The latest development in CAD/CAM/CIM. The Virtual Reality in Shipbuilding
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Abstract
An expected result of the prolonged use of Computed Aided Design, Manufacture and Integrated Manufacturing (CAD/CAM/CIM) Systems for the design and production of any kind of vessel is its use in Virtual Reality environments, primarily because now it has become an manageable technology. Virtual Reality is extended in every industry, in every sector, at any level. Important improvements both in software and hardware have had an important impact in its use in the shipbuilding industry, where it is necessary to handle complex ship 3D models with huge amount of data.
This paper describes in detail the main application and uses of Virtual Reality in shipbuilding, from different points of view. Just mention:
• Design. Review of the 3D model.
• Engineering. Avoid errors and inconsistencies as interferences and collisions.
• Planning. Review progress of project and supervise subcontracted works.
• Project Management. Evaluation of new requirements and changes.
• Production. Simulation of critical assembly tasks.
• Marketing. Commercial uses, fairs, exhibitions and product demonstrations.
• Military Shipbuilding. Crew trainings and Ergonomic studies.
• Early error detection in as designed model. Avoid expensive modifications in manufacturing and production stages.
• Cost reduction.
• Simulation of critical tasks.
• Quick evaluation of design alternatives.
• Fast decision making.
• Investment in Virtual Reality solutions is recovered.

The collaboration between an improvement in the marine technology and developments in CAD/CAM/CIM software, will be a great step forward for the use of Virtual Reality in shipbuilding. The use of new technologies in different ship design stages, will be a great benefit for the ship design offices, shipyards and ship-owners, and will improve hugely the production process. At the end, there are several scenarios of improvements for the next years. Some of these improvements seem to be unreal or very difficult in short term, but the reality often exceeds expectations in any field, and probably more in the technology.

Keyword: Virtual Reality, shipbuilding, software, technology, ship design, computer aided design.
1. INTRODUCTION

Under the concept of global economy, enterprises are distributing design and production environments around the world in different business areas. Shipbuilding industry is a good example for complex distributed processes as more than 75% of the creation of value is performed by numerous suppliers. The pressure to reduce lead-times and to cut design costs combined with more complex vessels is demanding a similar reduction in the design cycles. On the other side, there has been an important reduction in the direct workforce capacity of the shipyards, pushing them towards an outsourcing strategy by subcontracting more and more significant parts of the design work. As a consequence, today’s ship design is an activity that involves collaborative participation of multiple design centres worldwide.

Collaborative design can be analyzed by means of two approaches that are not considered mutually exclusive:
- Concurrent design, which allows separate teams to work simultaneously on the same design and accessing the same ship product model from geographically dispersed sites.
- Distributed design, by splitting the ship design and engineering activities into distinct areas allowing thus, several design teams to work at different locations.

Although the distributed design, either based on distribution by disciplines (functional), by zones (geographical) or by design stages (sequential) can be the only solution in environments where the communications are expensive or hard to establish due to inadequate technological infrastructure, distribution implies data duplication which may cause coordination problems. Therefore, this paper focuses on the concurrent design approach and describes the experience of SENER, a company that plays the double role of software developer (FORAN System) and ship design agent, in the development of tools to adapt a relational database as well as the associated database management software, to remote concurrent design environments by means of the use of database replication techniques.

2. STATE OF THE ART

A quick examination of shipbuilding magazines over the last five years will reveal that there has been much talk about the application of 3D models and applications of Virtual Reality. This all presupposes the existence of a digital prototype, in other words, a digital or virtual mock-up of a ship. The concept behind using digital prototypes is to do as much work, analysis, and communication as possible within a 3D digital environment, rather than in the physical world. This involves using computer simulations more than physical models and viewing videos and fly-through, rather than interpreting paper drawings. The concept of digital prototyping goes beyond simply creating product designs in 3D. Having digital prototypes on a screen of the engineers in their office is one thing but getting the 3D model down onto the shop floor, extends the concept even further. This goes beyond than simply having production workers viewing the design. It involves production department utilizing the CAD model on a day to day basis.

