hull form as a reference surface avoids the duplication of the geometry definition and reduces the size of the OCX model.

Most importantly the Vessel object contains the collection of all the structural elements defining the hull structure: Panel, Plate, Bracket, Stiffener and Pillar.

4.8 THE PANEL

An OCX Panel has an explicit structure or composition. The concept of a Panel is a composition of plates, seams and stiffeners. A Panel may also have larger cut-outs. An OCX Panel has its unbounded geometry given by the native XML geometry definitions described in Section 4.6. The Panel geometry must be fully bounded either by giving the specific trim curves, or preferably, by referencing other OCX objects. The limiting objects may be any combination of grid references, other panels or reference surfaces. The bounding objects must form a closed loop completely defining the trimmed panel surface.

The bounding definition is provided by the LimitedBy element. The LimitedBy concept is a means to represent the topology in the model, i.e. the relationships between structural parts or between a structure part and a reference grid location or a reference surface. Without the topology definitions defining a trimmed surface object, it is not possible to recreate the geometry in the receiving application.

The OCX also requires the authoring application to export its definition or instantiation of the outer contour geometry of the bounded panel geometry. The geometry of the outer closed contour is the limitation of the panel surface, represented by a set of trim curves forming a closed curve. It is not the intention that the receiving application shall use the OuterContour when establishing the UnboundedGeometry limits. The reason not to use the explicit OuterContour representation is to avoid geometry tolerance limitations. When the receiving application is responsible for computing geometry intersections based on the structure part relationships, one avoids the problem of loss of accuracy and tolerance differences between the authoring and receiving applications. It is still an advantage for the receiving application to have the explicit definition of the closed contour provided by the authoring application. In difficult cases where one may encounter ambiguities when reconstructing geometry from the topology, the explicit contour provided by the authoring application can be used to select the correct outcome of a geometry ambiguous computation.

The Plate elements may be part of a Panel and will then be a collection under the ComposedOf items. Or it may also be a stand-alone instantiation directly under the Vessel.

The StiffenedBy entity contains a collection of the stiffeners which is belonging to the panel.

The SplitBy definition represents the definition of splitting structural concepts defining the subdivision of a panel into plates split by one or more seams.

The CutBy entity defines the larger openings of the Panel. Any number of openings can be defined using two methods: 1) a collection of *closed* contour curves (InnerContour). The inner contour defines an explicit 3D curve of the opening, or 2) by a hole shape catalogue contour (Hole2DContour). The contour definition is defined once by the hole shape catalogue and can be re-used in many instances. To instantiate the cut-out, the OCX provides the reference to the catalogued item together with a transformation rule which projects the contour onto the Panel surface to form the final cut-out.

Figure 9 shows an example of a stiffened panel with a large cut-out.

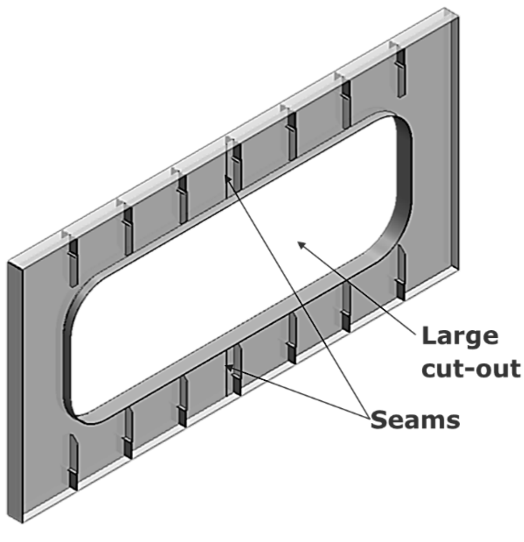


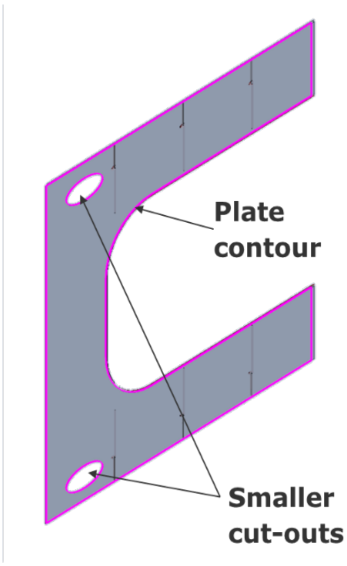
Figure 9. Example of a stiffened Panel with one large centre cut-out/opening and plate seams

4.9 THE PLATE

A Plate can be part of a Panel and must then be part of the ComposedOf items. Or a Plate may also be a stand-alone instantiation directly under the Vessel type. A Plate has also LimitedBy yielding plate limits. The objects limiting the plate are typically references to Seams but may also be other OCX objects such as a reference grid or a neighbouring structure part.

The authoring application should also give the explicit detailed OuterContour of the Plate, see Figure 10. The detailed outer contour of the plate gives the authoring application the possibility to provide detailed features of the plate boundaries such as slot openings and smaller trimmings. Such details shall not be part of the LimitedBy definition. The main reason for this design is to have separate levels of detail (LOD) in the model. This separation of detail levels gives the receiving application the possibility to display and use different model LODs which will often depend on the intended use.

The authoring application may also give the smaller openings or cut-outs in a plate providing more detailed features. This LOD can be given by defining a plate specific CutBy definition for the smaller openings, see Figure 10.



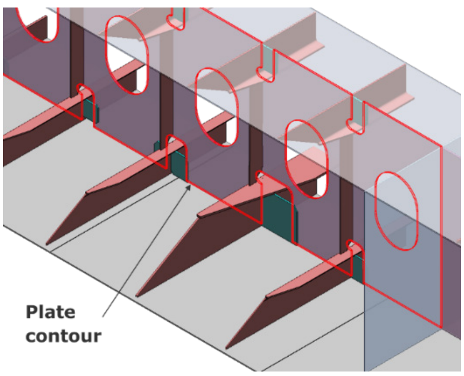


Figure 10. Detailed OuterContour of a Plate

It is possible to specify a material offset for all plates. The OCX provides the Offset entity for this purpose. This makes it possible for the OCX to represent the moulded modelling convention typically used in shipbuilding, see Figure 11. By default, OCX assumes that the plate surface is in the centre of the plate material. According to the moulded convention, the plate material must be offset t/2 in the direction of the normal vector. The surface normal of the plate will determine the offset direction. A negative number will give a material offset in the opposite direction of the plate normal.

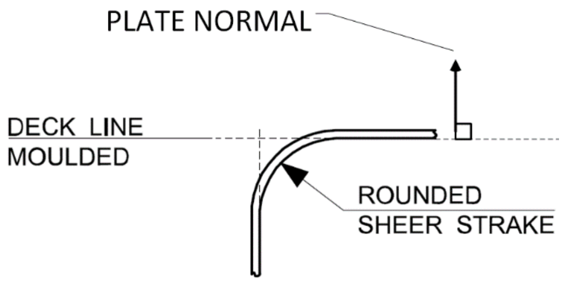


Figure 11: Moulded modelling convention

4.10 SEAM

The Seam is part of the Panel SplitBy items. This is how a panel subdivision into plates is defined, see Figure 9 for an illustration where a seam is dividing the panel into two plates.

