THE LATEST ADVANTAGES IN SHIPBUILDING CAD SYSTEMS

Abstract

The shipbuilding industry has varied widely throughout history. This paper traces the history of ship design since Roman times, when ship designers began to use curves for drawing frames, through the Venetian techniques (XIII-XVI centuries) reusing templates, to the most modern methods for ship design with CAD/CAM Systems.

Throughout the first half of the 20th century, ships were getting bigger; so it was necessary to work on larger scales. The templates allowed working on different scales, such as widely used 1:10 scale. But with growing ship size, the moment came it was no longer practical to use templates. This happened at a time when the first computers came to our industry, promoting the development of ship design CAD systems.

The new CAD Systems offer a comprehensive process for the design and construction of ships, offshore platforms and submarines, with the help of computers. There are many advantages of using CAD in shipbuilding: ease of design, speed of construction, use and reuse of information, etc. It is expected that in the future CAD tools will advance further and allow greater information management and virtual access through smart devices. In general, CAD systems provide tangible benefits while the process is optimized, reducing design time and production, and therefore costs.

Key words in English (up to five words): Shipbuilding CAD System, Product Lifecycle Managements, Virtual Reality
1. Introduction to CAD systems

Computer-Aided Design (CAD) Systems help engineers and designers in various industries, designing and building 3D models of airplanes, cars, bridges, digital cameras ... and of course, ships, submarines and floating structures. There are other acronyms that are usually accompanying the acronym CAD, such as Computer-Aided Manufacturing (CAM), Computer-Aided Engineering (CAE), and Computer Integrated Manufacturing (CIM), including instructions to Computer Numerical Control (CNC) machines. One could claim that these CAD/CAM/CAE Systems had their origin around the year 350 BC, with the mathematician Euclid of Alexandria. Many of the postulates and axioms used by today’s CAD systems are based on Euclidean geometry. Some 2300 years later, many see the birth of 3D CAD with the work of Pierre Bezier, a French engineer working at the Arts et Métiers ParisTech. After his mathematical work concerning surfaces, he developed UNISURF, between 1966 and 1968, to ease the design of parts and tools for the automotive industry. Then, UNISURF became the working base for the following generations of CAD software. Only onee decade later, CAD systems were introduced in academic courses. The real breakthrough in CAD systems came, logically, with the development of computers; and during the 1980s the application of CAD systems matured to a similar stage as known today.

CAD tools are usually divided into 2D drawing and 3D modelling programs. The drawing tools are based on 2D vector geometric entities such as points, lines, arcs and polygons. In 3D modellers, solids and surfaces are created. In the early stages of the development of CAD systems, the software was running on mainframes, which limited use of CAD systems for manufacturing. With the arrival of workstations and PCs came then widespread use of CAD systems in engineering on a daily base.

2. A brief history of the use of computers in shipbuilding

The shipbuilding industry has varied widely throughout history. One could argue that the first shipbuilders were the Egyptians, due to evidence of bundle rafts and big planked boats, first using sewn joints on the Cheops Ship around 2600 BC. All Mediterranean civilizations (Greeks, Carthaginians and Romans) were subsequently improving their fleets, as they were established as naval and military powers. Certainly, the increasing dominance of Rome over the Mediterranean World, defeating Greece and Carthage at the end of the first millennium BC, influenced quantity and quality of the ships built at this time. In those days, shapes and sizes of vessels changed, but also the construction processes. Leon and Domingo (1992) mention that the oldest assembly system known, the mortises-and-tenon edge-joining, was used in Greco-Roman ships.

During the first century BC, the increasing demand for cargo space required more strength to the hull structure and integrity, requiring thicker planking or hull structures with inner and outer planking with wool or other fabrics saturated in wax in between. These Romans techniques were perfected by the Venetians from the 13th to the 16th century. The Venetian Arsenal became one of the earliest large-scale industrial enterprises in history using the concept of production chain.

