Integration between Shipbuilding CAD Systems and a Generic PLM Tool in Naval Projects

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Abstract: In recent years, naval shipyards have increased their demand for the integration of CAD (computer aided design) applications with PLM (product lifecycle management) systems. This demand is usually addressed with file-oriented CAD systems, consisting of controlling the CAD model and assembly files in the PLM system, where those specific model relationships are reproduced and managed. However, integrating database-controlled CAD systems with PLM ones pose an additional challenge, as there may exist some overlapping between the functionalities of both systems. In this paper, it is shown how naval shipyards are implementing PLM systems as a global solution to the management of information through the life cycle of naval vessels, with the objectives of increasing productivity, reducing vessel design and production times, saving costs and improving the quality of the whole process. As result of this paper, an advanced architecture for CAD-PLM integration in a naval shipbuilding environment is presented. The architecture of the solution contemplates a bi-directional flow of information between both systems, in such a way that the most relevant vessel items can be defined in CAD or in PLM depending on the design stage and on the maturity of the available information. Also, the paper describes in detail how the solution meets the demanding requirements of military shipyards for CAD-PLM integration, and the benefits and advantages of this approach, which is based in FORAN system as the CAD tool.

Keywords: PLM integration, shipbuilding software, ship design technology, computer aided design, CAD/CAM (computer aided design/computer-aided manufacturing).

1. Introduction

As a result of the increased pressure to reduce cost and delivery times of modern surface ships and submarines, many military shipyards are revising their processes and tools to manage and share information across all shipyard departments.

An important part of this process is in many cases the implementation of PLM systems or an extended use of the PLM systems to manage all the information that must be shared by the shipyard departments (engineering, purchasing, planning, operations, production, etc.).

On the other hand, a specific shipbuilding CAD is another critical application in a military shipyard, to improve the design quality, to reduce design and production costs (by improving vessel manufacturability, operation and maintenance) and in general to provide relevant information to most of the shipyard departments during the vessel design and production stages.

Therefore, the integration of the shipbuilding CAD with the PLM is a key factor in the implementation of the new processes and tools.

The solution presented in this paper for an advanced integration between the CAD and the PLM intends to comply with the most demanding requirements of the military shipyards as well as to maintain the efficiency, the scalability and the performance of the shipbuilding CAD tool.

This paper presents in detail the architecture of the solution as well as the expected advantages and benefits for the military shipyard.
2. Shipbuilding CAD Systems in Naval Environments

The use of specialized shipbuilding CAD systems in naval environments is crucial for the efficient design and manufacturing of surface ships and submarines.

The heart of a shipbuilding CAD system as FORAN is a relational database (ORACLE) where the vessel CAD product model is stored. The product model includes geometry, topology, specialized technological and manufacturing information for all vessel disciplines and many relationships between the vessel items [1].

Shipbuilding CAD systems working in naval environments offer significant advantages over other generic CAD applications, some of which can be relevant for the purpose of this paper:

- Specifically developed for shipbuilding;
- Availability of shipbuilding smart modelling tools;
- Incorporation of many years of shipbuilding knowledge;
- Outputs adapted to shipbuilding manufacturing processes;
- Proven scalability;
- Proven performance;
- Adapted to military shipbuilding requirements;
- Reduction of design and manufacturing hours over generic CAD applications.

The scalability refers to both the number of CAD users and to the number of vessel items to be handled.

Military vessels are very complex products that may be composed of millions of items, requiring a large number of designers, accessing concurrently to the vessel product model (Fig. 1). The design cycles of these vessels are usually very long and there are many design changes along the whole vessel lifecycle [4].

Performance is another critical requirement, especially in the detail design and manufacturing stages, when the detail design is almost complete, there are hundreds of users working on the model, model changes are constant and information for the production processes must be provided continuously.

3. Some Key Requirements for the Integration

Until now, the most common requirements for integration between shipbuilding CAD systems and PLM’s were basically two:

- Transference of the vessel product structure from the CAD to the PLM, comprising both the geometry of the model items for visualization purposes and items attributes (metadata);
- Management of all documents generated by the CAD in the PLM.

The result of these integrations can be considered as a low/medium level of integration.

On the other hand, and based on the lessons learned and on the issues identified in the military shipbuilding projects developed in the last years, other important additional requirements for the CAD-PLM integration have been raised by many military shipyards.