4.11 BRACKET

An OCX bracket definition is a specialised Plate object and inherits the OCX Plate attributes with some important additions. As for the Plate, the Bracket has an UnboundedGeometry definition. In contrast to the Plate object, a Bracket is only limited by a mandatory OuterContour definition given by a closed 3D contour curve, see Figure 12. A Bracket may also be reinforced by stiffeners.

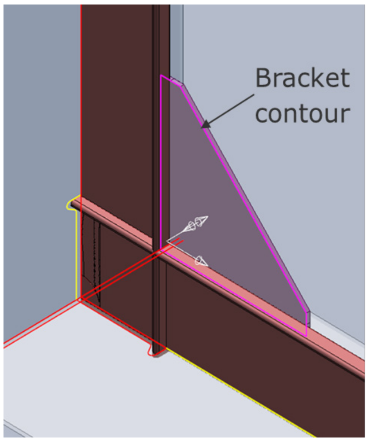


Figure 12. Bracket geometry and bracket contour

The OCX schema requires the authoring application to provide the bracket parameters depicted in Table 1. These parameters are used by the society's Rules for several scantling requirements. The mandatory set of parameters is the two bracket arm lengths, the bracket nose heights, and the free edge radius.

Table 1: Definition of main bracket parameters

Attribute	Description
ArmLengthU	The length of the bracket in the local U-direction.
ArmLengthV	The length of the bracket in the local V-direction.
Unose	The bracket nose depth at U end.
Vnose	The bracket nose depth at V end.
FreeEdgeRadius	The edge radius at the bracket free edge. Assumed to be straight if no radius value is provided.
FeatureCope	Parameters of cope feature defining additional bracket or stiffener end cut details.
EdgeReinforcement	Edge reinforcement parameters.
hasEdgeReinforcement	Boolean. False if bracket has no reinforcement (Default).
numberOfSupports	The number of supported (welded) bracket edges.
edgeReinforcement	The enumerator of bracket edge reinforcement types.

Often supporting brackets and stiffeners have additional details like a cope or heel. The OCX schema species an optional FeatureCope which can be used to provide these features for brackets or stiffener end-cuts, see Table 2.

Table 2: FeatureCope parameters

Attribute	Description
CopeHeight	The height of the cope.
CopeRadius	The cope or heel radius.
CopeLength	The default is CopeLength=CopeRadius

4.12 STIFFENER REPRESENTATION

An OCX stiffener is defined by a reference to a catalogue cross-section, a trace line on the Panel moulded surface and a set of inclinations giving the orientation and offsets of the cross-section relative to the moulded surface and the trace line. The geometry of the stiffener is represented by the stiffener trace-line given as a general Curve3D item. The trace-line describes the landing curve of the stiffener on the Panel mould surface. The inclination of the stiffener cross-section is defined by a set of vector pairs giving the local orientation of the web and flange directions at arbitrary positions along the stiffener trace-line. The flange direction is optional and not necessary for a symmetrical cross-section. Only one inclination is necessary for a non-twisted and linear (straight) stiffener.

The schema provides the possibility to give a detailed geometry in the form of web and flange end cuts. The detailed stiffener end cut contours give the possibility to display detailed stiffener features such as end cuts and sniped ends, see Figure 13.

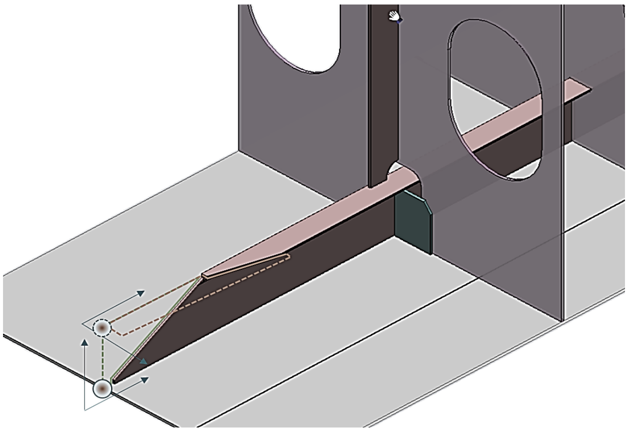


Figure 13. Stiffener detailed contour

The EndCut definition is used to capture these parameters, see Table 3.

In addition to the design parameters provided by the EndCut, the authoring application can give a detailed stiffener contour. The EndCut is necessary to provide the parameters required by the society's Rules while the detailed stiffener contours are necessary for display purposes and visual verification.

Table 3: End cut parameters

Attribute/Sub elem.	Description
CutbackDistance	Distance from stiffener logical end position to the start of the web cutback.
WebCutBackAngle	Sniped angle of stiffener web.
WebNoseHeight	Nose height of sniped stiffener web.
FlangeCutBackAngle	Cut angle of stiffener flange.
FlangeNoseHeight	Nose height of sniped stiffener flange.
FeatureCope	Parameters of cope feature defining additional bracket or stiffener end cut details.
symmetricFlange	True if stiffener is symmetric
sniped	True if stiffener is sniped

4.13 STIFFENER CONNECTION CONFIGURATIONS AND PENETRATIONS

The ConnectionConfiguration and the Penetration types are used to describe typical stiffener end configurations/ penetrations found in shipbuilding, see Figures 14 and 15.

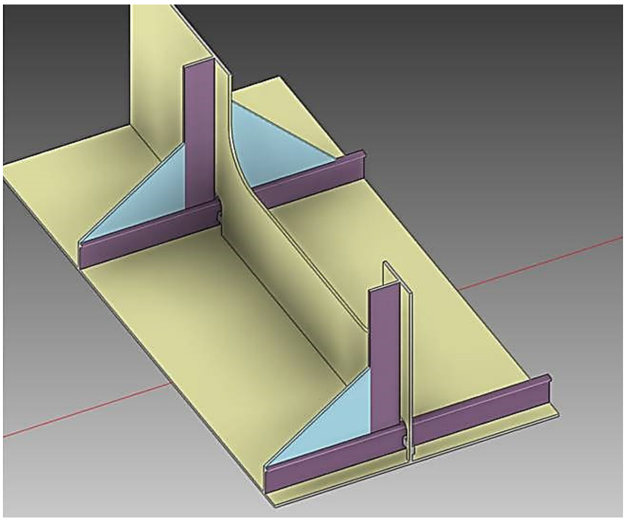


Figure 14. A shipbuilding detail with penetrations

The purpose of the ConnectionConfiguration and the Penetration types is to describe the parameters required for the society's rule calculations. Such parameters are necessary for many of the strength checks for yield, buckling and fatigue limit states. It is an advantage that the authoring application is responsible for providing this information. The authoring application can give the unambiguous parameter values relieving the receiving application from having to interpret complex geometry to retrieve these parameters.