The Venetians began to define the form of the frames in terms of tangent continuous circular arcs, ‘biarcs’ in modern dialect. A biarc is a model commonly used in geometric modelling and computer graphics; it is composed of two consecutive circular arcs with an identical tangent at the connecting point. The ship hull was obtained by varying the frames’ shapes along the keel, an early manifestation of today’s tensor product surface definitions.

Drawings to define a ship hull became popular only in the 17th century in England. The earliest existing mention of a spline, a wooden beam used to draw smooth curves, seems to be from the 18th century. The birth of classical splines is believed to come from shipbuilding, e.g. Nowacki (2000). So probably, shipbuilding was the earliest industry to use constructive geometry to define free-form shapes. In the late 19th and early 20th centuries the frames of a steel ship were stood up on the keel like those of a wooden ship, and the plates attached later. Frames had to be shaped to match the curves of the hull design. Each one was heated in a forge and then hammered or jacked to match the shape
of its template. In late 19th century, it was not easy fairing the hull. Flexible sticks called battens, were used for fairing the lines, i.e. checking the measurements against the lofting and making sure they looked fair with no kinks or irregularities. Finally, the lines were transferred onto full-sized moulds (patters) sawn from thin wood. These were traced to shape the timbers for the ships, much as a dressmaker uses paper patterns to cut cloth for a garment. Loftsmen cut the mould stock (thin pine boards) to shape using a band-saw. Each pattern was marked to indicate which piece of the frame it was. The patterns could be stencilled with the hull number to keep track of the sets. Often two or three sets of moulds were made: one to mark and cut the timbers, and one or two up in case the originals were damaged. Ship designers in the design office, figure 1, drew up construction details and compiled tables of offsets, or measurements, for the full-scale hulls. At some shipyards, drawn plans were used instead of, or in addition to, a half-model. In some shipyards, carving a half-hull model was the first step in designing a new boat. Drawing on both tradition and experience, shipbuilders carved hull forms that had been proven seaworthy and economical. Half-models were carved from layers (or lifts) of wood. Sometimes contrasting wood types indicated design features like the waterline. Old shipyards used models with the lifts glued together, taking measurements from the outside of the model.

![Fig. 1 An spanish mould loft floor on the early XX century](image)

Throughout the first half of the 20th century, ships were getting bigger; so it was necessary to work on larger scales. The templates allowed working on different scales, such as widely used 1:10 scale. But with growing ship size, the moment came it was no longer practical to use templates. This happened at a time when the first computers came to our industry, promoting the development of ship design CAD systems. From a historical perspective, figure 2 shows the evolution of the different CAD system in the last 50 years.
Computer-aided design of outfitting systems (pipes, machinery, HVAC...) is much more recent than hull form design or structural design. Outfitters used plastic models until the late 20th century. It was only then that CAD systems expanded the application range, covering all project stages, thanks to the evolution of graphics environments.

Traditionally, most shipbuilding CAD systems focused on hull form definition, naval architecture calculations and structural design. This changed when new challenges in shipbuilding, demanding closer coordination between hull structure and outfitting, obliged marine suppliers to devote special attention to this matter. Some marine CAD systems started the development of particular outfitting tools, others limited tried to find a closer integration with existing plant design oriented systems. The development of a particular outfitting design tool in FORAN was based on the fact that the actual requirements for outfitting design are not limited to a close integration with the structural design. Problems to be solved, regulations, working procedures, nomenclature, production information, etc. are so particular to ship design that it is convenient to have a dedicated tool rather than try to adapt an existing one. As time went by, outfitting tools have been increasing the scope of support. Today, tools usually include particular environments for equipment modelling and layout, piping and HVAC ducts routing, definition of auxiliary structures (foundations, gratings, ladders ...), and definition of distributor supports and hangers. In some cases also electrical and accommodation aspects are considered. Particularities of outfitting design require to work in a pure 3D environment and with a friendly and suitable user interface, but new developments in outfitting tools have been always handicapped by the available technology (hardware, graphic possibilities...). Nowadays it is commonly assumed that outfitting tools should be able to work in a solid visualization method, with huge amounts of information on the scene being dynamically handled.