May be the most important requirement is the need for a continuous synchronization of the information managed by the CAD and by the PLM. This requirement leads to the need of a bi-directional integration between the CAD and the PLM and to the availability of publishing and synchronization processes automating the integration.
Another requirement derived from the previous one is the possibility of defining the most important standard components and model items of the vessel (e.g., equipment and main fitting items) in both the CAD and the PLM, depending on the project stage.

Among all these additional requirements, it is also worth to mention some of them, especially relevant for the proposed integration:

- The integration should cover most of the phases of the vessel life-cycle (conceptual design, basic design, detail design, manufacturing …);
- Sharing of attributes between the CAD and PLM;
- Handling of unique item identifications in both systems. Usually these identifications are generated in the PLM;
- Access and locking control to the CAD items based on the maturity of the information and on security considerations. In many cases, this information comes from the PLM, but in other cases, it is generated in the CAD system. The visualization of the model items based on their maturity and security considerations in both the CAD and the PLM is also a derived requirement;
- Automatic generation of model, BOM (bill of material)-drawing relationships in the PLM as a result of the publishing of model items and drawings from the CAD;
- Transference of the vessel build strategy from the CAD to the PLM and vice versa;
- Control of CAD model publishability into PLM. Detect the new entities created as well as those that have been modified.

Although many of the simulation processes to check the manufacturability of a design are currently done in the CAD in an automated and efficient way (e.g., piping fabrication sketches-spool manufacturability), in some cases it can be necessary to use more general simulation tools for digital manufacturing, closely integrated with PLM, especially to simulate some of the vessel assembly processes.

The results of the simulation could produce a different build strategy that would be transferred back from the PLM to the CAD.

The integration must also facilitate the collaborative work of different partners in the vessel project, as this is a normal scenario in the current shipbuilding military projects, especially in aspects such as the spatial integration and the cross manufacturing of the zones of the project developed by the different partners.

The CAD-PLM integration proposed in this paper intends to comply at the maximum extent possible with all these requirements.

4. The Integration Scope

The proposed integration considers all shipbuilding disciplines and areas covered by the FORAN system (hull forms, naval architecture, hull structure, equipment, piping, HVAC (heating, ventilating and air conditioning)), electrical, supports, outfitting structures, etc.) as well as all the associated information for manufacturing or for other production processes.

The integration also covers all stages of the vessel life-cycle, from the conceptual and basic design to the maintenance of the ship.

That means, and as an example, in the basic design stage the information of the intelligent diagrams must be transferred to the PLM, including associated drawings in PDF format, and building automatically in the PLM the relationships between the diagrams and the related BOMs (equipment lists, piping fittings, electrical fittings, cables, etc.).

As the projects evolves and the 3D product model of the vessel is built in the CAD database, the 3D information of the routed systems must also be transferred to the PLM, but the product trees in the PLM must also evolve automatically, considering the project progress and building the connections between the diagrams and the 3D model.

To give an idea of the integration scope, following in Table 1, it is included a list of the most relevant
Table 1  List of the most relevant components and model items considered in the integration.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Supports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment components</td>
<td>Cables</td>
</tr>
<tr>
<td>Piping fittings</td>
<td>Cable types</td>
</tr>
<tr>
<td>Piping components</td>
<td>Electrical fittings and instruments</td>
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<tr>
<td>P&amp;I diagrams</td>
<td>Components of electrical fittings</td>
</tr>
<tr>
<td>Piping lines</td>
<td>Electrical diagrams</td>
</tr>
<tr>
<td>Duct lines</td>
<td>Cable transits</td>
</tr>
<tr>
<td>HVAC components</td>
<td>Types of cable transits</td>
</tr>
<tr>
<td>Cable tray lines</td>
<td>Build strategy trees</td>
</tr>
<tr>
<td>Hull structure items</td>
<td>Welding</td>
</tr>
<tr>
<td>Outfitting structures</td>
<td>Engineering change notice data</td>
</tr>
</tbody>
</table>

components and model items considered in the integration.

