An Effective Approach to 2D Drawings in a 3D World

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Abstract

Despite the existence of 3D shipbuilding software that allows 2D approval and workshop drawings to be generated automatically, many of these drawings are created or modified in AutoCAD because of its superior drafting capabilities and a more familiar user environment. Unfortunately drawings created in AutoCAD are then disconnected from the processes and capabilities in the 3D shipbuilding software. This paper will discuss an approach taken by ShipConstructor Software Inc. (SSI) allowing standard 2D AutoCAD drawings to be automatically generated from the 3D model according to specific class rules and shipyard standards while remaining linked to the 3D model as changes occur.

1. Introduction

Design and construction of a ship is too often composed of a larger number of disjointed and disconnected processes with far too little re-use of information or design intent being captured and moved to the next stage. One of the most significant examples of this is the gulf between basic and detailed design. While it is certainly true that almost every commercially available shipbuilding software package has the ability to import the surface model representing the initial design as well as other geometry, much of the design intent that is painstakingly represented in 2D approval drawings created for classification purposes must be manually re-captured in the detailed design.

In the most traditional approach, initial design software is used to create the surface model of the hull which is utilized, among other things, to perform a range of hydrostatic and hydrodynamic analysis. Towards the end of that process, 2D approval drawings are being created for inclusion in the package of drawings sent to the appropriate classification society. One of the most typical examples of approval drawings are those that detail the layout of typical planar sections (frames, decks, and longitudinals). In many scenarios today, these drawings are still created manually using conventional drafting tools.

1.1 Requirement for 2D Approval Drawings

Virtually all areas of the ship design and construction process have moved to 3D. The ability to design, visualise, analyse, simulate and check the design in 3D has led to many improvements in the industry, a few of which are:

- Significant reductions in the number of errors that would previously have only been caught in production
- Fewer in-service issues due to extensive simulation and materials analysis
- More innovative designs
- Shorter overall process due to "concurrent engineering" in 3D

Despite this shift to 3D in many areas, 2D drawings for class approval still play a critical role.

1.1.1 Wealth of Information

2D drawings, as they are used for class approval, contain a wealth of information that would be very difficult to convey on a similar number of 3D drawings. A properly executed set of 2D class approval drawings provide a decent 3D picture of the vessel being designed. In part, this is accomplished through the use of an incredible amount of symbolic detail that is laboriously added to a drawing. This ranges from specific line styles (thickness, continuity, color, etc.) used to communicate additional details, like the side of the plate to which a stiffener is attached, to specific symbol standards used to represent various items such as flanges, profiles, types of welds etc…

Due to the depth of information that is included in these drawings in this fashion they are perhaps one of the most difficult drawings to create and read. Accurately detailing and interpreting 2D approval drawings in the marine industry continues to require extensive specialized knowledge and skill.

Some may argue, perhaps correctly, that similar information can be easily communicated via live, intelligent 3D models of the ship. While this may be true, it would require a degree of standardization and interoperability between each of the multitude of 3D CAD systems in use in the industry that simply does not exist today. Classification societies simply can't be expected to maintain a library of 3D software applications and the trained people to use them. 2D drawings can be sent in industry standard CAD formats like DWG, or simply in PDF, without the requirement for any application specific intelligence or conversion. While class societies will, in some cases, create a 3D model of a portion of a ship to further analyze a particular scenario, 2D drawings remain the deliverable of choice. There are many reasons for this, not the least of which is the repeatable, 'checkable' nature of a 2D drawing for someone with the appropriate training.

1.2 Transition to 3D Detailed Design

Once the classification society has approved the structural drawings, the detailed design process can begin in earnest. In the more traditional approach, the 2D drawings along with scantlings, a lines plan and other resources, are referenced to manually build a detailed 3D model of the ship's structure. The majority of this work is performed by an experienced designer or draftsman who interprets the design intent of the 2D drawings and translates them into a 3D model.

There are a few apparent shortcomings with this type of approach. As mentioned earlier, reading these drawings requires a significant degree of experience and training. Even in cases where these skills exist in abundance, errors creep in due to the manual nature of the process. Additionally, as creation of the 3D model starts only after the design has been approved, future stages that depend on the structural model are restricted in terms of when they can begin. The absence of a detailed 3D model can also result in the late discovery of issues that can only be properly visualized in 3D. This is especially critical when remedying these issues will have an impact on the basic design.