3. Origin and evolution of a CAD System. FORAN

FORAN, shown on figure 3, has probably the longest tradition among the shipbuilding software currently in the market. Half a century since FORAN was conceived as a tool for marine design projects at SENER, and it has become a complete CAD tool for design, construction and engineering of all kinds of ships and marine units. Its multiple applications and constant improvements have made
it one of the most advanced CAD system for global shipbuilding, and a milestone in Spanish engineering.

![Image: Tanker designed using FORAN CAD System](image)

**Fig. 3** Tanker designed using FORAN CAD System

It was the 1960s, SENER, then purely a ship design office, could not find computing tools to boost the efficiency of its projects. In 1964, a small research team was formed with naval architects and students with special interest in computer science. This combination of experience and skills within the team proved to be extremely fertile and was subsequently maintained as a desirable requirement for successful development.

Soon it was realized that mathematical descriptions of ship hull forms could be used not only to represent or fair existing hull forms, but also to generate new hull forms starting from a set of main ship dimensions and coefficients.

The generation of intrinsically faired ship hull forms starting from the main ship design basic data was achieved in FORAN with the use of the module FORMG. The objective of this module was to obtain an approximate hull form sufficient for qualitative appearance and hydrostatics. Another FORAN module, FORMF, was used to fit (and optionally fair) an existing hull form defined by a table of offsets or by lines drawing, by means of bi-arc and splines techniques. The module can be used to modify locally fair forms created with FORMG, in which case only the local modification, defined by point coordinates, needs fairing after fitting. For non-fair forms designed by alternative methods, both fitting and fairing are required for the whole hull form for production purposes.

In 1965, the first version was launched (just for internal use) under the name of FORAN, a Spanish acronym of FORmas ANalíticas (ANalytic FORMs). It was soon realized that this system could be marketed and exported to other technical offices and shipyards. At that time, SENER’s marine activities were focused on contract and classification designs (a.k.a. basic engineering). The next step was to develop an integrated tool for all design and production activities of the vessel.

The new system was conceived with all ship design disciplines (hull form generation, hull fairing, naval architecture calculations, design and production of structure) coordinated, with ultimate
goal obtaining ship production in the shortest and cheapest way. The first commercial demand for the use of FORAN was a contract by Litton Industries Inc. (USA) in late 1965, to develop a mathematically hull forms fair for the Fast Deployment Logistics Ship (FDLS). The result of the work of SENER was considered highly satisfactory and was incorporated in the proposal that Litton sent to the US Navy. While the US Congress did not authorize the funds for the FDLS project and the ship was never built, the development of FORAN was unstoppable.

FORAN was continuously improved and used as an internal tool at SENER, supporting high-quality projects within unusual response time. In 1969, the Spanish company, Bazan (now known as Navantia) expressed interest in using it. This led to the first FORAN license agreement. Since then, SENER has granted license to use the System to more than 150 shipyards and marine engineering technical offices in more than 30 countries.

Early processors were in general completely devoted to computation and offered no easily available graphical interface or display until the late 1970s (i.e. blind punch cards on the DEC-10 terminals). On these 1970s, FORAN’s functionalities were expanded (structure, machinery, piping, electrical and beyond). This evolution ran parallel to the course of computers, from large computers operated with punching cards, modules running on mainframes only available for the largest shipyards, through the mini-computers like PRIME or VAX with monochrome graphical screens, then the UNIX operating system, moving forward for working on PCs, with amazing graphics and great computing capabilities and on the 1980s the Tektronics green on black display.

4. The Present on the Shipbuilding CAD System environment

A lot of technology exists today that can be put to use in creating, maintaining and exploiting the ship model. The FORAN System for example, since its creation, was differentiated into two stages, design (modules from F.1 to F.7) and hull production (F.8 to F.22), all of them shown on figure 4. This modular organisation has proven to be very beneficial. All recent CAD integrated shipbuilding tools use modular organisation, subdividing normally into five major groups: Hull Forms, Naval Architecture, Primary Structure, Outfitting/Machinery and Electrical Subsystem.

