Designing submarines 4.0 with CAD/CAM/CAE tools. The application of the Industry 4.0 to submarine design

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Synopsis

Virtually every new design in the modern society is supported by information technology tools. Starting from computer aided designs, backboned with adequate databases and operated with lifecycle management of the information. If this principle applies generically, it comes without saying that must be put to the limit when dealing with the most complex, expensive, restricted and deadly designs ever, only matched -somehow- by the space technology: submarines. Among the new concepts that arose related with new information technologies, the *Internet of Things* (IoT) has a special role due to its potential, and to address the challenge of the IoT for submarines, it is essential that *Computer Aided Design* (CAD) and *Product Lifecycle Management* (PLM) tools adapt each other in different manners.
The design of a submarine comprises a large number of very different disciplines. It seeks to optimize the product from different points of view, requiring design systems that need to be highly connected. They must be able to talk to one another, exchange data, geometry and attributes. It is necessary to have data communication agreements through either *Application Programming Interfaces* (APIs) or common interfaces.
The different systems operating on-board a submarine should not work autonomously, taking isolated decisions based on their own sensors feedback. Instead, there must be a higher-level supervisor system, capable to evaluate how they interact and what consequences are derived from system *A* action that would affect to systems *B*, *C*, *D*… That´s a huge responsibility, due to the submarine involves a very costly platform (the boat) that contains inside an even more expensive -and deadly- equipment (the combat system). Such higher-level supervisor should be powerful enough to cope with the thousands of different inputs, process them fast and accurately, take some automatic decisions and, finally, ease the work for the manager of the supervisor in the critical decisions: the human intelligence.
In this paper it is explained how future submarines should be connected to IoT. The connection of smart devices within a submarine must be human controlled. The control should start from the design tools because they control the shipbuilding process from the early stages of the design up to the final production. The set of design tools, product lifecycle management and device must be inter connected among them and will be the platform for the submarines connected to IoT. The information shared in the scope of the IoT must be managed by the human along the whole lifecycle of the submarine, starting from the beginning of the initial design. This need, as it will be described, requires the CAD tools to be prepared with specific characteristics to handle that information.

Keywords: Submarine Design; CAD; IoT; Digital Twin

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1. A brief history of CAD Systems

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 drew up construction details and compiled tables of offsets, or

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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, as were used during the construction of the USS Holland (illustrated in figure 1), taking measurements from the outside of the model. 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. However, 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 *Computer Aided Design* (CAD) systems (Perez & Gonzalez, 2015) that started dealing with the hull forms fairing, from where the hull structure would also be generated. Outfitting handled by CAD systems (pipes, machinery, HVAC...) is considerably newer than hull form design or structural design. Outfitters used wooden and plastic models until the late 20th century. It was only then that CAD systems expanded the application range, covering all project disciplines, thanks to the evolution of computer graphics environment, among other key factors.