Unfortunately almost every downstream process relies on at least having a partially complete structural model. Concurrent engineering capabilities are prevalent in today's software tools but they still require the structural model to be partially complete before outfitting can really begin. The earlier the structural 3D detailed design commences, the earlier all other disciplines can start, and the earlier construction can begin. This can lead to shorter design and engineering processes which can have a direct impact on milestone and project delivery.

It should be noted that to get a lead on project schedules and to compete in an increasingly competitive landscape, the choice to begin modelling before the classification society approves the drawings is being made more and more often. As the 2D drawings are being detailed and then submitted to classification societies, work in the 3D model continues because shipyards cannot afford to wait. While software is getting better at allowing significant changes to be made to existing designs, there can still be a significant cost to this approach. The risk of beginning the model earlier is also greater as the changes that come back must be interpreted and made in the same way in both the 2D and 3D environments. The risk is further compounded since these changes are often made by different individuals.

2. An Integrated Workflow

The result of the challenges with traditional approaches mentioned earlier, and new capabilities in many of the shipbuilding specific software packages in use, has led to the creation of software based approaches that in theory allow these drawbacks to be overcome.

The common threads in implementations of this newer approach are: the creation of a basic 3D model that will evolve within the same toolset to be used for the detailed design, and capabilities that allow 2D approval drawings to be automatically generated from the 3D model based on a knowledge base of predefined standards. In the most robust implementations, the generated drawings remain associatively linked to the 3D model and can therefore be updated as changes happen.

It is clear that this approach can have many advantages over the more traditional approaches:

- Issues that can only easily be seen in 3D are caught, sometimes even before the 2D drawings are generated.
- By the time the drawings are approved by the classification society, a large amount of the effort required to create the structural model is complete.
- As most of the detailed design tools would be available for use on the basic design, more accurate material estimations can be performed, and a more accurate weight and center of gravity (CG) can be calculated (key contributors to a vessels performance).
- Definition of the knowledgebase of standards used to generate the approval drawings must be created by an experienced naval architect or designer, but the drawings themselves can now be generated by the average designer or draftsman.
- Changes returning from the class society can be made once, in the 3D model and updated to the drawings provided the drawings remain associated with the 3D model.
- Fewer errors are introduced as both the drawings, and detailed design are created based on a single source of truth: the basic 3D model.

2.1 Challenges with Current Implementations

Despite the obvious advantages of the more integrated approach, there are still a few key drawbacks that remain to be overcome. These drawbacks are related to both the tools used and the skills of the people who are tasked with using the tools.

Historically 2D approval drawings have been detailed in purpose built drafting tools such as AutoCAD and Microstation as they have unparalleled drafting capabilities. The shipbuilding specific tools used in this newer approach generate approval drawings fairly well but additional detailing is almost always required. Often the additional detailing is required to convey additional information that was not automatically included in the drawing and sometimes it can be required to clean up or fix the generated information. Regardless of the cause, the designer will end up relying on the drafting tools that have been provided with the shipbuilding software. Unfortunately, the 2D drafting capabilities in these shipbuilding tools can leave much to be desired compared to AutoCAD or other general purpose drafting tools.

Naval architects doing the basic design don't necessarily wish to use complex, production focused software to perform the final detailing of 2D approval drawings. Their current skill set better aligns with specific hull design tools to perform the initial design in conjunction with common 2D drafting tools to detail drawings. Working in familiar software with familiar tools has been shown to reduce errors that would occur in an unfamiliar or new environment. Additionally, with so many 3D CAD tools available in the shipbuilding industry, skills learned in this area with one tool may not be transferable to another organization or project. This limits the pool of employees that an organization can draw from, increasing cost, and therefore reducing competitiveness.

Finally, these approval drawings need to be sent to class societies in a neutral format which can be read and reviewed without the use of proprietary software that requires additional training and cost on the part of the class society.

As a result of these factors, 2D drawings often end up in a general purpose CAD solution or neutral format. While there are other neutral formats used, Autodesk DWG is common due to its ubiquitous nature and the ability of most applications to read and write this format. Regardless of the format used conversion from proprietary software can cause:

- A loss of intelligence, as much of the intelligence was provided by the proprietary software.
- Errors or data loss due to conversion issues.
- Disconnection from the 3D model when changes occur.