Most of CAD suppliers are developing the Virtual Reality concept in order to achieve future success. For example, some of them are promoting the use of the shop floor 3D concept as a logical extension of its digital prototyping tools used in their programs. There are still limitations on the number of parts that the software can handle. Only limited strides have been taken in the direction of shop floor 3D at even the most progressive shipbuilding companies.

Another way where the CAD companies want to improve the Virtual Reality tools is using tablets. Showing complete build sequences, via 3D animations in tablets, would dramatically aid in communication compared to simply viewing static models. The use of tablets would also allow mobile shipyard workers to bring the digital prototyping experience with them, further enhancing productivity. It is true that due to the size and complexity of 3D CAD models used in shipbuilding, there are current limitations imposed by the software and hardware that affect the viability of this approach.

Product LifeCycle Management (PLM) tools are used for configuration management of the digital mock-up. The Virtual Reality applied to PLM will bring together the product, tooling and production line around a single database. The totality of processes and data necessary for the different functions will be included. As well as integrating the different skill areas, this Virtual Reality applied to PLM could be used to apply the design-to-build concept and enable complete product lifecycle management. Industrialization process must be optimized. The Virtual Reality applied to PLM could also be used to
simulate production processes and maintenance operations. Finally, Virtual Reality applied to PLM will achieve ever greater degrees of optimization: automatically produce instructions and documentation and follow project progress, reviewing the mock-up in Virtual Reality.

3. VIRTUAL REALITY IN A SHIPBUILDING ENVIRONMENT

Shipbuilding industry is affected by a global and extremely competitive environment. All processes and systems have to be adapted to this challenging scenario, making special efforts in innovation and applying the most advanced technology available in the market. The Virtual Reality application to shipbuilding is not new, but it is more extended now thanks to the important improvements in software and hardware. From a user point of view, it is possible now to find a wide range of solutions to meet the most demanding requirements, to achieve measurable results, in terms of efficiency and costs.

The ship 3D model is the core to all tasks related to ship design and manufacturing. As an added value, CAD suppliers develop smart tools to use this model in realistic navigations in Virtual Reality environments with multiple purposes. Some of the most important uses of Virtual Reality in shipbuilding are described in the following paragraphs.

3.1. Virtual Reality during the ship design stages

Maybe the engineering department of a shipyard is where is more extended the use of this kind of solutions. And production department is maybe where it should be extended because is where there are the most costly errors. They are not usually working with a Virtual Reality solution but now it is starting to be clear that it is very useful to check the model, to avoid errors and inconsistencies but also to improve the tasks of production.

So, the first and most important use of Virtual Reality is for avoiding errors. The possibility of viewing the ship 3D model as much realistic as possible is really effective to find out errors, in all stages of the design. From early design stages, to manufacturing and production phases, it is possible to use it to check all the elements, to see inconsistencies, to prevent interferences and collisions, to query about properties and attributes and to study different design alternatives and changes dynamically. In addition, the user and model interaction has become much more realistic with the implementation of tracking devices which give the sense of being inside the model, walking and moving on it, touching it.

Viewers allow an easy navigation and a fast-movement. Different modes of visualization, search and query options, inclusion of annotations and measurement of distances are important and useful capabilities. Ergonomic aspects in the design can be studied and checked better having a Virtual Reality solution, with the possibility to include dummies. It is possible also the collision detection, to check interferences and the insertion of annotations.

Simulation is another important area of application of Virtual Reality in ship design, engineering and production. It is being applied in the study of many tasks with different purposes, from the study of escape routes to the simulation of dismantling for maintenance of equipments. The help in the study of critical assembly tasks and how the surrounding elements are affected is relevant too.

No need to say that the use of Virtual Reality for the control of the design is very useful, just to see the progress of the project. And more, once it is being built, the comparison between the model and the real ship is necessary and Virtual Reality can help to find out errors that need to be solved as soon as possible eliminating further unnecessary costs.