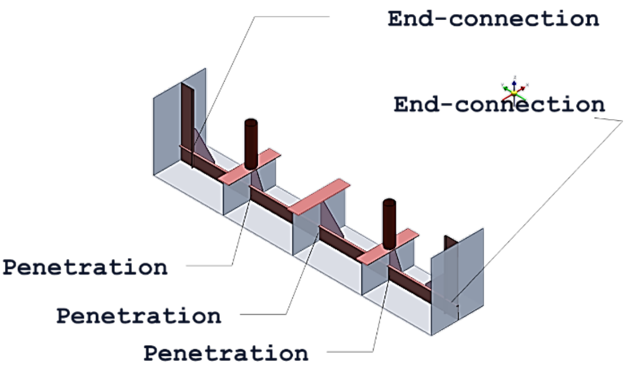
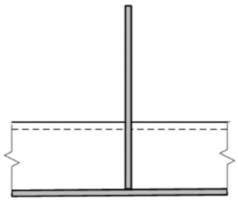
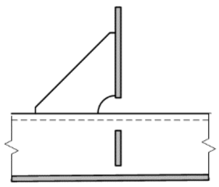
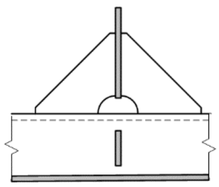
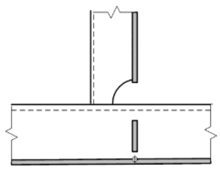
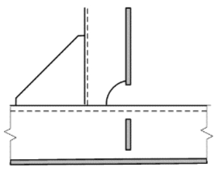
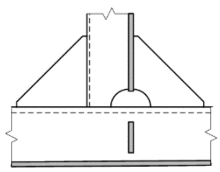


Figure 15. Stiffener with two end connections and 3 penetrations

The ConectionConfiguration definitions have been designed to represent generic configurations typically found in shipbuilding to avoid exposing the OCX to how such configurations are represented by the receiving application. It is the responsibility of the receiving application to map the OCX definition to its representations.

The ConnectionConfiguration or the Penetration must be one of the 6 generic types in Table 4.

Table 4: The OCX provides six generic end-configurations and penetration configurations for stiffeners covering typical shipbuilding details

Sketch	Description
	Untyped No configuration type has been assigned at the penetration
	SingleBracket The longitudinal stiffener has a single bracket connected at the penetration
	DoubleBracket The longitudinal stiffener has a double bracket connected at the penetration
	WebStiffener The longitudinal stiffener has only a web stiffener connected at the penetration
	SingleBracketWithWebStiffener The longitudinal stiffener has a single bracket and a web stiffener connected at the penetration
	DoubleBracketWithWeb Stiffener The longitudinal stiffener is supported by double brackets and a web stiffener connected at the penetration

4.14 SLOTS

A Slot is part of the Penetration object and represents the structural concept of a cut-out (opening) typically used in shipbuilding when stiffeners penetrate a plate or a primary supporting member, see Figure 16. The main purpose of the Slot definition in the schema is to capture parameters enabling the verification of the shear connection between the stiffener and the primary supporting member (PSM) which is penetrated.

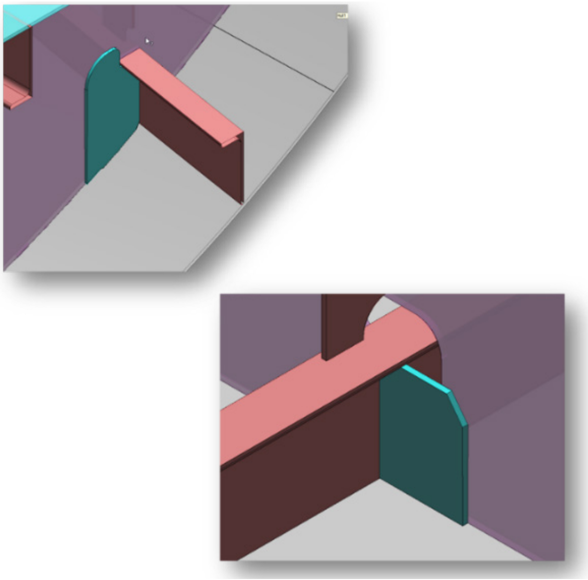


Figure 16. Typical ship-building slot types

4.15 MODEL TOPOLOGY

One of the unique features of the OCX format is the capability to represent the model topology. Figure 17 depicts a simplified UML diagram representation of the relationships and composition of the structure parts represented in the OCX schema. As seen from the diagram, a Vessel (the object for classification) consist of any number of Panel objects which again can be composed of Plate, Stiffener, Seam and CutOut objects.

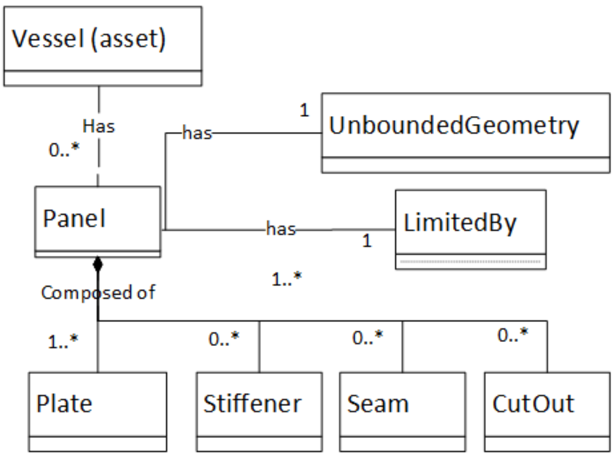


Figure 17. UML diagram of OCX Vessel and structure parts representation (simplified).

Every Panel has an UnboundedGeometry definition defining the panel surface geometry with representations as described in Section 3.4.

The unbounded geometry limits are explicitly coded in one LimitedBy object as shown in Figure 18. The limits shall resolve to a closed-loop on the unbounded surface yielding the final resulting geometry instance.

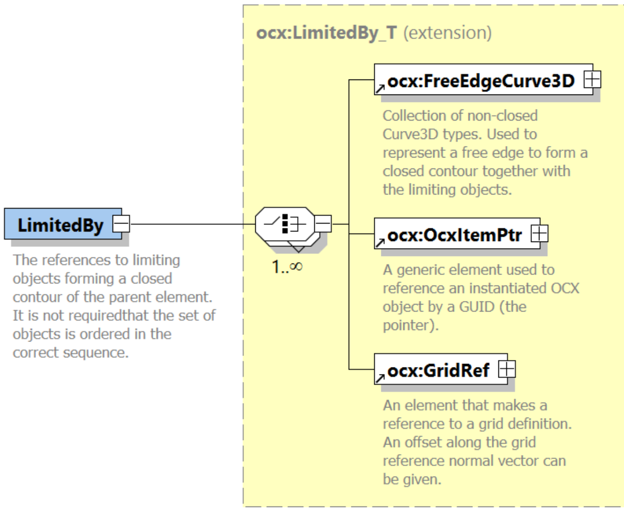


Figure 18. The LimitedBy topology definition

The LimitedBy objects contain two different object types:

- A pointer to another structure part instance (an OcxItemPtr, see Section 4.3 for further details) or a pointer to a grid reference, named GridRef.
- A FreeEdgeCurve is an instance of a curve in 3D space used to limit the panel geometry and represent a physical free edge.

The GridRef is a reference to a grid position in the vessel coordinate system and can be either an XGrid, YGrid or ZGrid. When a grid is used as a limit to the panel geometry, we use the plane at the grid position as the limit, e.g., for XGrid, it will be the YZ-plane. It is possible to specify an offset from the limiting plane when the limit is given. A FreeEdgeCurve cannot be shared between two panels.

The sole purpose of the LimitedBy concept is to provide the receiving application with sufficient information to re-create the same geometry based on parametric representations and topological information. This is best explained by an example. Figure 19 shows how the geometry of a transverse bulkhead can be defined using the UnboundedGeometry and LimitedBy concepts.

In Figure 19, the transverse bulkhead (target geometry) is represented by a YZ plan (the unbounded geometry) at an X position in the ship coordinate system. The boundaries (limits) of the bulkhead are given by the hull shape (usually a NURBS surface) and a free edge assuming here that the hull shape only represents the port side of the vessel. These limits will define a closed-loop curve in the transverse bulkhead geometry plane representing a valid LimitedBy definition yielding the final shape of the transverse bulkhead.