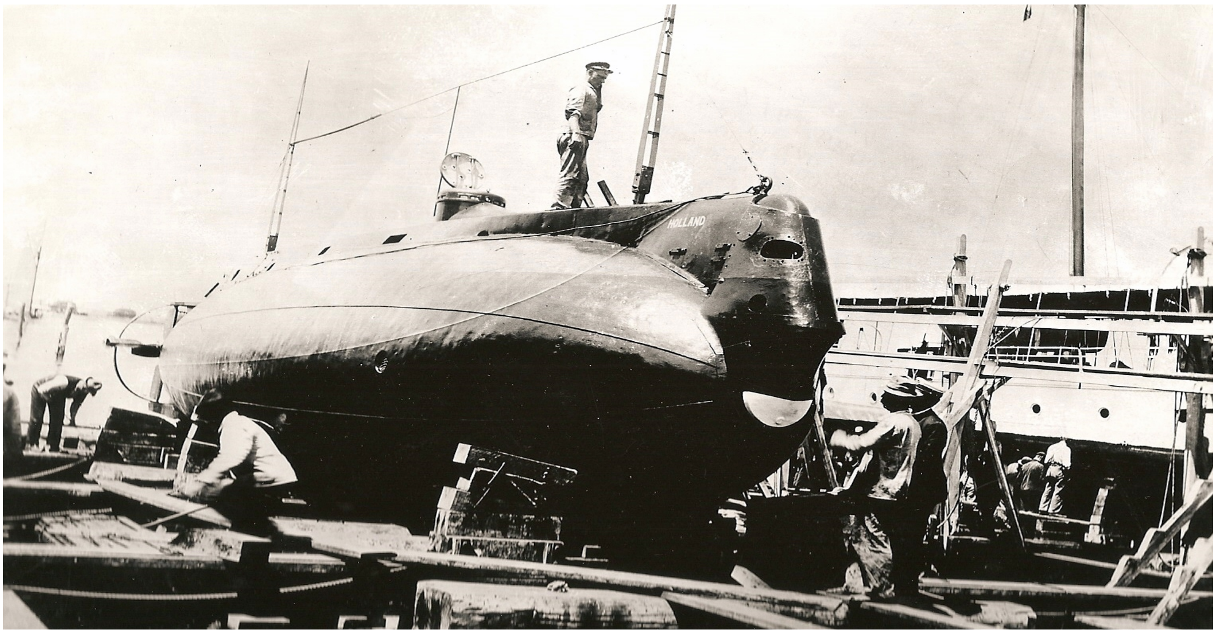

Figure 1: USS Holland (SS-1). *Source: www.ussholland.org*

Traditionally, most shipbuilding CAD systems focused on hull forms definition, naval architecture calculations and structural design. This changed when new challenges in shipbuilding forced marine suppliers to devote special attention to this matter, demanding closer coordination between hull structure and outfitting. It was a time and cost saving matter, and most shipyards started to pre-outfit the units before their assembling in the slipway.

Some marine CAD systems started the development of their particular outfitting tools, others preferred to find a closer integration with existing plant design oriented systems. The development of a particular outfitting design tool 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 shipyard environment 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. Singularities 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 (Perez & Gonzalez, 2015).

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2. Introduction to the Industry 4.0

The Industry 4.0 transformation implies a huge collection of interrelated and joined technologies, which can be analysed independently, but must be applied as a complete integrated implementation in each industrial field, moreover, in the CAD development industry. Each technology expose a set of boundaries, which cannot be differentiated evidently from its neighbouring technology.

Virtual, Augmented and Mixed Reality are closely associated to the Digital Twin and interconnected with the Big Data, which is produced by the CAD tools and all surrounding solutions, which applies some cloud/edge/fog computing to this data in a merged technology between finite state machines and *Artificial Intelligence* cognitive processes (Benayas-Ayuso and Perez, 2019).

To perform in an agile manner all these computing, it requires a network which supports different connection ways to add special devices, i.e. *Internet of Things* (IoT), which can access to the data, creating and modifying it, in a different layer which affects to the basic information layer created by the CAD System in the shipyard.

This network should be safe, pertaining cybersecurity, but open to allow distributed work, which must be step controlled in a manner that records any modification of each working step done in an open, transparent, trusted and non-modifiable working method for all actors involved in process, like the shipyard, the design offices, the classification society and the ship owner, blockchain. Moreover, blockchain technology can address the issue of security.

Results of the design should be easily integrated with future building ways like 3D printing, generating printing orders directly from the CAD model. Shipbuilding engineering phases involve design and production, but an integrated Industry 4.0 CAD System should also be involved in operation and maintenance.