On the other hand, it is very common that the ship design and engineering and also the manufacturing is divided in different blocks that are subcontracted to different design offices, subcontractors and shipyards. The shipyard receives all the information of the ship and needs to supervise that everything is correct. Having a Virtual Reality tool that allows the integration of all the information in a simple way makes possible to have a single model, which is much more effective than having many different models. In figure 1 it is showed an example of two operators, checking the engine room.
3.2. Virtual Reality for commercial uses

Benefits of using Virtual Reality for marketing and commercial purposes are evident. That is why Virtual Reality tools are having a great reception in sales and marketing activities. Thanks to the wide range of possibilities available in the market, from small and portable solutions to big and on-demand solutions, the present and future applications of Virtual Reality is higher than we can imagine. From the marketing point of view, the possibility to present a ship 3D model with the higher level of detail in an immersive Virtual Reality experience adds incalculable value to the sales activity. Many shipyards are already taking advantage of this technology, not only in their facilities but also in fairs and exhibitions thanks to the portable solutions that will be described later.

3.3. Shipyard management

Shipyard management play the role of ensuring that the commitments made to the clients are fulfilled. The project needs to be accurate, with the highest quality level and in accordance with estimations to ensure customer satisfaction. To achieve it, it is very important to have a clear idea about the progress of the project and also about changes that can affect further requirements, schedules and costs. Having the opportunity to check the Virtual Reality model from early design stages is a great advantage and allows a friendly checking, quick evaluation of alternatives and fast decision-making. At the end, the great impact in cost reduction is possible thanks to the early error detection, being much more expensive the modifications in manufacturing and production stages.

3.4. Ship-owners management

The presentation of the progress of the ship project to ship-owners is another important use of Virtual Reality, adding the value of being very easy to conceive the project in a very realistic and intuitive way. This has become a great advantage in comparison with conventional presentations. In fact Virtual Reality can substitute the old scale ship models that are expensive and with short level of detail. The capabilities to present the information available in the Virtual Reality solutions are as big as the user’s ability, because now it is possible to provide realistic finishes and all the level of detail required. Ship-owners can also check and monitor the progress of the model and also to promote design alternatives less cost-effective than in further stages.

3.5. Naval shipbuilding management

Military shipbuilding industry is affected by the most demanding requirements both in the design and production stages. It is true that this kind of naval projects, both in submarines and in surface ships, are lengthy and complex although they have more human resources. But, at the end, the project needs to comply with the strictest rules and also with the budgets imposed by the ministries. This is not an easy task, and that is why all the help in the control and supervision of the process is really welcome. Is in this area of shipbuilding where Virtual Reality solutions have been well received time ago. The application of the most advanced technologies usually starts in ambitious softwares with major innovations and budgets. That is the case of application of Virtual Reality in shipbuilding, because we
cannot forget that having an appropriate Virtual Reality solution is costly, and that long-term military projects are those that a priori have a larger budget to afford them. Other important use around the naval shipbuilding is in the side of the Army. The use of Virtual Reality is an advantage for the crew training. In submarines this can be particularly interesting for the lack of space. Simulation is the other important activity, since there is really difficult to enhance some kind of operations inside a submarine but also in a surface ship. The help of Virtual Reality to simulate operations and dismantling and maintenance tasks is unquestionable. Here there is a great area of improvement.

3.6. Areas of improvement

From another point of view, there are still some drawbacks to mention around the use of this kind of technology in shipbuilding. The most important one is the price, huge savings can be achieved with Virtual Reality in return to more focus on ROI aspects than just the investment (on its own), because although there are cheaper devices available in the market, the true is that the hardware is expensive, and it is necessary to add the costs of the software, the implementation, the conditioning of the room, the training, etc.

Another important drawback is that there is necessary to have a good ship 3D model of the ships. Sometimes this is not possible, because there are multiple CAD systems applied in the same project, with the difficult of having just one model of the ship with all the information. To avoid this situation it is much better to develop the whole project in the same CAD, or at least to have the necessary tools to integrate the information in a viewer compatible to all of them, which sometimes it is a very difficult task.

Finally, the ergonomic aspect of the solution is important too. The use of 3D glasses for a long time is annoying for the eyes, and the standing position looking to a screen without any light could be unpleasant if used too often.