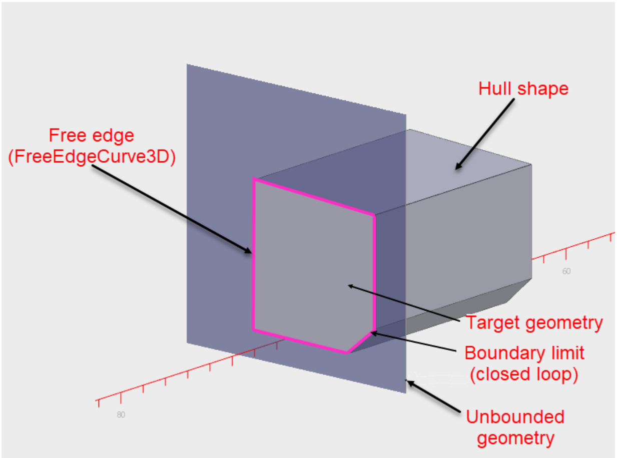


Figure 19. A Transverse bulkhead limited by the hull shape and a free edge

4.16 TOPOLOGY GRAPHS

It is straightforward to create an undirected graph of the OCX 3D model by representing Panel and LimitedBy objects as vertexes. All edges are given by the connection between the Panel node and the LimitedBy nodes. (Wikipedia, 2022). The graph is undirected as both the Panel and the objects in the LimitedBy have a relation to each other.

A simple box model first published by the Open HCM web pages(OpenHCM, 2018) is used for illustrating the concept, see Figure 20.

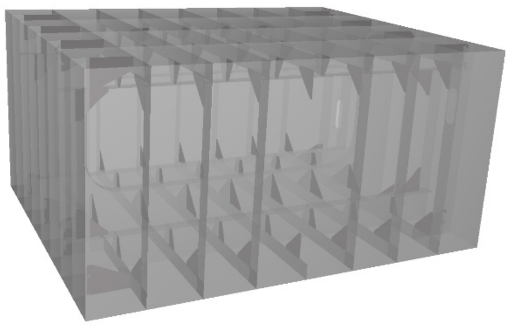


Figure 20. The Open HCM box model. Made transparent for this illustration. (OpenHCM, 2018)

The box model has been modelled in the three software systems, NAPA, Aveva E3D, Hexagon S3D and Siemens NX. The resulting model graphs are depicted in Figure 21 and the individual graph particulars are listed in Table 5.

It is noted that the NAPA model contains 6 isolates, i.e., panels without any limits. This is not correct according to the OCX schema as every Panel shall have limits given by LimitedBy.

Table 5: Box model graph particulars

Graph	NAPA	Hexagon	Siemens
Nodes	21	15	35
Edges	32	28	28
Isolates	6	0	0
Av. degree	3.05	3.73	1.6

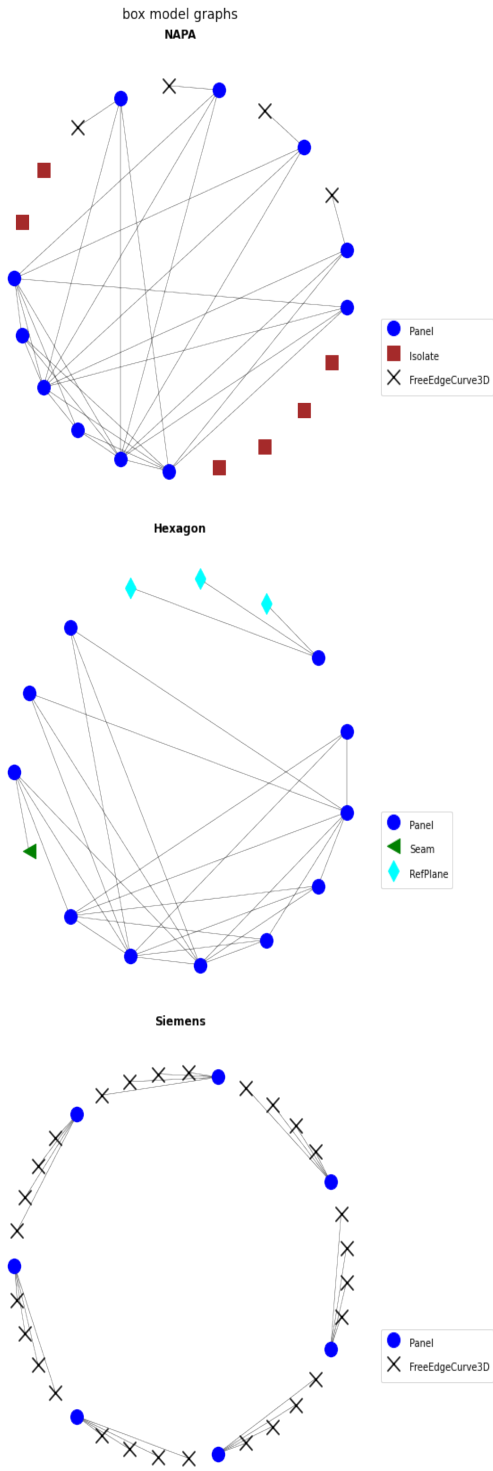


Figure 21. Model graphs of the HCM Box model from three different vendor exports

One can also observe from Figure 21 that the Hexagon graph forms two unconnected graph clusters. This behaviour is allowed and can be expected. In this case, there is one box side (a Panel) which is limited by three reference planes (grid planes) that are not referred to by any of the other nodes.

Further, one can observe that Siemens represents their topology by limiting each panel by FreeEdgeCurve3D curves. This is not a recommended representation of the topology according to the OCX implementation guidelines (O. C. Astrup, 2019) as the FreeEdgeCurve3D is intended to represent an actual free edge of the panel. In the case of the box model, it is obvious that all panels cannot have free edges.

Although the vendor system represents the model topology differently, the OCX exports all yield the same results when displayed in the neutral web viewer Sesam Insight (Astrup, 2022), see Figure 22.

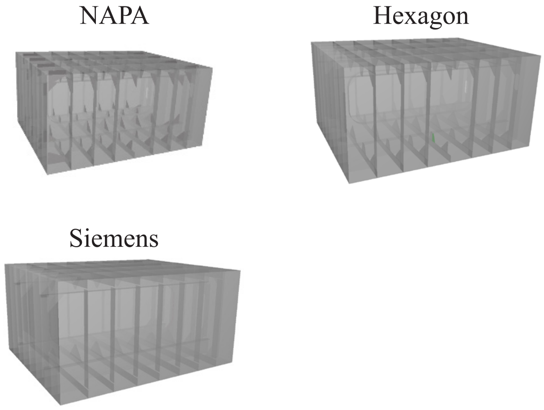


Figure 22. Visual representations of the Open HCM box models by NAPA, Hexagon and Siemens.

The graph degrees are shown as histogram plots in Figure 23. Here, the number of nodes is displayed on the Y-axis while the X-axis depicts the degree (the number of edges for a particular node).

As one can see, the Siemens model has 7 nodes with degree 4 (these are the panels) and 28 nodes with degree 1 (the free edge curves). The histogram of the NAPA graph shows that 6 nodes have degree 0. These are isolates identifying a schema error.