2.2 An Improved Integrated Workflow

As discussed, there are many benefits to this newer approach and only a few notable drawbacks. The drawbacks that exist are not insurmountable and could be overcome in a number of ways. A potential solution that mitigates the disadvantages of the way this approach is implemented today would be to create a system in which:

1. 2D Approval and Workshop drawings could be generated automatically from the 3D model in the AutoCAD DWG format with a substantial amount of shipbuilding-specific standards applied and with little to no user intervention required.
2. Further detailing to the 2D drawings could be performed using the AutoCAD program, with little to no additional skills required.
3. The 3D design model and drawings could be continuously associated so that any subsequent changes to the 3D model would be capable of being automatically reflected in the 2D drawings.

3. ShipConstructor MarineDrafting

MarineDrafting is currently being developed by SSI to specifically address these drawbacks.

SSI is the creator of the AutoCAD based ShipConstructor suite of products. ShipConstructor has an AutoCAD foundation utilizing AutoCAD's native format and many of AutoCAD's own menus and commands while also incorporating shipbuilding-specific tools corresponding to the various engineering disciplines such as Hull, Structure, HVAC, Piping etc. The 3D product model is stored inside a Marine Information Model (MIM), at the heart of which is a Microsoft SQL Server relational database.

Consideration of the problem at hand quickly led to the realization that ShipConstructor has key characteristics that could be leveraged towards an improved workflow that has clear advantages over alternative implementations. The two key advantages that ShipConstructor has in this area are the AutoCAD Platform as well as the Marine Information Modelling engine that drives the software.

3.1 AutoCAD Platform

AutoCAD would be an obvious platform of choice for any product that generates and manipulates 2D drawings. As the most commonly used 2D software with millions of users of AutoCAD worldwide, and with a recent focus on improved 3D capabilities, the skills required to use any AutoCAD-based product are everywhere. Additionally, the 2D drafting capabilities of the product are extensive and allow the software to handle almost any requirement in this area.

However, the shipbuilding industry has very specific requirements for its design tools, a penchant for everything 3D, and generally adopts industry specific software packages that use either proprietary or less universally adopted CAD engines. When considering the requirements for the industry and the specific requirements in this case for associativity between 2D approval drawings and the ship specific model, utilizing the capabilities of AutoCAD in this newer workflow may seem unlikely. In this case however, the AutoCAD platform provides the drafting toolset, user interface and graphics engine for much of ShipConstructor. As a result, these AutoCAD capabilities can be leveraged by MarineDrafting as part of SSI's implementation of this approach.

3.2 Marine Information Modelling

In a world of topological and geometric modelling tools, ShipConstructor takes a different approach. Although built on AutoCAD, the actual modelling engine developed by SSI overlays the foundational graphics and CAD engine provided by Autodesk. ShipConstructor's Marine Information Modelling engine is a hybrid providing many of the benefits of both a topological and associative geometric model without being either. The engine was developed from the ground up to allow for the efficient design of marine structures.

Individual parts are built based on boundaries defined by the intersections and location of individual lines, 3D planes and three dimensional points, *and* the association of this same geometry with both defined shipbuilding standards (endcuts, cutouts, bevels, corner treatments, weld seam reliefs etc…) as well as other parts either directly (mirror or identical relationships) or via relationships between sub geometry of the parts.

The result is a 3D model that is defined by relationships between the individual geometric elements as well as by the complex logical relationships that exist in a real ship. Stiffeners attached to either side of a plate as part of a panel, or the cutout caused by a shell stringer passing through a transverse plate are examples of this type of relationship. The ability to easily extract both types of information from the model, during the generating of drawings or while manually detailing afterwards, is of critical importance to this approach.

The ability to utilize built-in AutoCAD capabilities such as hidden line removal (HLR) and AutoCAD drafting standards, plus the ship specific information stored in the ShipConstructor model, ensures that the 2D drawings generated from MarineDrafting are of the highest fidelity and can be easily detailed to suit specific needs.

3.4 Creating MarineDrafting

3.4.1 Automatic 2D Drawing Generation

As mentioned earlier, ShipConstructor's Marine Information Model is a natural source for drawing generation as it already contains a large amount of information about each part and its associated relationships that is critical for approval drawings.