5. An Overview of CAD-PLM Integration Solution

5.1 General

The architecture of the solution for the CAD-PLM integration is based on the following components (Fig. 2):

- A vessel product structure in the PLM, referred as the VPTree (vessel product tree), reflecting the CAD Product Structure at any time during the vessel project development;
- The current PLM classification structure, referred as PLMCStr, which will support the management of standard parts between the CAD and the PLM;
- A mechanism to transfer data from the CAD to the PLM, which will be referred as the publishing mechanism;
- A mechanism to transfer data from the PLM to the CAD, which will be referred as the synchronization mechanism;
- A set of relational tables in the CAD database, that will support the publishing and synchronization processes between the CAD and the PLM and vice versa. It will be referred as the CAD-PLM synchronization table;

Fig. 2 Integration components.

- A neutral framework for the integration of the CAD (FORAN) with different PLM systems, referred as FPLM.

5.2 The Vessel Product Tree

The VPTree is a product tree created within the PLM where the CAD model items will be published.

The VPTree is automatically built and modified during the publishing processes, to provide to the PLM users with an up to date view of the CAD product model during the project development.

The VPTree has a structure very similar to that of the CAD (FORAN) product model, so the position of the model items in the FPTree depends basically on the item type (Fig. 3).

The VPTree is another view of the vessel model in the PLM that will be permanently synchronized with the CAD 3D model. These VPTree data will allow the PLM to control the CAD product model, through the model locks, as well as to add or modify all the necessary information required by the management of the vessel along the whole life-cycle.

5.3 Standard Parts Integration

The integration of the standard parts (components) between the CAD and the PLM will use the current PLM classification structure. Both the publishing and the synchronization mechanisms will use this PLM structure.

The capability of defining standard parts in the PLM, to be automatically transferred to the CAD by the synchronization mechanism, requires the assignment
of some fixed attributes to these standard parts that will allow the synchronization mechanism to identify them as standard parts to be transferred to the CAD. These attributes will depend on the type of standard part (See Fig. 4 for equipment components).

6. The Publishing Mechanism

6.1 Publishing

Publishing is the process of sending the following information from the CAD to the PLM:
- Model items created or modified in the CAD;
- Standard parts created or modified in the CAD;
- Intelligent diagrams;
- Plate and profile cutting information (nesting);
- Build strategy trees created or modified in the CAD;
- Drawings or other files handled by the CAD.

Deleted items are also handled by the publishing mechanism. Some production assemblies defined in the CAD (e.g., spools) are also transferred to the VPTree in the PLM, creating, during the publishing process all the necessary relationships with the model items, so reorganizing the VPTree, so reflecting a more mature status of the model.

Usually, FORAN deleted items are will be marked with some level of obsolescence in PLM system, so they will become inaccessible for normal usage.

A CAD entity can only be published if it meets some specific conditions (Fig. 5):

- The entity is marked as publishable;
- The entity has not been deleted in the PLM;
- The entity is not locked in the PLM;
- The CAD entity’s date is later than the entity’s publishing date.

6.2 Publishing Modes

A specific Publishing process has been devised to facilitate all the publishing tasks. The Publishing process will provide tools to facilitate the selection of massive information to be published. Another relevant feature of this process will be the capability of being launched in a scheduled way.

The Publishing process will connect with the PLM through the FPLM (Section 10), by means of some specific PLM integration service, depending on the PLM system (web services and others). The aim of
this publishing process is to facilitate and automate the publishing tasks, reducing the impact of these tasks in the normal operation of both the CAD and the PLM (Fig. 6).

In addition to this standard publishing process, it will also be possible to publish CAD information on demand.

The available publishing methods are the following:
- Publish on demand those entities that accomplish the selection filtering criteria indicated in a publish configuration file, previously created (e.g., equipment items belonging to a particular system and zone);
- Batch publishing of the entities that accomplish the filtering criteria indicated in a publish configuration file, previously created;
- Publish all publishable entities loaded in the scene;
- Publish entities not directly included neither in the scene nor in a configuration file, but are strongly related to other entities that accomplish the filtering criteria used. This is automatically handled by publishing command to ensure that the data published to PLM is consistent.

6.3 Information Published

The publishing process will transfer attributes of the published items as well as the geometry of the items, if available.

Only a restricted number of attributes will be transferred from the CAD to the PLM, those shared by the CAD and the PLM and those CAD attributes selected for publishing but not editable in the PLM.