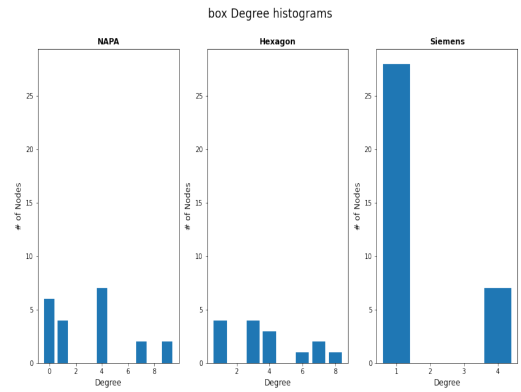


Figure 23. Degree histograms of the Open HCM box model

The Open HCM Use case (OpenHCM, 2018) has been extensively used as a test model during the development of the OCX schema. The model contains typical shipbuilding details, and it is relatively complex, see Figures 8 and 24.

The graphs have been created for the OCX exports from S3D, NX, NAPA and Aveva. The graph plots are shown in Figure 25.

The graph structure is more clustered with a few objects with many degrees. These are typically the outer shell and deck panels with many connected parts. It can be noted that the Siemens model has 4 isolates which are not allowed according to the schema. In the graph of the AVEVA model, we see 7 SurfaceCollection nodes. The

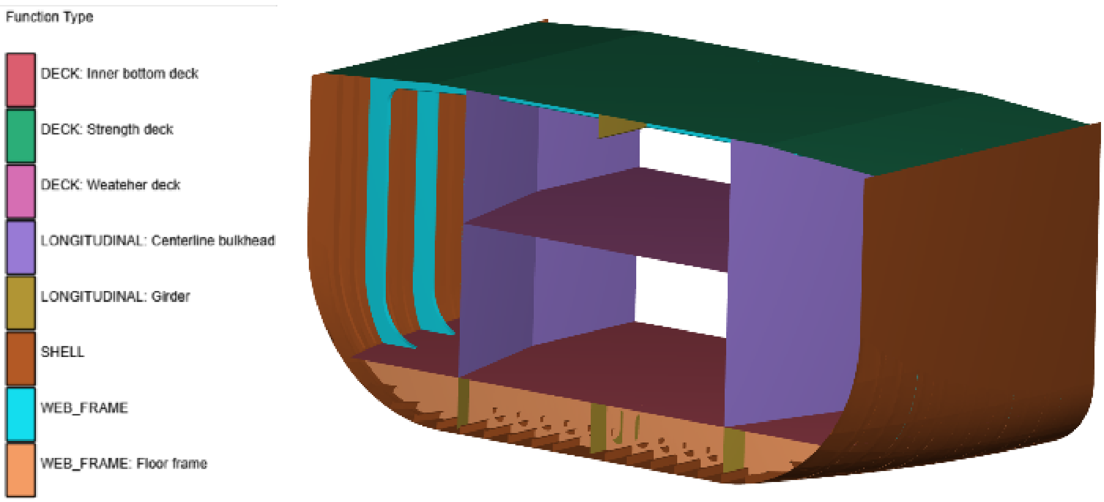


Figure 24. Hexagon S3D visual representation of the HCM mid-ship model in Sesam Insight

OCX schema allows exporting geometry as a collection of surface patches that can be used as one entity for limits. Typically, the outer shell parts will be exported as surface collections.

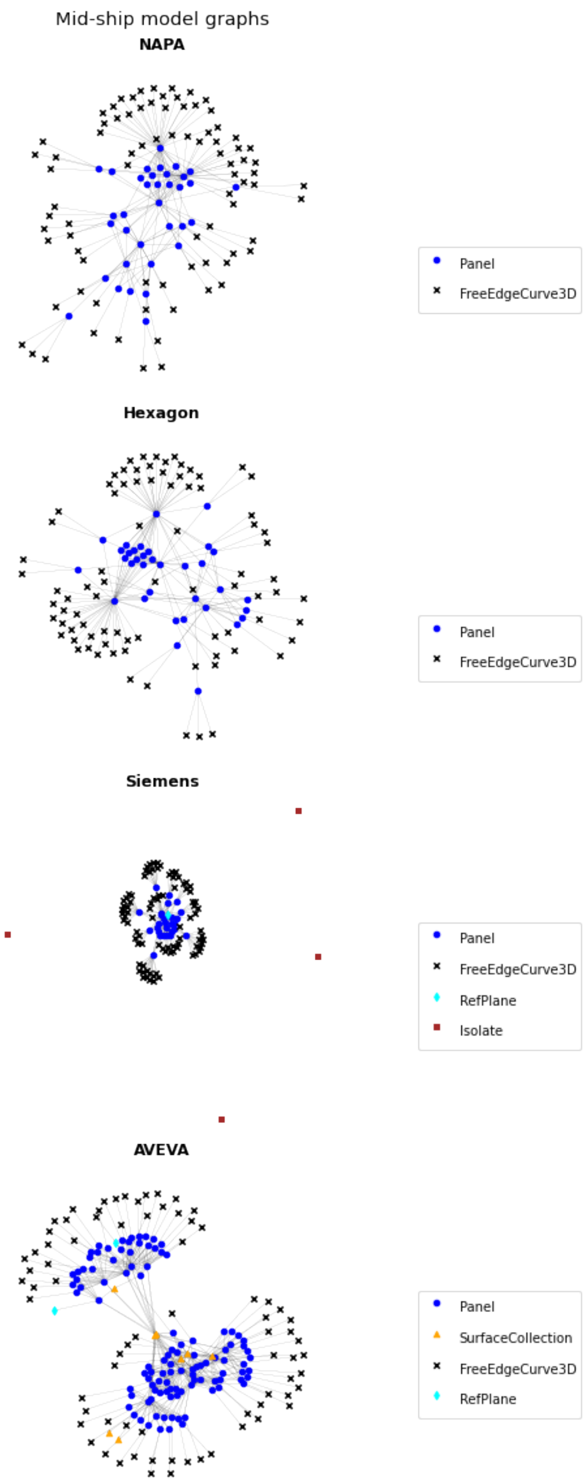


Figure 25. Model topology graphs of the Open HCM mid-ship model from 4 different vendor exports

Figure 26 shows the visual representations of the 4 CAD models after importing the 3Docx models to Sesam Insight. Here, one can see that the Siemens model is not complete. This is due to the isolates detected by the graph analysis. The isolates are two shell panels and two deck panels (port and starboard sides). The missing panels are due to the invalid schema.

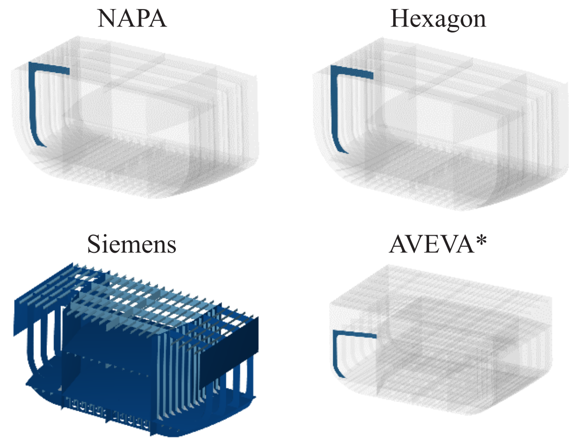


Figure 26. Visual representations of the Open HCM box models by NAPA, Hexagon and Siemens (made transparent for visual presentation). The AVEVA model differs from the other models by having an extra deck

The model graphs and a graph analysis can be used as a tool for validating OCX models in addition to the normal syntax schema validations.