However, before the initial 2D drawing is created, extensive configuration options are provided and captured within the ShipConstructor Library. These standards are defined once and can be implemented across all drawings reducing both errors and the tedium of repetitive rework. Capturing this combination of drafting and shipbuilding standards, as well as the scenarios where they are intended to be used, is what allows expert knowledge to be captured and re-used by less experienced designers who can simply detail the drawings after they are generated.

3.4.1.1 Configuration and Standardization

The ShipConstructor MarineDrafting application provides a significant degree of configurability to shipbuilding customers by utilizing a range of AutoCAD's built-in features that are targeted at allowing drafting standards to be controlled and managed across any organization. Configurable AutoCAD templates have been setup in ShipConstructor's MarineDrafting application that can be used as standards for various items such as:

- Drawing settings
- Drawing measurements (imperial/metric)
- Views
- Layouts
- Layers
- Linestyles
- Textstyles
- Dimensionstyles
- Title blocks
- Snap rules
- Grid ortho settings
- Annotation styles

These settings can all be managed in a single drawing or across the entire organization using the native capabilities that provide millions of AutoCAD users around the world the same benefits in their work. In this case, ShipConstructor seamlessly works hand in hand with AutoCAD to ensure that the standards can also be controlled and configured in ways that are specific to the shipbuilding industry. As an example, ShipConstructor manages which linestyles are to be used in specific situations (a hidden stiffener on the far side of a plate for example) but allows AutoCAD to manage what that linestyle looks like when applied to a line in a specific drawing.

The MarineDrafting application also makes extensive usage of AutoCAD layers by automatically arranging common types of geometry that are extracted from the 3D product model onto their own layers. This allows users to control groups of information in the drawing with a broader brush. Again, just like with any AutoCAD drawing, these layers and other properties can be set in the template drawing used to create approval drawings by an experienced designer. Each drawing generated will be pre-populated and configured with these settings, requiring a minimal amount of effort to achieve a maximum amount of flexibility and control. Layers options include settings for:

- Color
- Thickness
- Continuity
- Visibility

However the degree of configuration available does not begin or end with AutoCAD capability. Within the ShipConstructor library many shipbuilding specific symbolic standards can be defined that will be used when 2D drawings are generated. These include configurable symbols used to mark plate seams, to mark whether parts are intercostal or continuous, to mark profile cross sections and more.