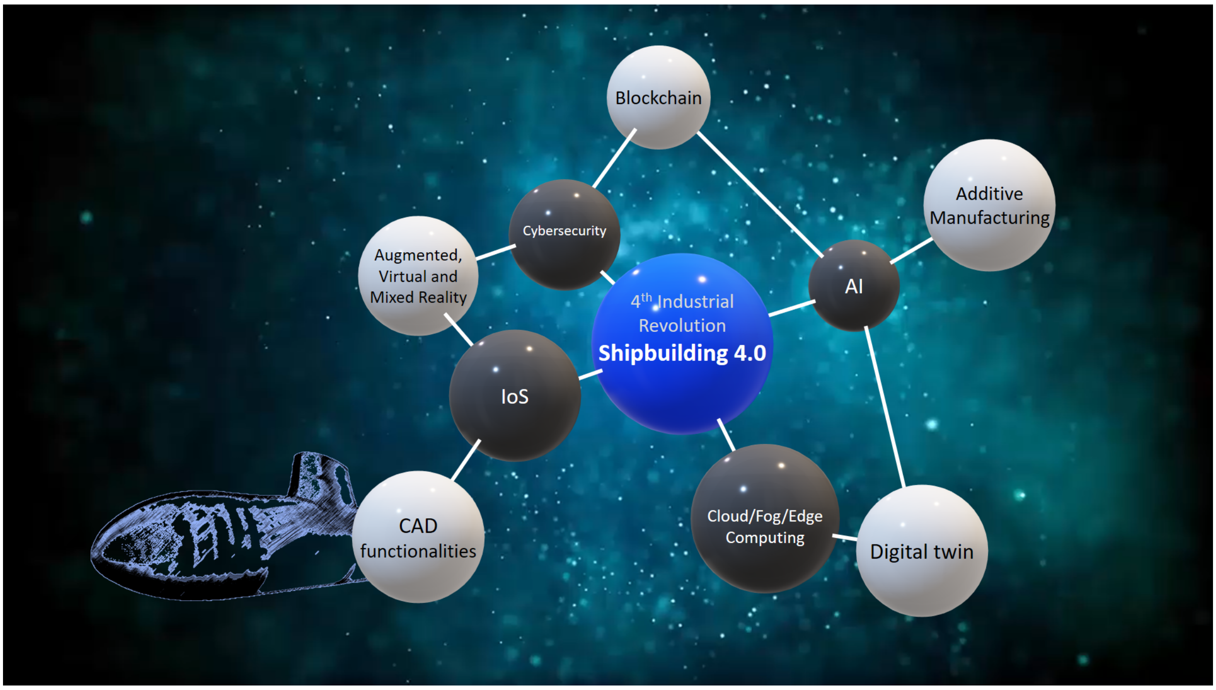

Figure 2: Related Industry 4.0 Technologies in a Shipbuilding CAD environment

At the end, this is just a short summary of the *Industry 4.0* technologies, which can be applied to a *CAD* System (as shown in figure 2), included in, or as an integrated surrounding solution, or as information producers for the evolving design process.

3. Submarine 4.0 design philosophy

With submarines 4.0, we are referring to the application of new technologies (Industry 4.0), to submarine design. Although the submarine hull forms are not the most complex compared with other floating units, the existence of bridge fin, skegs, appendages…, turns the former statement upside down and really makes the

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submarine more complex than standard vessels, from the hull forms point of view. The possibility in CAD Systems for importing surfaces defined with third party tools (mainly mechanical systems), valid for naval architecture calculations, could be not enough, as the importing procedures normally imply reformulation of surfaces that make them heavier than in the original format and therefore producing worse performance and further problems in production information (i.e. shell plates development). It means that it is preferable that the CAD System has its own advanced hull forms definition tools, and if it has not them, at least to have optimized links with such those programs.

Submarines are far more complex compared with commercial vessels of similar size, and that means much more data. At the same time, submarines have more dense spaces, compelling therefore the CAD System to handle huge amount of information. It means that the data structure and the visualization options of the CAD System should be optimized to guarantee a good performance. Nevertheless, the aspect of the complexity of the vessel does not refer only to amount of information, but to the level of detail with which it should be generated in the 3D Product Model. All elements of the 3D Product Model are created with a very high level of detail, eventually producing therefore more computer´s performance problems. This requirement is even more important in the case of submarines, where due to lack of space the 3D Product Model is built very accurate.