![Fig. 4 Ship design phases with a database oriented CAD system](image-url)
4.1. Surface definition

One of the first tasks in CAD is the definition of hull forms, including external hull, decks, bulkheads, appendages and superstructures. In FORAN, the geometrical representation for all these surfaces is based on trimmed NURBS patches, Bezier patches, ruled surfaces and implicit surfaces as planes, cylinders, spheres and cones. The surfaces can be imported from files using different generic formats such as IGES and AP-216 of STEP.

In the CAD system market, there are two complementary tools for surface definition. The traditional tool permits defining the hull surface, either conventional or special forms, such as non-symmetrical ones, multi-hull and platforms. The traditional tool includes advanced fitting and fairing options and allows several transformations of the hull forms (based on block coefficient, longitudinal position of the centre of buoyancy, quadratic). Operations like lengthening or shortening of a ship can be easily performed. More recently, some CAD systems (like FORAN) have incorporated an additional functionality based on the latest-generation of mechanical design that can be used for improving hull forms, by means of target driven deformation for improving design creativity and final shape quality, implementing thus parametric design and global surface modelling.

4.2. Main structure definition

In the hull structure definition, there are several approaches, according to the philosophy of each CAD system. There are mechanical, parametrical and topological ones.

Despite the capabilities of the 2D or 3D structure modelling, an important aspect refers to the design-for-production concept, which is based on the definition of build strategy. Thus the CAD system must be able to establish and organize a project in accordance with the manufacturing and assembly processes taking place in the shipyard. In FORAN, the build strategy is defined by arranging a hierarchical tree describing the structure of the ship, figure 5. The full product model is organized into a hierarchy of intermediate products and may create alternative build strategies, providing for the creation of interactive intermediates functions, allocation of parts, the possibility of classifying using configurable attributes for each type and the definition of the assembly sequence, so that drawings and intermediates lists can be generated automatically.

Fig. 5 An AHTS vessel scene defined with a CAD System
Currently CAD systems can automatically calculate welding lengths and welding type classification according to various criteria (position and assembly interim level), yielding welding reports and drawings. The CAD systems generally provide solutions to produce nested plates and profiles according to the standards of the yard, their means of production and manufacturing methods. FORAN can be used to calculate the material take-off as well as to generate information for CNC machines, cutting patterns and statistics during the detailed design phase raw material.

4.3. Outfitting & electrical design process and cost

In shipbuilding, normally only few units of a particular project are actually constructed (very often only one). Due to this, shipyards and design offices try to re-use previous designs. In the case of outfitting/electrical, it is traditional to re-use data regarding standards, materials, specifications, equipment models, etc. Sometimes, complete or partial outfitting/electrical designs may be used in another project. The CAD system should be able to support this practice. Data must be transferred between different systems, by zone, by module, by block and even by interim product, at user decision, including attributes, geometry and layout. Transferred data could be handled in the new project as any other data defined directly on it, capable of modifications and updates. The trends towards modular outfitting makes the re-use of data even more useful, not only from a single previous project, but from several ones.

The trend in shipbuilding towards pre-outfitting of blocks and sections to the highest possible level makes it compulsory that outfitting design must be fully coordinated with the rest of the design. All aspects of the design become small pieces of the puzzle called vessel, and failure in one of them could produce failure in others. The earlier failures occur, the more serious the consequences are. Thus it is essential to have a complete control of the design. This control is even more important for outfitting design. Here, modifications impact all the stages, due normally to early starting of activities when the design is still immature. Changes (due to class society comments, changing owner requirements, availability of equipment, production subcontracting, feedback from previous projects, etc.) are common. This obliges outfitting design change management to be very efficient.