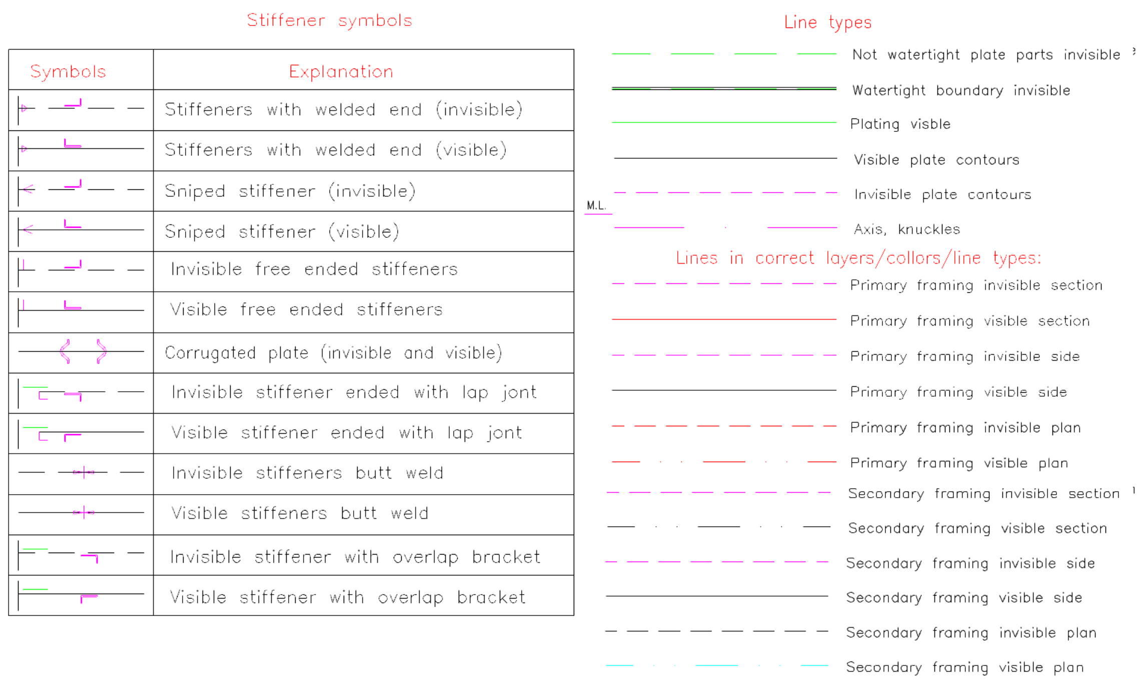

Fig.1: Example Standard Shipbuilding Symbols

3.4.1.2 Drawing Generation

What ShipConstructor does with its MarineDrafting application can first and foremost be thought of as flattening the 3D solids in its information-rich 3D model into two dimensions. However, during this flattening, the model is interpreted based on part types, details, materials, edge preparations and more. Required geometry is automatically converted, based on preset standards, from the ‘accurate’ 2D into the symbolic representation required to convey additional information. As mentioned in the previous section component geometry is placed onto separate layers, depending on the type, and purpose of each individual piece.

Hidden lines are automatically removed by ShipConstructor utilizing AutoCAD’s HLR (hidden line removal) capability which produces a decent baseline of geometry for MarineDrafting to proceed with.

Looking back at the prior section of this paper which discussed Marine Information Modeling we saw that ShipConstructor’s modeling engine contains both geometric relationships as well as the associative relationships between parts in the model and standards used to define those parts. Leveraging that same engine and the relationships already built into the model, specific portions of the 2D drawing are replaced or added during drawing generation. This is done by interrogating the product model for these relationships and applying the symbolic standards that are defined for use in each situation. The standard symbols used in these instances are associatively linked to the created geometry in the 2D drawing as well as to the portion of the 3D model they depict. When the 3D model changes or the symbols themselves change for any reason, the drawing can be automatically updated, eliminating duplicate effort and ensuring consistency across processes.

The result is 2D documentation containing the required symbolic information according to shipbuilding standards. For instance, a profile attached to a plate is not represented simply as the flattened 2D version of the 3D profile (i.e. a flatbar would simply be a rectangle if flattened) but instead as a line with the profile cross section positioned next to the line to denote the type of profile stock applied.