Although in the last years there have been attempts by regulatory bodies, classification societies and maritime organisations to force the different states to apply international rules and class notation to submarines, usually submarines do not comply with international regulations or rules applicable to naval ships (Perez & Peter, 2019). They are conceived, in most of the cases, following particular rules (intact and damage stability, collision and impact) established by each Navy. Although these rules are in most of the cases more strict and restrictive than those for naval ships, their peculiarities make them generally not covered by CAD Systems. This implies the use of specific calculation tools, different from the CAD System used for the rest of the project. In order to avoid this, the CAD System should be flexible enough to incorporate new functionalities, and if this is not possible, at least allowing to interface suitable tools in an easy way and maintaining the integrity and consistency of data.

The complexity of submarines, as well as the huge investment that they involve, lead often to situations in which submarine programs are developed as a result of the collaboration of different companies, not only design offices, but also the manufacturing shipyards. Even more, in latest times is being more and more common to have submarine programs shared not only by different companies, but also by different countries. There are several possibilities for this collaboration (for example splitting the ship by zones, by technological concepts, by functions), but all of them contemplate that CAD Systems used by each collaborating part should be the same, or in case this is not possible, at least that both systems could understand each other and interchange information in an efficient and fast way. This implies also a rational handling of legacy data.

4. Submarine design processes

In submarines, the long duration of the construction program turns the time factor not very relevant. This means more segregated design phases, and in most of the cases minimisation of the use of preliminary or not approved information, thus avoiding the necessity of re-work in modelling tasks. It also means that drawings and outputs are not generated according to the just-on-time policy, but in advance to the fabrication phase. This aspect significantly facilitates the use of a CAD System.

The same nature of the product, its purpose, the harsh operation conditions and the materials used, as an example, leads to a higher control of the production process, including the design. This control implies, among others, the validation of previously defined data, the access control to the 3D model and the record of all interaction with the Database for further tracking (change control). All these aspects should be covered by the CAD System, which should provide innovative solutions without losing any performance or handicapping the efficient work of the designers. Special attention should be put in the maturity control of the design through the validation of the 3D model, as the most suitable tool to measure the degree of advance of the design.

Submarines are complex platforms in which many participants are involved. Even in design phases (a schematic representation of all the phases is presented in figure 3) it is very common that the design itself is shared by different specialists, each one devoted to a particular task but at the same time handling the ship as a single entity. It is preferable that all the participants would be physically located in a single place, but this is not the most common case. Thus, the CAD System should provide a suitable solution not only for integrating

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specialists remotely located, but also for integrating the tools used by these specialists. This integration will allow interchanging data, both geometrical and technological. For example Digital Twins, sourcing a single source of truth, can address the issue of remote working of different groups.