4.17 A SHIPBUILDING TAXONOMY

One of the unique features of the OCX neutral schema is a standardised taxonomy for the naming of the loadbearing structure parts used in shipbuilding. A structural component can be assigned a functional property. The functional property will enable the Classification Society to link the structure part to regulatory and other relevant requirements. It is a pre-requisite to assign functional properties for automated verification according to the Classification Society's Rules.

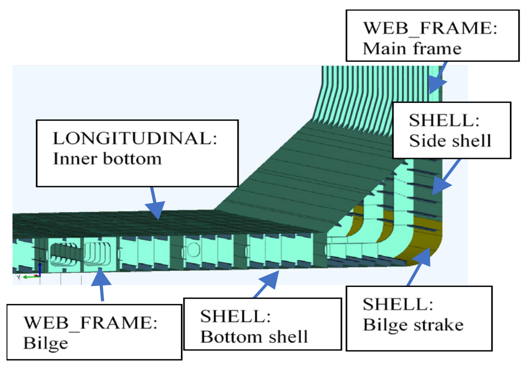


Figure 27. Examples of function properties for different parts of a ship

The function-property is an enumerator defining the structure's function. The structure-function shall be assigned to the parent structure concept by the authoring application. The OCX schema defines more than 90 types organised in 15 main categories as LONGITUDINAL, SHELL, WEB_FRAME etc. The naming convention follows the STEP AP218 (ISO-AP218, 2004) coding and the IACS Rec 82 Glossary (IACS, 2003). Figure 27 shows some examples of how shipbuilding parts are assigned function properties.

It is the responsibility of the designer to assign the correct function properties during the design. The properties will be validated by the classification society. This may be carried out using the visual representation of the OCX model and can be displayed n a neutral web viewer, see Figure 24 for an example.

5. USE CASES: MODEL EXPORTS

The presented OCX schema definitions have all been implemented in Aveva, Hexagon Smart® 3D (S3D), Siemens NX and NAPA Steel. The following section is a brief presentation on some of the models used to demonstrate OCX capabilities.

5.1 HEXAGON S3D MODELS

A Cruise Ship model developed by Chantiers de l'Atlantique (CdA) is shown in Figure 28.

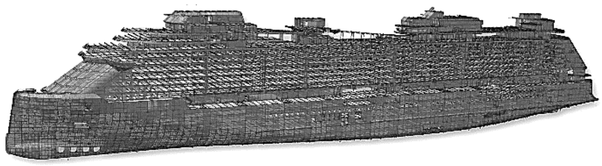


Figure 28. S3D model of the cruise ship designed by CdA

For Cruise ship projects, the approval by the classification society will proceed on a block basis and regions of the model will mature at different points in time. For that reason, the OCX Schema has been designed to support incremental exchanges of subsets of the full model where applicable. For example, we have the image and metrics for Block 107, see Figure 29.

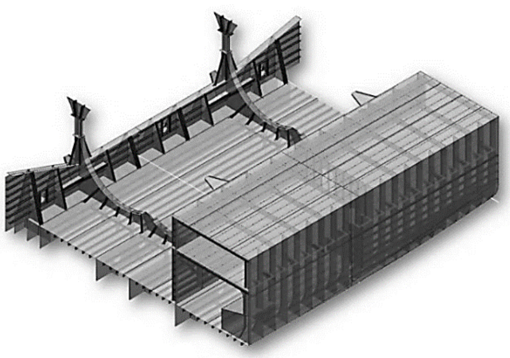


Figure 29. S3D model of Block 107 of the CdA design

The exported model of block 107 contains a total of 715 objects: 285 plates and 426 stiffeners. The OCX size metrics of the block export are reported in Table 6.

5.2 AVEVA MODELS

Aveva has provided two use cases: a midship model for the initial design phase shown in Figure 30 and a larger model of a design by Kongsberg Maritime shown in Figure 31.

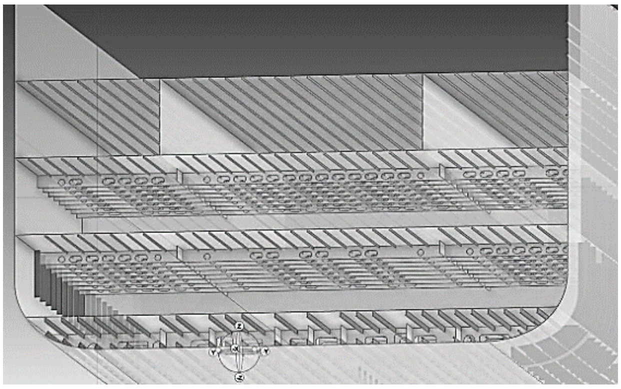


Figure 30. Aveva mid-ship model

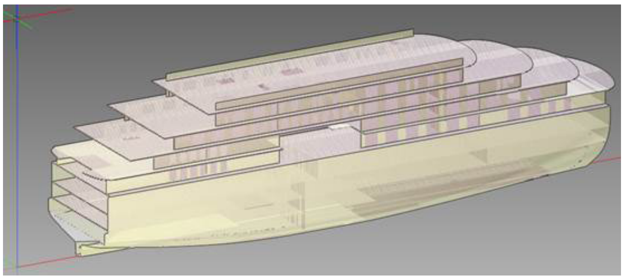


Figure 31. AVEVA representation of the KM design

5.3 SIEMENS NX MODEL

The use case by Siemens NX represents a partial model of a design by Ulstein Design and Solutions shown in Figure 32.

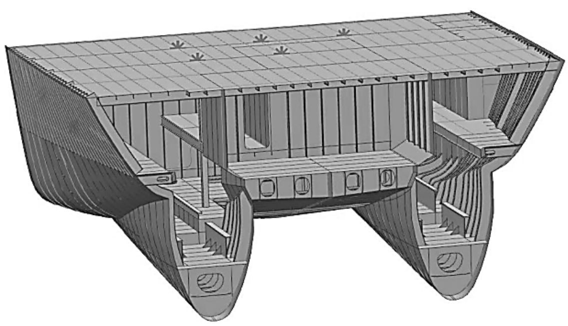


Figure 32. Siemens NX representation of the Ulstein design

The exported OCX model contains a total of 2017 panels composed of 314 plates and 487 stiffeners. The OCX size metrics of the block export are reported in Table 6.

5.4 NAPA MODEL

Both the compartment model and NAPA Steel model can be exported to the OCX file. The OCX interface supports models created by both Classic NAPA and NAPA Designer. The NAPA model here represents a demo VLCC model as shown in Figure 33.