4. FORAN-IC.IDO SOLUTION FOR VIRTUAL REALITY

SENER and ESI Group, two companies sharing the same objective, bringing to the shipbuilding market a robust product integration for virtual reality.

FORAN, the pioneer CAD/CAM/CIM System conceived for the global shipbuilding process, and IC.IDO also pioneer in the development of an industrial grade Virtual Reality solution.

4.1. CAD/CAM/Virtual Reality integration

Well defined workflows and business process that ensure an easy and fast access to design data is key for user acceptance and finally business success for Virtual Reality applications. This is proven evidence based on more than 15 years’ experience of IC.IDO conducting numerous implementation projects in various industries. FORAN and IC.IDO have started a close collaboration to address this topic for to come up with a straightforward solution for shipbuilding industry.

4.2 Main IC.IDO use cases

The above mentioned outsourcing trend in shipbuilding industry that more and more creation of value is performed by suppliers lead to complex distributed processes and to challenging integrations topics at manufactures. The FORAN-IC.IDO solution is addressing this challenge by virtually performing and validating integration processes along the entire value chain.

To support the high demands from shipbuilding industry the combined solution of FORAN and IC.IDO is designed for engineering, service/maintenance and manufacturing related processes providing a real-time environment for interactive operation on a virtual prototype (section only or the complete vessel) for collaborative decision making.

4.2.1 Interactive, immersive design reviews

Interactive, immersive design reviews means engineers from different domains get actively engaged with the ship, virtually to safeguard the engineering process for optimal designed from the very earliest stages. All involved stakeholder either internal or external can validate as early as possible the current
design to identify problems and collaboratively define resolution. Continuous reviews on a regular basis including suppliers will improving product quality and speed-up maturity and fast problem understanding.

4.2.2 Design for manufacturability

Next step, e.g. after design freeze, is the virtual validation and optimization of manufacturing and assembling processes. The FORAN-ICIDO solution enables users to evaluate the manufacturability of a ship respective on sub-sections level of larger ship modules. Also human interaction in terms of ergonomic concerns with the assembling procedure are assessed; as well as the feasibility and effectiveness of tooling and fixtures.

It is common practice to compare and evaluate multiple solutions to determine the best course of action. Afterwards, proposed changes are evaluated and documented. The effect of those changes on material flow, space claim, and ship infrastructure can be examined and validated before they are put into place. Consequent virtual design for manufacturability typically leads to a reduction of planning times with simultaneous increasing of planning certainty by virtual review and validation of clearance issues and tool operation. And it leads to higher reuse of standard assembling/manufacturing tools and less rework of tooling is required. All in all product maturity is increased, costs for rework is reduced and inefficient manufacturing processes can be avoided in time.

4.2.3 Design for maintainability

The third area for FORAN-ICIDO applications is focused on design for maintainability, which basically means the validation of serviceability and repair operation during operation of the ship.

Investigating the production design intention FORAN-ICIDO allows for evaluation of the ease of servicing based on a virtual model. This includes early hour maintenance tasks and ease of access to commonly serviced parts. Versioned representations of the entire ship or subsystem can be validated in detail. Clearance and interference are assessed. The exploration is aided by sectioning capabilities and the ability to toggle the visibility of features. Issues discovered are collected and can communicated in a systematic manner to the later owner to define resolution.

Again, ergonomic considerations for service and repair can be assessed virtually. Which finally will lead to less downtime due to inadequacy of tooling/handling devices. As a result of the conducted investigations, interactive work instructions are deliver including enriched information to the service teams. This aspect typically leads to reduced training costs and elevate the overall quality of maintenance.

5. FVIEWER, THE NATURAL APPROACH

FVIEWER is the native FORAN tool to walk through the FORAN 3D model. It gives the user the possibility, not only to look at the model, but also to walk through it in real time and to query about the properties and technological data of the different ship’s components.

It is possible to use multiple lights and to assign special properties to surfaces, like texture or translucency. It is also possible to simulate maintenance operations by defining paths and moving and rotating elements of the scene along these paths. Also ergonomics of the design can be checked by importing in the scene human models.