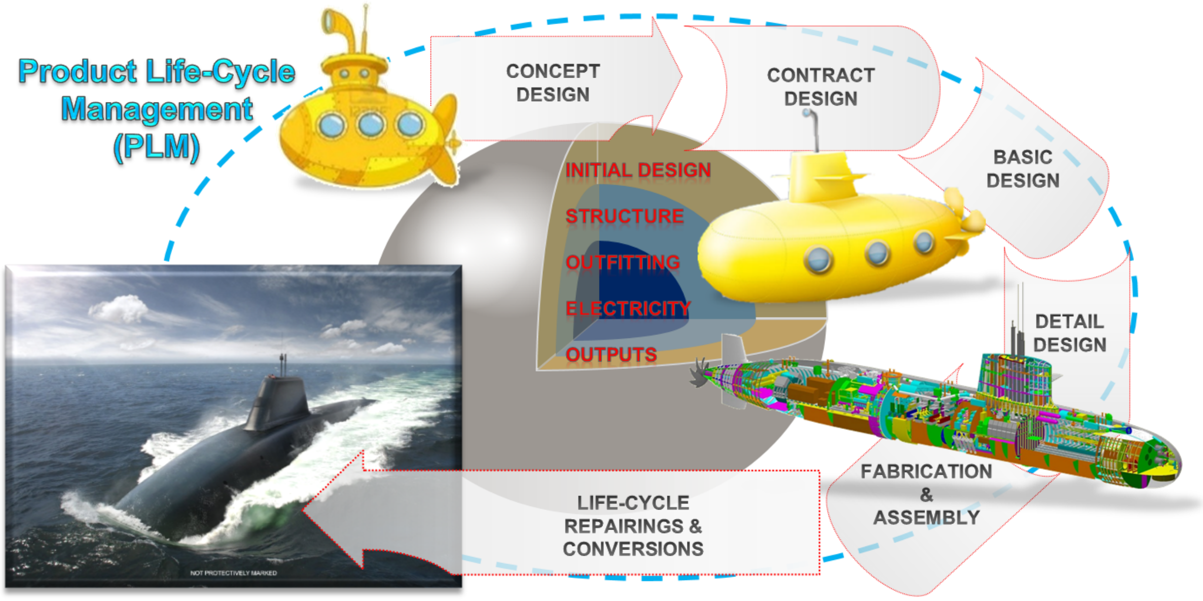

Figure 3: Submarine design process overview

The participation of different suppliers, design agents, work procedures and design tools should not affect the consistency of the information and its confidentiality. Therefore, all data transference and remote access must comply with specific requirements for secure work that produce a reduction in the efficiency of the design. Regarding the CAD System, these requirements mean an additional obstacle as they make more difficult the technical assistance and consultancy services.

A CAD System should have different possibilities as regards the visualization, as certain objects would be shown to certain users by means of a "secure" representation. The aim of this level is to contain the geometry to be shown to non-authorized users during the different design tasks (equipment reading, etc.)

The Shared, Detailed & Simplified or Secure representation group should be read depending on the user privileges for the library model.

The unique characteristics of submarines, the long duration of the design and the necessity to improve existing solutions could derive in the parallel study of different design alternatives. This affects the concept of single product model, and the CAD System shall be able to manage the subsequent situation and to merge approved alternatives. In some cases, different alternatives are consolidated, being also the source for having different projects to be managed simultaneously. The study of alternatives could also imply the use of simulation tools (augmented, virtual and mixed reality) that shall be available in the CAD System, or at least compatible with it.

As in surface ships the rule-based design is focused mainly in production aspects, trying to optimise fabrication processes, in submarines rules are mainly devoted to actual design aspects. CAD System shall allow designers to propose solutions acceptable from that point of view and avoid other ones contrary to it. In addition, as these rules are very particular for each builder and Navy, CAD System shall be adequate in order to be customised and provide suitable solution for each organisation.

Among others, types of data needed to design submarines include:

- Design and fabrication requirements
- Design rules
- Class Societies and Navy regulations
- Best practises
- Technical specifications

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- Information from suppliers
- Legacy data
- User manuals
- Lessons learnt
- Operational data

Submarine implies the design of many prototypes, from which only some of them will arrive to a later stage of the design, and only very few become projects to be actually built. At the same time, there are data from actual projects valid for the future. All of this means that shipyards and design offices have available data that could be reused for new designs, saving therefore time and effort on them. If the existing data is available in the same format in which the new design is being developed, the data transference is not difficult, as all CAD Systems have export and import tools for own data. However, if the data is in different format (information from equipment suppliers, standards,) the process requires not only the data exchange through *Application Programming Interfaces* (APIs), but also the format translation, direct or through a neutral format. In such a case, it should be taken in consideration the size of the data once imported, as normally it produces degradation in the performance of the CAD System.