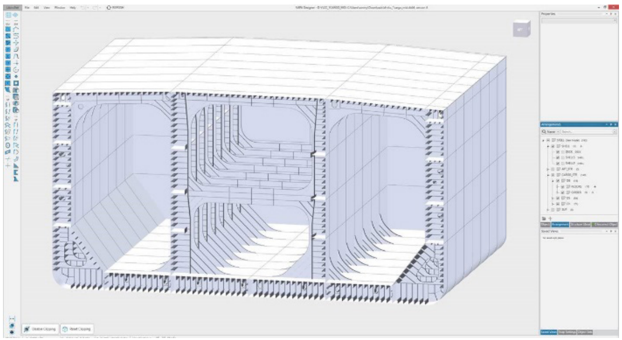


Figure 33. NAPA VLCC model

5.5 SUMMARY OF OCX MODEL EXPORTS

Hexagon's experience mapping and exporting S3D models to the OCX Schema was very favourable. This was partly due to involvement in the OCX schema definition and partly due to our experience in providing an earlier "neutral XML" interface to support both FEM and class rule checks (Polini, 2011). Since the OCX schema is an idealization, it is necessary to extract various aspects of the design model (e.g. the moulded surfaces, trim curves, etc.) and map them to the appropriate OCX object. Since the OCX schema was developed with generic, repeated patterns, the effort to implement was reduced because the mapping could be reused. Exporting a "panel's" LimitedBy was similar to exporting a "plate's" LimitedBy. The same logic and algorithms could be used to export OuterContours and FreeEdgeCurves. In most cases, all the objects, properties, geometries, and parameters needed by the class (as expressed in the OCX Schema) were present and accessible from the S3D model and capable of being exported using S3D's .Net Application Programming Interface (API).

Aveva's experience working with the development of the OCX has been positive as it has been a combined effort by both designers and vendors as well as the classification society. Moreover, the OCX format structure is in line with previous experience with the native XML output of Aveva Marine software. It is important to underline that the format is not about creating another geometry format but representing the topological relationship between components including necessary information elements and semantics giving the design documentation and allowing the classification society to perform its verification activities. Such topological information is already presented in the Aveva Marine core product and is easily supplied with uppermost quality directly from the native data product model along with the required geometry information. As demonstrated by the selected use case, KM successfully exports a substantial part of their basic design of a ship, see Table 6 for the metrics of the OCX exports.

Table 6: OCX uncompressed and compressed model sizes in MB

	S3D		AVEVA		NX	NAPA
	HCM	CdA Block	Mid-ship	KM design	Ulstein design	VLCC
Uncompr.	3.6	10.8	9.2	27.6	35.0	66.2
Compr.	0.2	0.1	0.7	2.5	0.8	2.4

Siemens has experienced that the OCX standard being developed as part of the Approved project has generated significant interest in Siemens' customer base in the Marine Industry. As 3D CAD tools become more sophisticated and their use increases in the marine industry there is a growing desire to move away from 2D drawings toward 3D models as the medium for exchanging information.

The OCX standard is a key enabler for a move to a model-based classification approval process. While the OCX standard is still evolving, and the implementation of an OCX translator is still under development in Siemens' NX we are seeing a growing interest in this standardisation effort as it becomes more widely known in the marine industry. Many of Siemens' customers have expressed an interest in being able to output their data in this format.

NAPA experience: The OCX schema is a comprehensive, yet straightforward representation of the vessel. NAPA was able to fetch the geometric representation of the compartments and structures from its internal NAPA Object Model (NOM) and produce the OCX file in a relatively short time. A fairly complex model with around 100 compartments and 1800 panels takes just a few minutes to export from NAPA Designer. The file size of such an OCX model (with compartments, panels, general brackets, plates, stiffener and openings data) is around 130 MB. The compressed size is 7 MB, see Table 6.

6. INTEROPERABILITY BETWEEN THE SOFTWARE SYSTEMS

6.1 VERIFICATION OF PARTS

The OCX schema requests the authoring application to output the dry weights and COG for each physical part (Plate, Stiffener, Pillar, Bracket). A rude check on the completeness of the re-created model is to compare the dry weights of the re-created model with the part dry weights coming from the authoring application.

The NAPA VLCC model has been used to verify the interoperability between the authoring software system and the recipient class software Nauticus Hull. The model consists of 143 panels, 522 plates and 4102 stiffeners, see Figure 31.

When Nauticus Hull reads the 3Docx file, Nauticus Hull builds up its 3D representation of the model geometry using the topology and surface information included in the OCX model, see Figure 34.

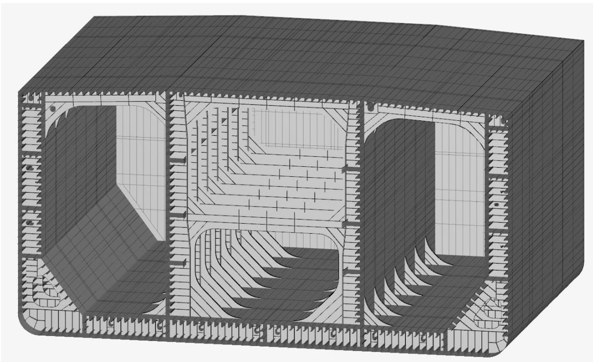


Figure 34. Nauticus Hull VLCC model re-created from the 3Docx

To verify that the model geometry has been recreated correctly, we compare the dry weight (in kg) of the parts created by Nauticus Hull with the dry weight of the parts from the authoring system. Table 7 compares the total dry weight of stiffeners and plate parts between the two software systems. We see that the difference in the total dry weight between the two systems is less than 0.6%.

Table 7: Total dry weights of parts in the authoring and the receiving systems

type	DW_{origin}	DW_{new}	Ratio
plate	4085.70686	4086.25778	0.999865
stiffener	1938.76352	1971.60358	0.983343
Total	6024.47038	6057.86136	0.994488

Table 8 summarizes the statistics for the ratio *r* between the dry weights between the authoring system (origin) and the re-created part weights in Nauticus (new):

$$r = DW_{origin}/DW_{new}$$

Table 8: Statistics of the dry weight ratio between original and re-created parts

type	count	mean	std	min	max
plate	523	1.0000	0.0002	0.9983	1.0001
stiffener	4103	0.9944	0.0128	0.9636	1.0003

As one can see, the 523 plates are re-created to almost perfection with a standard deviation of only 0.02%. The stiffener dry weight ratio varies slightly more and has a standard deviation of 1.2%. The source of this error can be explained by Figure 12 as Nauticus Hull does not subtract the stiffener end contours when computing the stiffener dry weight. We can therefore conclude that it is possible to achieve full interoperability between systems using the OCX exchange format.

The OCX format also carries the centre-of-gravity (*COG*) for all parts. The *COG* can be used to add additional QA to the import by comparing these values between the authoring and receiving applications. This has not been done in this study.

6.2 VERIFICATION OF KEY STRENGTH PARAMETERS

The main purpose of importing the OCX model to a classification calculation tool is to verify the structural integrity of the vessel and its compliance with the classification society's strength rules. The longitudinal strength of the vessel is one of the key verifications for all major vessel types above a certain length. The key parameters for the cross-section strength are the cross-sectional area and moment of inertia. Table 9 compare these key strength parameters between the authoring application (NAPA) and the classification calculation tool Nauticus Hull.

Table 9: VLCC cross-section properties at frame position 169.8 m

Property	NAPA	Nauticus	Unit	Ratio
A	10.765	10.934	m^2	0.985
COG_x	169.800	169.800	m	1
COG_y	0	0	m	1
COG_z	14.425	14.295	m	1
I_y	1500.160	1528.560	m^4	0.981
I_z	4461.000	4511.000	m^4	0.989

The numbers depicted in table 10 show a 1.5% difference in the cross-section area while the horizontal moment of inertia has a 1.9% difference, and the vertical moment of inertia differs by 1.1%. This shows that the key strength parameters differ less than 2% between the authoring and receiving systems. This confirms that the OCX representation fulfils the objective of transferring the design intent to fulfil the main strength requirements.