The viewing control in FVIEWER is performed by direct mouse or joystick manipulation and supports different navigation modes. Other capabilities are:

- Selection of components by different criteria.
- Operation with groups of selected items.
- Interference checking, collision, class detection...
- Measurement between items.
- Addition of notes, annotations...
- Remember camera position.
- Camera and objects paths manager.
- Generation of videos in 4K resolution.
- Dummies...
- Stereoscopic view.
- Tracking System and Head Mounting Display (HMD) supported.
Simulation management.

**Figure 2. FVIEWER user interface**

_FVIEWER, see figure 2_, allows users a navigation experience with stereoscopic 3D vision. Also can be used a tracking system that consists of a head position detector and a wand which is used for interaction with the program. The _HMD_ detects the movement of the viewer and passes the viewer’s head position to _FVIEWER_ which uses the data to calculate the camera position. Together with stereoscopic 3D visualisation the result is an immersive navigation for the user that wears the tracking detector. This makes possible the creation of virtual reality rooms to have a complete navigation experience through the 3D model and also interacting with it. The module has an import/export capability of _v3d_ 3D models from/to other systems. It is possible to convert _.p3d_ files into _v3d_ files.

6. CONCLUSIONS. VIRTUAL REALITY FUTURE APPLICATION IN SHIPBUILDING INDUSTRY

Virtual Reality technology is going to be evolved for the purpose of providing virtual experience to users. Not only do they reproduce a real-world experience in a virtual space, Virtual Reality systems could also provide, in future, virtual experiences that are impossible to reproduce in real life. In some cases, experiences in virtual spaces appear to work even better than in real-world situations in terms of safety and cost.

The future applications of Virtual Reality to shipbuilding and the technology progression will be analysed in the following paragraphs.

6.1. New ways of dealing with ship design

The Virtual Reality is a tool to evaluate, analyse, simulate and visualize the design/model in advance on a secure and interdisciplinary basis to take necessary decisions. This solution could be improved to be used for more purposes: for reviewing projects, examining and demonstrating content, searching for ground-breaking solutions, etc. All depicted in a one-one scale model, which will be a tremendous aid for engineering work. Through this system, the 3D environment could be watched by users in full-size, giving them an accurate idea of the model dimensions, the real feelings it will produce or the ergonomics of a system.

Shipbuilding industry is known to be one of the most labour-intensive industries and requires skilled workers. Hundreds of people in a shipyard work together with different specialties including welding,
painting, heating, piping, and so on. While most of the jobs in the shipbuilding industry involve hard and difficult work, there are some tasks that create a continuous demand on human resources since many workers resign due to the poor working environment, for example, workers are exposed to noxious gasses and heat produced in paint and welding processes. In these tasks, the Virtual Reality could help simulating the virtual environment in as real a manner as possible, providing additional information for training, such as virtual motion guides could improve the proposed training system. With such features, it would be much easier for trainees to correct their faults and practice in a more standardized way. The use of modern digital design and evaluation tools is indispensable to take safe predictions about the future characteristics of a ship. The evaluation about how certain engineering and design changes impact the overall ship can be done with the help of modern simulation and visualization technologies, much easier and faster than before. For this reason, one of the main tasks in the future, for the shipbuilding software developers is to improve the Virtual Reality tools.

There are important challenges in the ship design and production around the Virtual Reality application. This is especially true when dealing with heterogeneous data structures (multiple, discrete authoring systems). Also, the high collaboration and discussion efforts in the construction and detail design stage (especially for distributed, collaborative projects) and the high degree of interaction between supplier and customer during the development and production phase (triggered by the time and cost pressures in the design and production and the often very complex systems and equipment) are another important issues to be considered.

Painting and welding jobs in the shipbuilding industry require a continuous supplement of human resources since many workers leave due to the poor working environment. While painting and welding are known to be difficult jobs, they are also ones of the most important processes in ship construction. Not only affecting the construction schedule, these processes are also directly related to the quality of the ship under construction. So it is particularly important to train workers so that they can paint evenly on large surfaces with a uniform thickness and they can weld properly too.