The integration of the CAD System with the *Product Lifecycle Management* (PLM) system in submarine industry is needed to perform an integral management of the design, but not only this; also of the product through the whole vessel lifecycle. All departments involved in the design and manufacturing of submarines need to address important requirements like: document management for all related CAD documents and files, maintenance of the relation between the 3D Product Model and the documents generated by the CAD System, management of standards, workflows and processes associated to the design and manufacturing processes, common access control, coordination of project participants, supply of updated and correct information to all parties. It is therefore necessary to make available the CAD information to all departments of the shipyard (non design departments), as operations, planning, production, purchasing, shipyard management... and this is something to be done by linking both the CAD System and the PLM system (Perez et al., 2018).

One of the most complex aspects designing submarines is the outfitting design, as well as one of the most designer time consuming tasks is the routing of distributors (pipes, ventilation ducts, cable trays) on board. But not only this: the interaction of distributors with other elements as equipment, the restrictions for routing, the fulfilment of regulations, the objective of optimizing designs, fabrication and assembly.

Due to this, routing of pipes is one of the paradigmatic cases in which the application of Industry 4.0 technologies, as IoT, to the design can help designers and make the design itself more robust, consistent, and efficient. The application of IoT techniques would assist the designer in taking decisions and adopting routings that optimize the design and minimise the design time.

For it, the Industry 4.0 technologies, as *Artificial Intelligence*, uses algorithms considering all documentation relevant to the design: material specifications, requirements from the navy, fabrications constraints from the shipyard, applicable regulations, information from equipment suppliers and electrical connections, guidelines, experience from existing submarine projects, available P&ID´s or preliminary flow diagrams, structural consistency… All these documents, once structured, would allow the user to ask for help (or to get this help without interaction from the naval architect) for any task in execution.

But not only this. The application of Industry 4.0 techniques would assist the designer in taking decisions and adopting routings that will optimize the design in a shorter working time. Among others, the following aspects are considered as suitable for optimization and automation (Muñoz & Perez, 2017):

- Systems prioritization
- Main routing areas selection
- Elements technological attributes selection
- Routing optimization
- Previous projects analysis for improvement
- Impact in production analysis
- Actual ship´s operation feedback for design review

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The result of the application of Industry 4.0 technologies in routing tasks would lead to the automatic routing, avoiding more than 70% of the hours currently spent in this part of the design (de Gongora, 2019). Even more, the design is more robust as the designer and the workers know exactly the restrictions or incompatibilities of any design.

5. Submarine production process

Submarines use particular standards, which apply to structural materials (steel, alloys or profile cut-ends), outfitting components (pipes, fittings, duct sections, hangers and penetrations), electrical elements (transits and connectors for example), fabrication methods (plate bending, welding, and pipe bending) and assembly units. Standards provided by commercial off-the-shelf CAD Systems are not applicable, and the CAD System shall allow the creation and edition of particular standards. Moreover, it shall provide suitable tools to adapt existing standards to new ones according to shipyard internal procedures.

Riveting remained the principal method of plate joining until the early part of *World War II* (WWII). At the start of the WWII, welding was being used to join the circumferential butts of pressure hull plates in submarines, but seams still were riveted.

Current welding practice for submarines manufacture involves many resources, increase the weight and the cost of the boat, so it is necessary to be able to manage hull structure welding and pipe joins in the CAD System. IoT may be use for improving welding practices.

It is well-known the importance of the structural integrity of the pressure hull in submarines, where outstanding hydrostatic force due to the submarine depth is even increased by the need to withstand submarine explosions, adding extra pressure and accelerations. The design is relevant but the execution becomes critical at this point, so both teams require the highest degree of acquired skills. Industry 4.0 would help not only ensuring that the 3D model is properly generated in terms of stiffness (by allowing all type of virtual simulations) but also that the real structure fulfils the characteristics derived from the 3D model. Hence, designers and welders have to work in a very tight environment and that´s possible thanks to the complete integration of

There is an aspect very important for the submarines, which consists on handling of groups items/equipments in relation with the installation phase. The design in narrow spaces often require the consideration of the installation sequence (i.e. valve and actuator, fire extinguisher and its associated support, etc.). There are two generic cases where this aspect has to be addressed in the design stage.