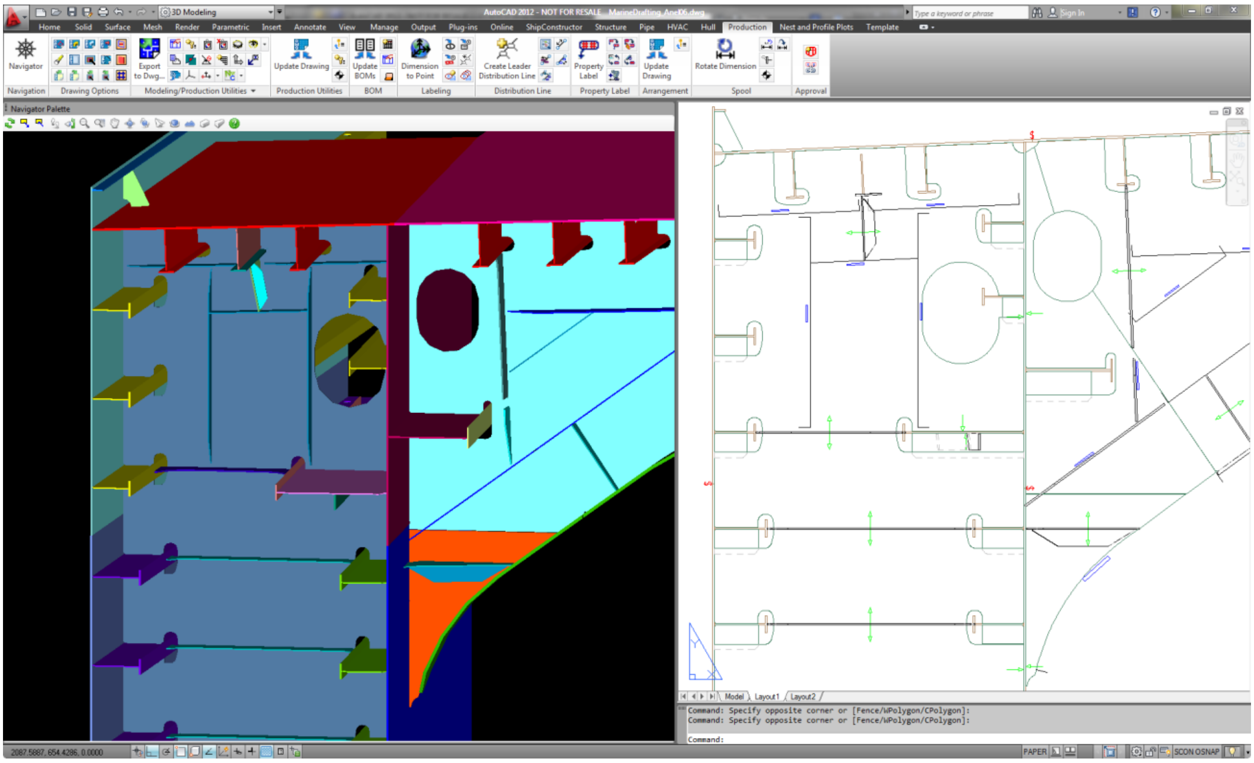

Fig.2: Profiles attached to plates as represented via ShipConstructor's MarineDrafting application

3.4.2 Drawing Detailing

Despite the extensive abilities to configure MarineDrafting in order to generate a drawing that is as close to what is required as possible, additional detailing is often required.

As stated earlier, the 2D drawings are natively created in the AutoCAD format. All AutoCAD features are supported and very little specific ShipConstructor knowledge or skill is required to detail the generated drawings. The objects in the generated 2D drawings are standard AutoCAD objects utilizing only AutoCAD geometry and standards. The result is a drawing that they can later be modified, added to, or removed using only AutoCAD knowledge and tools.

MarineDrafting includes several capabilities to ensure that detailing is performed correctly and that future changes are performed with as few errors as possible. First, due to the fact that all geometry is associatively linked back to the portion of the 3D model from which it is generated, information about the parts in the model including material, standards and part number can be viewed on the geometry. This information can be used in conjunction with AutoCAD labelling to add any required labels that were not included in the generated drawing by default. Like the rest of the drawing these properties, and any labels based on them, are associative and will update as the underlying model changes. Second, any additional geometry that is added to the drawing can be linked by the user to existing parts of the model. This ties any additional AutoCAD geometry added by the user into the associative engine upon which ShipConstructor relies during an update process and ensures that users will see this manually added geometry when going through the process of updating a drawing when changes have been made to the 3D model. Finally, tools exist that allow the user to quickly flip from the drawing to a specific part of the 3D model by simply selecting a piece of geometry in the drawing that is associated with a ShipConstructor part. Once back in the appropriate place in the 3D model, required changes can be made such as moving items, adding new attributes to objects, deleting objects or modifying parts directly. All of these changes to the model can propagate back to the linked drawings if/when required as will be explained in the following section. This facilitates rapid changes to both the model and drawings which can be critical very early in the design process.

3.4.3 Managing Change

Change happens. This is perhaps the most important principle to accept in the shipbuilding industry and is truer the earlier in the process you are. When it comes to class approval drawings, change is a constant and needs to be managed very carefully via both tools and process, especially when the drawings are generated from a 3D model from which those changes will propagate.

Within MarineDrafting, and all of ShipConstructor, a method for quickly identifying which drawings need updating is provided based on changes to library and drafting standards and the 3D model. This ensures that drawings are not sent to the classification society, or to production, purchasing or any other department, when they do not accurately reflect the product model.

Once the drawings to be updated have been identified, an intelligent mechanism for updating 2D documentation to match the latest 3D model representation exists. Updates to the drawings are initiated by a user and then performed automatically. This allows the user control over when updates occur. Once an update has been initiated changes are identified and illustrated both in a user interface that allows the content of a change to be analyzed, as well as visually in the model using different colors to denote additions, modifications, and deletions.