Although there are large variations due to ship type, on average 50% of the total design cost is related to outfitting tasks (piping, equipment, HVAC ducts, auxiliary structures, etc.), 40% to hull structure, and the remaining 10% to electrical. Based on these numbers, and assuming 7-10% of the total price of the ship are attributed to design, we have outfitting design accounting for 3-5% of the total cost of the ship. But not only this. An efficient outfitting design means also a good project, and this has direct impact in the cost of the overall construction. Considering that of the total cost of the construction 40% is related to outfitting tasks, we have that decisions taken during the outfitting design phase impact more than 35% of the total cost of the ship. So, an efficient outfitting design is an opportunity to dramatically reduce costs and improve productivity.

Achieving 100% valid production information requires an interference-free design. It is thus necessary to detect interferences between all the elements of the 3D model directly when an element is added or modified in the 3D model. This detection must take into account not only elements visible, but any element stored in the database, including those insulation, operating spaces, escape routes, etc. The CAD system must provide tools to classify the detected interferences (soft or hard), to eventually approve them, and to generate detailed reports. On top of that, suitable tools must solve interferences detected also in an on-line regime. Interference detection algorithms must be optimised to avoid negative effects on performance and response time of the system due to the on-line calculation process.

During the design process, when creating the 3D model, it is necessary to consider already the fabrication and assembly phases, adapting the design to the actual production methods and devices of the shipyard. Among others, the following aspects must be considered:

- Maximum length for pipes considering the straight pipes supplied to the shipyard.
Handling of fixed angles for elbows, for optimization of materials.
Bending machines and restrictions for bending of pipes (clamping, collisions, allowable nominal diameters ...).
Size of pots for galvanizing and other treatments for pipes.
Availability of automatic flange welding machine.
Gross plates used for development of HVAC ducts.
Standard plates and profiles used in auxiliary structures.
Use of standard support and hangers.

It is necessary to complete the production-oriented design by assigning outfitting elements to interim products, reproducing the actual build strategy according to which the ship would be built and allowing the pre-outfitting of blocks and sections.

In addition, all production and assembly information must be generated mostly automatically. Due to the common modifications that appear during the design process, the system must maintain an automatic control of the production information and the 3D model, providing warnings when the changes affect already generated production information. CAD systems must provide NC data for feeding machines and devices of the shipyard such as bending machines, welding machines, etc. Thus it is necessary to customise formats in order to match each shipyard’s specific machines.

![Fig. 6 Representation of different aspects of the electrical design inside a CAD System](image-url)
5. The future on the Shipbuilding CAD System environment

There are several fields where CAD systems could improve in the near future. However, here
the focus is on functionalities that are being improved right now. E.g. in hull forms fairing, the global
shape modelling or the advance continuity and capping could transform complex surfaces with
excellent results, less interaction, high accuracy, and full control. These techniques shorten
dramatically the design time, from days to minutes while obtaining excellent results.

Another area of improvement concerns one of the most time-consuming tasks in outfitting
design, the routing of pipes, HVAC ducts and cable trays. Automatic routing options minimise this
time, but without reducing the robustness of the design. Automatic routing provides simple solutions,
with optimisation of material, and several algorithms exist. But the matter is not only to consider
existing elements for future routings; it is also necessary to assign priorities, and eventually handle
automatic modifications of existing elements as a consequence of new ones. The complexity of the
problem explains that there is not yet fully satisfactory solution for the automatic routing in practice.
Current solutions provided by CAD systems solve partial problems, offering already significant
support.

![Fig. 7 Marine design information in each stage of the ship using electronic devices](image-url)

Another area where the CAD companies are active is Virtual Reality. The objective is to create
a user-friendly environment in order to review, audit, obtain metrics such as the progress of a project,
etc. This type of review process of the model does not need to use tools for designing, just a simplified
tool allowing easy access (“viewer”). In figure 7, a 3D visualization model is reviewed in a tablet,
where the authorized designers/engineers could have all the project information. These navigators
allow access for reading 3D information in order to load the component tree of any customer project
to obtain information about any item. Other basic tools available in these programs have different
modes, allowing navigation commands to take action such as measuring distances or angles, creating
sections to access internal components, etc. The interface with the program is via a mouse, but Virtual
Reality opens windows of opportunities, with globes, glasses or helmets.