The first case is related to the auxiliary structures hierarchy, the modelling process and the way parts can be organized for planning purposes, e.g. ladders with their mounts. Modelling an auxiliary structure in a CAD System gives the possibility to create a hierarchical structure, made of single parts (plates, profiles, special) and substructures (groups of parts). However, planning processes require to being able to organize these parts in a different way that they are modelled.

The second case deals with equipment composed of multiple items, e.g. fire extinguisher and the bracket, or a door and the frame. Normally, in submarines, the equipment is composed by individual items that can be grouped in an interim product.

The complexity of the design process in submarine industry has its parallel in the production phase. Fabrication and assembly documentation shall be adapted not only to own requirements of each shipyard or subcontractor, but also to particular needs of submarines, both in the content of the documentation and in the format used. This means that the CAD System must allow to generate outputs (including NC) according to these needs, and this implies that it shall include tools for customising outputs in an easy way.

This customisation is also needed because special materials, standards and processes involved imply the use of particular production equipment, so the data should be generated in a particular way to feed that equipment.

Moreover, once generated, in submarine, fabrication and assembly documentation follows more rigid flow procedures of validation and revision, being almost compulsory, a complete *Documentation Management* (DM) System. Although this DM system usually is not part of the CAD System, at least shall be interfaced with it, so the status of version of each document could be controlled.

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The long duration of submarine projects provides designers with enough time for generating all production documentation. However, the complex and rigid approval, procurement and testing processes operate in the opposite direction, requiring to issue information, material take-offs and drawings quicker.

Design is only a part of the building process. There are many other tasks getting the data from the design or providing data to the design that have big influence in the overall building quality, timing and cost. Regarding CAD System, it shall provide suitable interface with material management system, planning system and simulation tools (augmented, virtual and mixed reality). The paradigm of this problem appears in case there are two or more companies (shipyards or design offices) collaborating in the same project, even at fabrication stage, and each one has own tools. In this case the systems shall provide not only data exchange (APIs) between CAD System and other systems, but also between different CAD Systems (heterogeneous design in context) leading to different degrees of integration like visualization, spatial integration and cross manufacturing (Benayas & Perez, 2019).

With the objective of reducing as much as possible the fabrication (production) time, the application of Industry 4.0 technologies can help the production manager to immediate assembly the block and to mount missing elements (mainly from outfitting) in a further stage. Among others, the following aspects are considered as suitable for optimization and automation in submarines:

- Mounting sequence.
- Production planning.
- Pre-outfitting of blocks.
- Blocks stand-by area.
- General impact of any decision in the cost/delivery time of the project.
- Optimization of material.
- Production workflow.
- Jigs, rigs and scaffolding location (an example exposed in figure 4).

Figure 4: German submarine *Type 212. Source: Associated Press*

These examples affects not only to the design phase, but also considers actual fabrication and assembly restrictions, balancing the impact in one phase and in the other ones. It is not possible to establish the savings that could be obtained in these practical case, as it works in a “failure” mode, it means that requires a previous circumstance or failure to appear, but in most of cases the effect would be the elimination of delays in the finishing of the project.

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6. Submarine operation

In order to comply with the objective assigned, submarines shall remain in optimal operational conditions during all their life, and shall be updated to technological innovations during that time. This implies that modernisation works in systems, equipment, weapons and telecommunications, in bigger or smaller scope, shall be carried out periodically. Although the control of changes, updates and modernisation are usually controlled and managed with the help of a PLM system, it has also consequences in the CAD System. From this CAD System point of view, the as-build 3D Product Model shall not remain frozen, but shall correspond at any moment to the actual state of the vessel in order to be the basis for that modernisation works, so any change in the vessel must be also reflected in the 3D Product Model. This problem is more complicated as not all built units of a series and corresponding to a particular 3D Product Model are modernised. In that case, the 3D Product Model is split and from that moment handled as two different ones. Applicability management is therefore compulsory. The necessity to maintain updated the 3D Product Model of a vessel through all its operational life has an impact in the versioning policy of the CAD supplier, as a version of the CAD System that correspond to the 3D Product Model must be available at any time during this period. This is common to other industries, including surface ships, and is best handled by adopting digital twins concept.