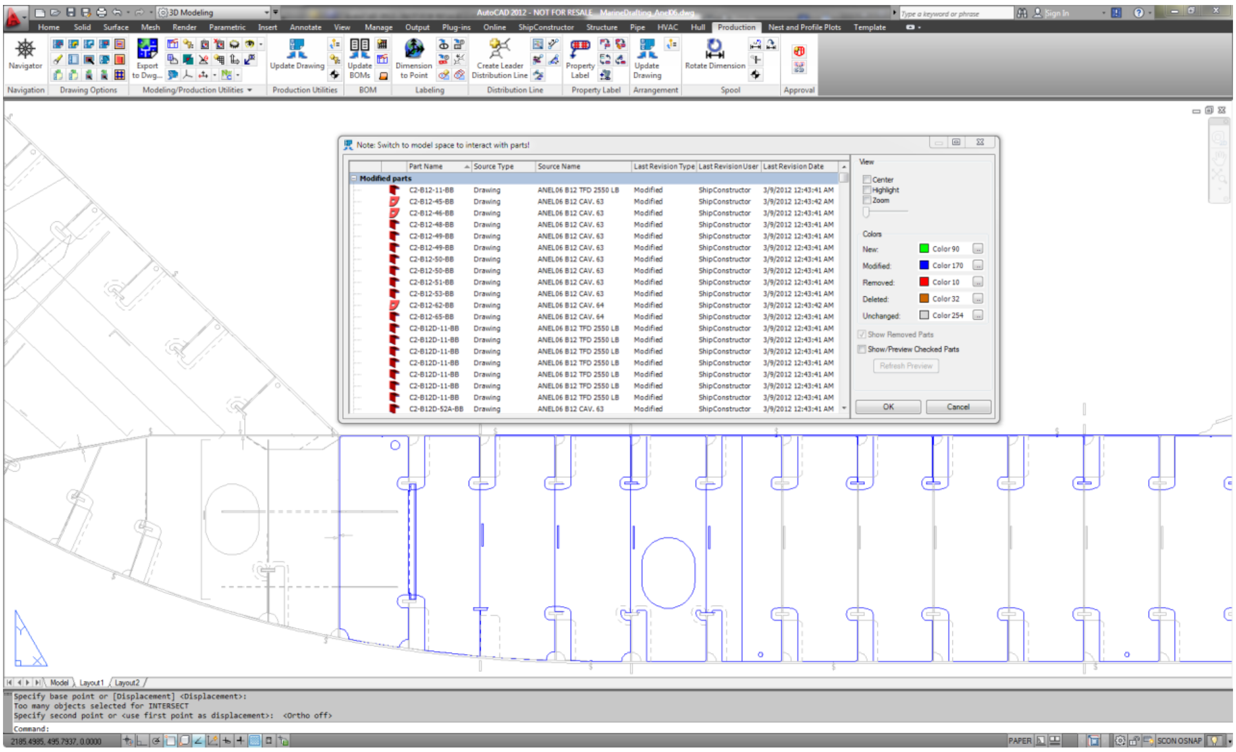

Fig.3: Change management within a MarineDrafting approval drawing

Within the 2D drawings themselves, individual changes are tracked. For example, as geometry that is not to be included in the drawing is deleted it is automatically moved to a different layer with visibility turned off. Modifications to existing geometry are similarly tracked. This ensures that when the drawing is updated ShipConstructor knows what to update, what to leave if it has been changed by the user, and what to add. These mechanisms allow the maximum amount of prior change and effort put into a drawing to be retained as changes are handled.

This degree of associativity is critical for approval drawings in this approach. Once the drawing package has been submitted to a classification society, work on the project does not cease. Invariably, class returns the drawings with comments and required revisions to the design. Many of these changes will be made in the 3D model, but additional changes will be required to the drawings themselves.

The change management and tracking features outlined combined with the associativity that provides the ability to quickly find the related part in the 3D model is critical, as comments from the class society are often directly on or related to the 2D drawings they receive.

4. The Technology Today

All of the features described in this paper so far have been incorporated into a working pre-release version of the ShipConstructor MarineDrafting product that is being used and analyzed by both shipyards and designers in the industry. SSI is engaged with the industry to determine how to improve the functionalities of this program going forward.

5. Conclusion

In an industry that has adopted 3D technologies in almost every aspect of the shipbuilding process, 2D approval and workshop drawings still play a critical role. These drawings convey shipbuilding specific information in a predictable, manageable way, provided the required skills, training and experience are in place. Traditional methods, where approval drawings are drawn entirely in 2D, are becoming less effective in the 3D world, and don't align well with basic and detailed design processes that are slowly becoming more integrated.

Newer approaches that use the same 3D model for basic and detail design, and allow 2D drawings to be generated automatically from that 3D model, are available but have a few shortcomings related to the drafting toolsets available and the skills (and desires) of those who traditionally create approval drawings.

SSI has identified and created a MarineDrafting, system that implements these newer approaches, and includes what the industry has learned from earlier attempts.