7. CONCLUSIONS

The authors have presented an extensive schema of a vessel-specific information model: Open Class 3D exchange (OCX). The successful and seamless exchange of the design models exported from 4 independent 3D CAD systems to the classification society's rule calculation tool has been demonstrated. The application of the OCX models for the prescriptive rule calculations demonstrates that the

OCX model can carry all the information required by the classification society's Rules for this purpose. The possibility to also display all the detailed features of the design model provides the necessary capability for visual verification of the design models. The demonstrations provide the proof of concept of the project's vision of a full and seamless digital model exchange between the yard/designer and the classification society ultimately replacing 2D drawings as design documentation. With the successful implementation of the OCX schema by four major CAD vendors and one major classification society, the schema is a strong candidate for wider adoption by the industry and can potentially become an industry standard for the exchange of design information between designer/yards and the classification societies filling a long-missing gap for this industry.

8. FUTURE WORK

The authors envisage that the concept may be expanded to other disciplines which have to be integrated with the hull structure, typically including piping, electrical and other safety-critical functions such as fire and emergency planning. In addition, there are still gaps to be closed for the hull discipline for direct strength calculations by the Finite Element (FE) method.

An important challenge the maritime shipbuilding will have to address is how the OCX format may change the current paper-based newbuilding approval process. If the standard is widely adopted this must lead to changes in the classification societies' verification process to reap the benefits offered by the OCX standard.

9. ACKNOWLEDGEMENTS

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10. REFERENCES

1. 3DOCX.ORG. (2021a) 27 Companies Have Joined the OCX Consortium. Available at: https://3docx.org/news (Accessed: 9 March 2022).
2. 3DOCX.ORG. (2021b) OCX Consortium. Available at: https://3docx.org/ (Accessed: 1 February 2022).
3. 3DOCX.ORG. (2021c) Why Is the OCX Standard Unique?. Available at: https://3docx.org/what-distinguishes-the-ocx-standard-from-other-shipbuilding-standars (Accessed: 10 February 2022).
4. AIA. (2013) *Aerospace Industry Guidelines for Implementing Interoperability Standards for Engineering Data*. Arlington, VA. Aerospace Industries Association.
5. ASME/Y14.41. (2019) *Digital Product Definition Data Practices*. New York, NY. ASME International.
6. ASTRUP, O.C. (2017) *A Model Based Definition for Shipbuilding*. DNV 2017-0413, Oslo Norway.
7. ASTRUP, O.C. (2019) *Model-Based Approval - The Open Class 3D Exchange (OCX) Standard*. 19th International Conference on Computer Applications in Shipbuilding, Rotterdam, The Netherlands.
8. ASTRUP, O.C. & CABOS, C. (2017) *A Model Based Approval Process for Basic Hull Design*. 18th International Conference on Computer Applications in Shipbuilding, Singapore.
9. ASTRUP, O.C. (2022) Paving the Way for 3D Model-Based Class Approval - DNV. Maritime Impact. Available at: https://www.dnv.com/expert-story/maritime-impact/Paving-the-way-for-3D-model-based-class-approval.html (Accessed: 11 March 2022).
10. ASTRUP, O.C. (2019) *OCX- The Open Class 3D Exchange Standard. A Digital Specification of the Hull Structure for the Classification of Ships*. DNV 2019-1093, Oslo, Norway.
11. BRONSART, R., WIEGAND, G. & KOCH, T. (2005) *A Collaborative Platform for Ship Design*. 12th International Conference on Computer Applications in Shipbuilding, Busan, South Korea.
12. CELEBI, I. *et al.* (2010) *'Improving Interoperability by Incorporating UnitsML Into Markup Languages'*. Journal of Research of the National Institute of Standards and Technology, 115, pp. 15–22.
13. DNV. (2021) '*Rules For Classification Ships Part 3*'. In Rules For Classification Ships. DNV, Oslo, Norway.
14. HABIBIC, A. (2022) BV, NAPA to Facilitate Use of 3D Model in Class Approval Process - Offshore Energy. Offshore Energy. Available at: https://www.offshore-energy.biz/bv-napa-to-facilitate-3d-model-use-in-class-approval-process/ (Accessed: 11 March 2022).
15. HALFHIDE, R. (2019) APPROVED Redraws Requirements for Class Verification. The Naval Architect, Available at: https://www.rina.org.uk/APPROVED_redraws_requirements_for_class_verification.html (Accessed: 16 January 2022).
16. IACS. (2011) *Classification Societies - Their Key Role*. Available at: https://www.iacs.org.uk/media/3784/iacs-class-key-role.pdf (Accessed: 19 January 2022).
17. IACS. (2003) *Rec 82 Surveyor's Glossary - Hull Terms and Hull Survey Terms - July 2003*.
18. ISO-AP215. (2004) *ISO 10303—Part 215: Application Protocol: Ship Arrangement*. Geneva, Switzerland, International Organization for Standardization.

19. ISO-AP216. (2003) *ISO 10303— Part 216: Application Protocol: Ship Moulded Forms*. Geneva, Switzerland, International Organization for Standardization.
20. ISO-AP218. (2004) *ISO 10303— Part 218: Application Protocol: Ship Structures*. Geneva, Switzerland, International Organization for Standardization.
21. ISO. (2015) *ISO 16792:2015 Technical Product Documentation*. Geneva, Switzerland, International Organization for Standardization.
22. MBE. (2021) Model-Based Definition. Available at: https://en.wikipedia.org/wiki/Model-based_definition (Accessed: 15 January 2022).
23. OASIS. (2011) *UnitsML Guidelines Version 1.0*.
24. OPENHCM. (2018) OpenHCM Standard Description. Open Hull Condition Monitoring. Available at: https://openhcmstandard.github.io/. (Accessed: 10 January 2022)
25. POLINI, M.A. (2011) *A Neutral XML Schema for Basic Design Stage Interface to Class Societies*. 15th International Conference on Computer Applications in Shipbuilding. Trieste, Italy. DOI: 10.3940/rina.iccas.2011.32.
26. QUINTANA, V. *et al.* (2010) *Will Model-Based Definition Replace Engineering Drawings throughout the Product Lifecycle? A Global Perspective from Aerospace Industry.* Computers in Industry, 61(5), pp. 497–508. DOI: 10.1016/j.compind.2010.01.005.
27. RACHURI, S. *et al.* (2008) *Information Sharing and Exchange in the Context of Product Lifecycle Management : Role of Standards*. Computer-Aided Design, 40, pp. 789–800. DOI: 10.1016/j.cad.2007.06.012.
28. SCHJØLBERG, I. *et al.* (2016) *MARITIM21-Muliggjørende Teknologier*. Lysaker, Norway. Norges Forskningsråd.
29. SEPPÄLÄ, L. (2022) *White Paper - The Digital Fabric of Data-Driven Shipbuilding – 3D CAD Data Exchange in Shipbuilding Projects*. Available at: https://software.cadmatic.com/l/892011/2022-04-11/bdjhp?utm_source=Maritime+Executive&utm_medium=newsletter&utm_campaign=Marine+|+White+Paper+Legacy+Data+March+2022
30. W3C. *XML Technology - W3C*. Available at: https://www.w3.org/standards/xml/ (Accessed: 18 January 2022).
31. WIKIPEDIA. (2022) Graph (Abstract Data Type). Available at: https://en.wikipedia.org/wiki/Graph_(abstract_data_type) (Accessed: 17 February 2022).