Concerning geometry, the Publishing process will automatically export to the PLM the geometry of the items, in the format more adequate for each PLM. Usually the geometry will be transferred at the level of elementary items (e.g., one part), but in some cases, it will also be possible to publish the geometry at a higher level (e.g., one spool).

7. Synchronization

7.1 The Synchronization Mechanism

Synchronization is the process of getting from the PLM information of the CAD items or standard parts created, modified or deleted in the PLM and still pending of transference from the PLM to the CAD, through the synchronization table described in Section 7.2.

A specific synchronization process has been devised to facilitate all the synchronization tasks (Fig. 7).

The synchronization process will connect with the PLM through the FPLM by means of a FORAN FPLM application server Servlet that will apply the changes to FORAN in real time. This Servlet is expected to be invoked from some PLM process (e.g., a workflow custom task or an event trigger). The Servlet will incorporate the data to update in FORAN by invoking a specific FORAN tool called FSYNC,
which will finally write the changes into FORAN synchronization table.

Model items can be locked by the PLM. The locking avoids the modification of the item in the CAD. Item locking can be temporal, due to updating needs, or can be permanent due to having reached a more mature status.

### 7.2 The CAD-PLM Synchronization Table

The CAD-PLM synchronization table (FORAN_PLM) is a set of relational tables in the FORAN/Oracle database that contain all the necessary information to manage the whole CAD-PLM Integration process.

The synchronization table contains information related to the entities participating in the CAD-PLM integration process, such as:
- Identification of the entity in the CAD and in the PLM;
- Unique identification of each entity (provided by the PLM);
- Publishing process related information;
- Synchronization process related information;
- Entity maturity information;
- Entity locking status;
- Entity shared attributes.

### 8. Definition of Model Items in the PLM

The automatic management of the VPTree by the publishing mechanism makes possible the definition of new model items in the PLM, out of the VPTree, to be transferred automatically from the PLM to the CAD. The process is as follows:
- Model items are created in the PLM;
- These model items must have the necessary attributes to uniquely identify the model item in the CAD (e.g., those indicated in Fig. 3 for equipment items);
- The synchronization mechanism will use these special attributes to identify the items to be transferred to the CAD and to transfer the model items to the set of relational tables in the CAD database supporting the integration;
- The CAD reconciliation tools will allow to use these items in the CAD side, completing the item information (geometry, additional attributes, layout information …);
- The publishing mechanism, when required, will publish these model items in the VPTree.


The CAD-PLM integration includes a complete set of document management functionalities inside the CAD.

Some relevant aspects of these Document Management functionalities are the following:
- Functionalities available in all FORAN modules (Document Manager).
- The most relevant document management functionalities are available:
  1. Download file content;
(2) Check-out of a document;
(3) Undo a previous check-out;
(4) Check-in of a document;
(5) Upload a new document;
(6) Create a new document version;
(7) Remove local file;
...
- Search documents in the PLM vault.
- Editable XML template to configure document contents.
- Dynamic documents attribute mapping between the CAD and the PLM.

Fig. 8 shows a capture of the Document Manager.

As indicated in Section 3, an important requirement for the publishing of drawings from the CAD side is the capability of creating and maintaining automatically in the PLM the relationships between CAD drawings and the items themselves (BOM lists), with the entities included in each drawing.

These links must be maintained for the most relevant types of drawings in all design stages (diagrams, layout drawings, manufacturing drawings, etc.).

The publishing of drawings has been designed in such a way that the process maintains automatically this connection, allowing the PLM users to get the items included in a drawing.

The publishing process maintains these links using the items information contained in the FORAN/Oracle database, for the diagrams, and the items information contained in the FORAN drawing files for other types of drawings.

Fig. 9 is a capture of the FPLM schema manager showing the equipment units used in a diagram.

10. The FPLM Neutral Framework Architecture

The FPLM (FORAN-PLM Neutral Framework) is a neutral framework developed by SENER [2, 3] with two main objectives:
- To facilitate and to simplify the integration of FORAN with different PLM systems;
specific PLM context and data model to the neutral FPLM object and data types; (2) The PLM Adapter. It is a set of web services, PLM templates and other PLM tools that are embedded and run into the PLM server. It provides the appropriate FORAN data environment for the PLM.