Advanced browsers allow incorporating human models in order to study ergonomic aspects,
creating highlights and textures for advanced renders, movements of components to perform
simulations, etc. Browsers can connect to the database of a project in order to access information in
real time. Sometimes there is a need to take information from an on-line database and if there is an
Ethernet network through the shipyard, it is possible to implement a shared computer with a viewer
that allows connecting to a project. If there is not an accessible database, viewers should be able to
read files with the project information required for 3D modelling of the product and component data with optimal performance. So far it was prevalent to implement viewers on laptops, because laptops are usually equipped with processor and graphics cards that allow navigating through the entire project. In recent years there has been a breakthrough in mobile devices like tablets or smartphones. This hardware progressively incorporates new processors that enable enhanced graphics. On the software side, operating systems have been developed specially adapted for such devices (such as Android or IOS) allowing interfacing naturally by touch gestures.

The widespread use of these devices nowadays has precipitated its use by software companies. Software developers have taken time preparing oriented solutions and among those that allow us to have project plans or 3D models on tablets or others electronic displays. In modern projects, there is the need, for technicians, to carry these devices to work better, with a quickly access the 3D model of the project, with all parts information and construction drawings needed. A wi-fi connection would allow connecting to an information server to be updating the information needed, mainly in files, as for example: 3D models, classification or production drawings, between others. Another advantage of mobile devices is that the user interface might interact with the project model or parts using gestures just as everybody does every day with smartphones. One develop line of navigator’s evolution would incorporate augmented reality technology. It would be helpful for production technicians to scroll through the project and pointing the camera of their mobile device to a particular component to obtain information from it and have the actual image of the same 3D design model displayed. This is possible through the use of markers that help the device to position itself within the project and also for the use of QR codes.

CAD systems must handle the information necessary for creating a collision-free design and for generating all production and assembly information, but not only this. The 3D model information is, at the same time, necessary for other activities and other departments involved in the construction of the ship, as planning, purchasing, subcontracting, accounting, etc. It is common that several design agents collaborate in the same project; so it is necessary that 3D model information should be shared between them to serve as reference. The paradigm of this problem appears when two or more design agents collaborate in the same project, using different CAD tools. In this case, the CAD systems must provide data exchange between them, leading to different degrees of integration, like visualization, spatial integration and cross manufacturing, depending on the characteristics and size of 3D model information transferred. At least, it should be geometry and key attributes. A worldwide format for data transfer has not yet been found. Despite recognised international standards, in most cases we see dedicated formats or particular adaptations from standard ones. Transfer of 3D model information could produce loss of performance due to different geometrical approaches to represent elements in both CAD systems. In this case, special solutions must be adopted in order to minimise this impact.

Achieving the common objective of making relevant information available in a way that is meaningful to the recipient, another recent milestone is the integration between different CAD systems and Product Lifecycle Management (PLM) tools, e.g. the FORAN Product Lifecycle Management (FPLM) tool with a neutral architecture. In this case, all the information generated in FORAN may be transferred to a PLM and may be subject to all processes: control, configuration and releases lifecycle and process management. FPLM consists of a series of tools and features that enable bidirectional integration between different modules of FORAN and PLM tools. The solution is based on standards such as XML, Web Services and Common Object Request Broker Architecture (CORBA).

There are many advantages of using CAD in shipbuilding: ease of design, speed of construction, use and reuse of information, etc. It is expected that in the future CAD tools will advance further and allow greater information management and virtual access through smart devices. In general, CAD systems provide tangible benefits while the process is optimized, reducing design time and production, and therefore costs.
As a summary, there are several scenarios of improvements for the next years. Some of these improvements may seem unrealistic in the short term, but reality often exceeds expectations in any field, and probably more in technology.

6. References