The test for checking the validity of any ship design is the response or behaviour of the ship under particular conditions in its operational life. For submarines, those conditions include some circumstances that are very difficult to test in advance, being thus necessary to simulate them. In order to carry out these simulations, the best option is to get the data from the 3D Product Model, as it corresponds to the actual state of the ship once built.

Although the own CAD System may have tools for performing some simple simulations, more complex simulations should be carried out by special tools for this purpose. Therefore, CAD System shall have tools for exporting 3D Product Model to those simulation tools. Moreover, it would be convenient that CAD System is retrofitted with data coming from the results of the simulations. During the design phase simulations could affect the design itself, and once the design is finished the results would affect the design of future projects or produce an update of the simulated one.

Among others, the following aspects are considered as suitable for applying Industry 4.0 technologies (Augmented Reality, IoT…) in conjunction with CAD systems and PLM software packages:

- Data sensorization (i.e. to identify those data coming from sensors that are actually significant to improve every aspect of the performance of the submarine).
- Performance monitoring of submarines (i.e. to guarantee, based in predefined standards and requirements, the fulfilment of expectation in terms of performance).
- Meteorological conditions.
- Consideration of crew and consumables.
- Management of stocks.
- Management of permissions and navy certificates.

7. Conclusion

Submarine 4.0 is not a matter for science fiction; is a set of technologies that have a tremendous impact in the design of submarines using Industry 4.0 technologies, helping to build and operate submarines better, faster and cheaper. However, the technology is not completely developed, being the responsibility of CAD/CAM/CAE system to adopt it in order to improve its functionality.

As a conclusion, we remark the following ideas:

- IoT and Artificial Intelligence are ones of the enabling technologies that are going to most change the current shipdesign, having a direct impact in the development of the concept of Shipyard 4.0.
- Industry 4.0 can be adopted in every phase: design, construction and operation (lifecycle).
- Augmented and mixed reality in shipbuilding are currently in development process. However, its potentiality is huge in all aspects of the production chain.
- Industry 4.0 technologies could facilitate the training and improve the skill development of the design staff and submarine building yard, which is a challenge for many shipyards as on date.

- Industry 4.0 implies the participation of experts. The collaboration of the bests is the most secure guarantee for successful implementation. CAD/CAM/CAE vendors must involve in the development of their systems the best Artificial Intelligence experts whose experience obtained in other industries is almost in full applicable to shipbuilding industry. Communication and collaboration are the basic essence of Shipyard 4.0. These are the key to adaptation and success of Industry 4.0 in other industries.

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References

Benayas-Ayuso, A. & Perez Fernandez, R.: “What should shipbuilding expect from the CAD/CAM systems of the future?”. The Naval Architect magazine. April. pp. 28-31 2019.

de Gongora, R.: “Practical use cases of artificial intelligence in the shipdesign stage”. ICCAS 2019. Rotterdam, Nederland. Volume 3. pp. 203-209.

Muñoz, J.A. & Perez Fernandez, R.: “CAD tools for designing smart ships in the world of the Internet of Things” SMART SHIP 2017, 24 and 25 January 2017.

Perez Fernandez, R.; Benayas-Ayuso, A. & Perez-Arribas, F.: “Data management for smart ship or how to reduce machine learning cost in IoS applications”. SMART SHIP, 23 and 24 January. 2018.

Perez Fernandez, R. & Peter Cosma, E.: “The use of CAD systems to manage modularity in multi-role warships”. Conference Warship 2019.

Perez Fernandez, R. & Gonzalez, C.: “History and Evolution of Shipbuilding Oriented CAD Tools”. COMPIT 2015 (14th International Conference on Computer Applications and Information Technology in the Maritime Industries). Ulrichshusen, Germany. pp. 8-21 2015.