The FPLM plug-in usually relies on existing or to be developed PLM web services and other tools to allow the communication between the FPLM server and the PLM (Section 11).

11. The PLM Integration Tools

The bidirectional communication FPLM-PLM is done through the use of specific PLM web services and other integration tools. Many of these are standard PLM web services existing in most of the current advanced PLM systems. In addition, some other Web Services could be developed ad-hoc when necessary, to make possible or to optimize some specific integration functionalities.

In addition to the previously indicated PLM web services, the integration will require the creation of specific configuration tools and data templates to facilitate the integration and to map items and attributes between the CAD and the PLM.

12. Change & Configuration Management

12.1 Change Management

A set of tools will exist in FORAN-PLM integration to handle the data involved in an ECN (engineering change notice) process (Fig. 11).

Functionality is described below:

- ECN’s will be managed in the PLM;
- When an entity is included in an ECN in either role (problem item, affected item or solution item), synchronization process in which the entity is included will hold data related to the ECN;
- If a synchronized entity includes ECN data, the ECN will be registered in FORAN, if it is new;
- FORAN will have a ECN Manager tool to handle all data related to the ECN related to FORAN, which includes the status of the modifications expected in the change process for the entities; add additional entities to the ECN in either affected or solution entities, as detected in FORAN as a result of the work done or to be done in the model; and the execution status level of the ECN itself;
- A new filtering criterion will exist to select the entities related to an ECN, for publishing to PLM.

12.2 Sister Vessels Management

This point mainly focuses in how to manage in the CAD-PLM integration the applicability of the items in a multi-vessel (sister ships) project context.

FORAN system already has functionality related to sister vessels management and therefore for the PLM integration some assumptions have been considered:
• In a sister ships environment, each vessel or unit will be a FORAN project;
  • There will exist a CLASS project to centralize FORAN locking and applicability data;
  • The existence of an item in a FORAN project is considered as an item occurrence in that project;
  • Modifications on an item will be done from a single project, but all other projects sharing the item with the same applicability will also be locked, to prevent modification on them by other user;
  • Once the modification changes are applied, FORAN will update them in all projects sharing the items applicability (multi-save concept);
  • The use of applicability on an item within a sister ship series might be (1) To all vessels (e.g., 1-UP); (2) To all vessels newer than a specific one (e.g., 3-UP); (3) To some vessels specifically (e.g., 1-UP); (4) A combination of the above (e.g., 1-UP); (5) If no applicability is set, it means “effective for all vessels” (1-UP).

12.2.1 Applicability Management in FORAN Modules

Every project created belonging to a series of vessels will be uniquely identified with a specific vessel number (or unit number) allowing thus the mapping with the corresponding concepts in the PLM.

12.2.2 Applicability Management in CAD-PLM Integration

The necessary tasks required to gather information of the changes performed in PLM and to update the items in FORAN, through the CAD_PLM synchronization table, will be driven by one synchronization process.

As the CAD-P LM synchronization table includes the applicability context information for each item, then every synchronization process will update the applicability data in the CLASS project.

If an applicability change is performed on an item in PLM, indicating a change in the range of units where the item is valid, that modification will be also updated in the FORAN projects accordingly, through the information stored in the CAD-P LM table as shown in Fig. 12.

13. Conclusions

This paper presents a solution for the integration of a shipbuilding specific CAD system (FORAN) with an advanced PLM system in a naval shipbuilding environment.

The proposed integration presents several important advantages:
  • Taking profit of the experience and results of previous integration of FORAN with different PLM systems;
  • Incorporating the most outstanding requirements for the CAD-P LM integration coming from some relevant European shipbuilding companies, designing and manufacturing surface ships and submarines;
  • Improving predictability by providing a single point of truth for the whole organization;
  • The design of the integration has been done with the objective of limiting the degree of coupling between the CAD and the PLM, with several important aims in mind: (1) to reduce to a minimum the impact of the integration on the performance of both systems (the CAD and the PLM); (2) to produce a scalable solution able to work with hundreds of designers in the CAD engineering side and with thousands of PLM users in the whole shipbuilding organization;
  • It would allow the PLM to take benefit of all the vessel information handled by the CAD from the early stages of the design.

Fig. 12 Applicability management.
The proposed integration is now under implementation for several important European Naval Shipbuilders.

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