The Virtual Reality greatly simplifies the planning and re-planning process, making it easy to create a good production plan and keep it current. This simulation model of the shipyard production process captures both the essential physical shipbuilding activities and the essential management decision-making activities that support the physical production processes.

The Virtual Reality could identify the overall shipyard facility and manpower resources and the construction tasks required to build a ship. The Virtual Reality will interact to calculate the specific allocation of resources over time necessary to produce the ship. The Virtual Reality will provide both schedule and resource use. The Virtual Reality can also help to quantify the cost and schedule impact of delay and disruption as well as assist in identifying the most effective management actions to overcome such problems.

Nowadays simulators only can handle simple object movements. In the future, it will be possible to do complex consecutive movements with, for example, equipments, topological movements, dismounting elements, advance information displayed and connexion to a PLM.

A Virtual Reality navigation tool could involve superimposing a 3D virtual model on a user’s real-time, natural perception of reality. The Virtual Reality concept is designed to enrich perception of the real world by adding virtual elements that are not normally perceptible. The Virtual Reality system would moreover, improve management of bridge crew stress in conditions of reduced visibility, fog, poor visibility, darkness, etc.

Training, as it is mentioned before, is one of the representative application fields of Virtual Reality technology where users can have virtual experience in a training task and working environment. Widely used in the medical and military fields, Virtual Reality-based training systems are also useful in industrial fields, such as the aerospace industry, since they show superiority over real training environments in terms of accessibility, safety, and cost.

### 6.2. Advanced technology applications

Progression is running very fast in hardware Virtual Reality applications. One of the most representative applications in this field are the immersive displays. There are two main types of immersive displays widely used in Virtual Reality systems for providing high-level spatial presence: CAVE display and HMD. CAVE displays utilize a number of large projection screens forming a cubical room to cover the whole view of the user. On the other hand, an HMD is worn by the user, and the display screen is attached to the user’s head, following the user’s view. By tracking the user’s head motion, an omni-
directional view of a virtual scene can be provided to the user by updating the virtual scene image according to the user’s view direction.

6.2.1. Immersive CAVE
The future is a six-walled Cave Automatic Virtual Environment (CAVE) equipped with six projectors, designed for a complete immersion of the user in the simulation. The viewer is surrounded by six walls (front, left, right and back side, floor and ceiling) so that they can experience a true feeling of realism and of touching objects which seem to be next to the viewer in the middle of the room. The immersive CAVE is the main challenge, in this moment, of Virtual Reality installation. This system is very difficult to get right, because the images must be razor-sharp and adjust perfectly to the different walls, to the mirrors hanging in the middle and the position of the projectors.

6.2.2. Connexion with Haptic Technology Devices
Developers are constantly seeking new ways to increase the realism of the experience of Virtual Reality. A way to do this is by allowing users to use their sense of touch through a peripheral device such as a control, to move. This technology allows users to use their sense of touch is called haptic technology. The haptic technology is the study of how to couple the human sense of touch with a computer-generated world. There are two types of haptic feedback: kinesthetic force feedback and tactile feedback. In Virtual Reality the haptic feedback usually is originated in the control of the actions. All haptic devices are derived from a convergence of mechanical and electrical engineering and software.

6.2.3. Collaborative work environment remote between Virtual Reality CAVES and multiuser interface
One of the advantages of doing 3D visualization of a ship in an immersive environment is the ability to have geographically distributed participants sharing space with each other and the objects under discussion. This allows the different participants to point at specific objects in the scene or set the parameters of the simulation to specific values to clarify the information. It gives the users a common context for their discussions, especially in international collaborations.

When there are collaborators (very common in this days), and they are distributed in different workstations, inclusive around the world, Virtual Reality becomes more challenging as this involves multiple networks, multiple time zones, and multiple cultures. Because of time zone issues it may be inconvenient to schedule meetings, so Multiuser Interface may be the most appropriate mode for transoceanic Virtual Reality. Multiuser Interface will also have the advantage that geographically distributed teams could work on the same Virtual Reality project.

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