The Artificial Intelligence applied to *CAD*/CAM Systems for designing the future Naval Ships

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ABSTRACT

At this time all industrial designs are made by *Information Technology* (IT) tools, as *Computer Aided Designs and Manufacturing* (*CAD*/CAM), maintained and sustained with suitable databases and with lifecycle management of the information. To address the challenge of the *Artificial Intelligence* (AI) for designing better Naval Ships, it is necessary the *CAD*/CAM tools to adapt in different manners.

The difference items of a Naval Ship should not be autonomous objects that decide by themselves, but they should be supervised by a central system that takes into account the product as a unique entity. A Naval Ship is a product with a huge value, but also has a vast importance for what it contains, so it cannot be left to the edge of technological autonomy. It is necessary to have a higher responsibility and this responsibility must be of a human intelligence.

Future Naval Ships must be connected to be Smart thought *Internet of Things* (IoT) technology. The connection of smart devices within a Warship 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 operation management through detail and production stages. The collection of design systems, *Product Lifecycle Management* tools and other devices must be inter connected among them and will be part of the *AI* platform for the Naval Ships. The information shared in the scope of the *AI* must be managed by the human along the whole lifecycle of the Warship, starting from the beginning of the initial design. This need requires the *CAD* tools to be prepared with specific characteristics to handle that information.

1. INTRODUCTION

The *Industry 4.0* revolution involves a big bunch of interconnected and interlaced technologies, which can be studied separately, but should be implemented as a whole integrated development in each industrial field, moreover, in the *Computer Aided Design*, *Manufacturing* & *Engineering* (*CAD*/CAM/CAE) System, from now on referred just as *CAD*, development industry.

Each technology reveal a set of limits which cannot be distinguish clearly from its neighboring technology.

Augmented reality, virtual reality and mixed reality are closely related to the digital twin and interlaced with the *Big Data* which is generated 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* (AI) cognitive processes.

To perform in an agile manner all these computing, it requires a network which support 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 secured (*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: shipyard, engineering offices, classification society and ship owner (*blockchain*).
Results of the design should be easy integrated with future building ways like 3D printing, generating printing orders directly from the *CAD* model.
Shipbuilding phases involve design and manufacturing, but an integrated *Industry 4.0 CAD* System should also be involved in operation and maintenance phases.
When a warship comes for a reparation, sometimes the model is not available for this operation of maintenance.
In reparation and maintenance steps, replicating the full engine room or any other local in the *CAD* System could be a nightmare, unless *CAD* system has an *AI* processing toolkit which, from a cloud of points, can recreate *CAD* equivalent items which can be converted with a minor user intervention, and lesser as the *AI* learns, in a *CAD* integrated and full modifiable design.
At the end, this is a brief sum up of the *Industry 4.0* technologies which can be applied to a *CAD* System (as illustrated in *Figure 1*), included in, or as an integrated surrounding solution or as information generators for the evolutive design process.

Figure 1. Related *Industry 4.0* Technologies in a Shipbuilding *CAD* environment [7]

2. THE ORIGIN OF THE AI

To be able to understand how *Industry 4.0* became today's buzzword, it is necessary to understand that the *Fourth Industrial Revolution* takes the automation of manufacturing processes to a new level by introducing customized and flexible mass production technologies. This means that machines will operate independently, or cooperate with humans in creating a customer-oriented production field that constantly works on maintaining itself. The machine rather becomes an independent entity that is able to collect data, analyse it, and advise upon it. This becomes possible by introducing self-optimization, self-cognition, and self-customization into the industry. The manufacturers will be able to communicate with computers rather than operate them. All of this will be possible through *AI* example.

As regards *AI,* it can be said that there is no single origin of the concept known as *AI* and therefore there is no consensus to define that concept, but to be able to understand any of the definitions that apply, it is convenient to know at least briefly the most relevant facts and some of the milestones in its history.

It can be considered that *AI* was born as a philosophical study on human intelligence based on the concern of man to imitate the behaviour of other beings with capabilities beyond the reach of human beings (such as flying or diving), reaching the point of trying to imitate itself. In this sense, it can be said that *AI* is the search to imitate human intelligence. It is clear that it has not yet been completely achieved, but it is also increasingly true that we are closer.

The first man who became aware of his own existence and was able to think, surely wondered how his thought would work and would conclude the idea superior creator, an intelligent being capable of creating another one. In this sense, the idea of a virtual design for intelligence is as old as human thought.

In 1920, the Czech writer Karel Čapek [6], published a science fiction stage play called *Rossum's Universal Robots*. The play is about a company that builds artificial organic humans in order to lighten the workload of other people. Although in the play these artificial men are called robots, they have more to do with the modern concept of android or clone. They are creatures that can be passed as humans and have the gift of being able to think.

The English mathematician Turing publishes an article entitled *Computing Machinery and Intelligence* that opens the doors to *AI* [5]. The article itself began with the simple question: Can machines think?.

Later Turing proposed a method to evaluate if the machines can think, which got to know itself like the Turing test. The test, or Imitation game, as it was called in the document, was presented as a simple test to judge if machines could think.

1956 Dartmouth conference convened by McCarthy and where the term *AI* was coined. The conference was attended by researchers from Carnegie Mellon University and IBM, including: Minsky, Newell and Simon. In this conference extremely optimistic forecasts for the next ten years were made that were never fulfilled, which caused the almost total abandonment of the investigations during fifteen years, known today as *AI* winter [4].

3. ARTIFICIAL INTELLIGENCE AS A FUTURE SOLUTION

Control system in the ship can include some *AI* predictive processes integrated in the bridge overall control system, which helps to deduce the consequences of maintenance operations, from doing in the correct time as well as delaying or skipping them [2]

This procedure applied is including in the edge/fog computing methods, due to only involves the ship inner communication network, delaying the massive download of operation data upon arrival at port. During navigation data transfer should be only applied to critical operations.

Navigation data can be also useful in design and production phases, to correct some processes in order to obtain more efficient systems, and more efficient designs. This is only possible applying some *AI* process to this data, classifying, processing and getting some results.

This working methodology, to be deeply profitable for both actors, requires a joint venture between *Ministry of Defence* (MoD) and shipbuilder.

AI processes based on navigation data, in the multi-boat paradigm, can obtain information to improve design and production processes, which can be applied to the current series, or an evolved variant of this naval ship type, or other ones.

Ship operation phase is not the only one which produces a set of *Big Data* to be processed by an *AI* system, in the production phase, some calculus can be done in the workshops or even delegated in a cloud system, to be distributed.

This data, in *CAD AI* tools, can be classified generating working sequences, design automatic checks, and automatic design processes.

Now, setting the focus on the Designer, sometimes for the tight schedule or for the start-stop working requirements of the design office, like meetings, designer does not have much time for its principal task: create full effective designs, which requires concentration and calm.
This problem can be solved by *AI,* applying some design rules, and exposing a bunch of effective solutions, delegating the final decision on designer but helping discarding a big group of previous solutions which have shown some problems (learned lessons).
At this point, some sceptic people can think: *AI* is going to substitute designers work, but *AI* is going to augment the capabilities of this designer, making work less stressing and more efficient.
All available *AI* processes which can be applied in a *CAD* system to help designer are represented in *Figure 2*.

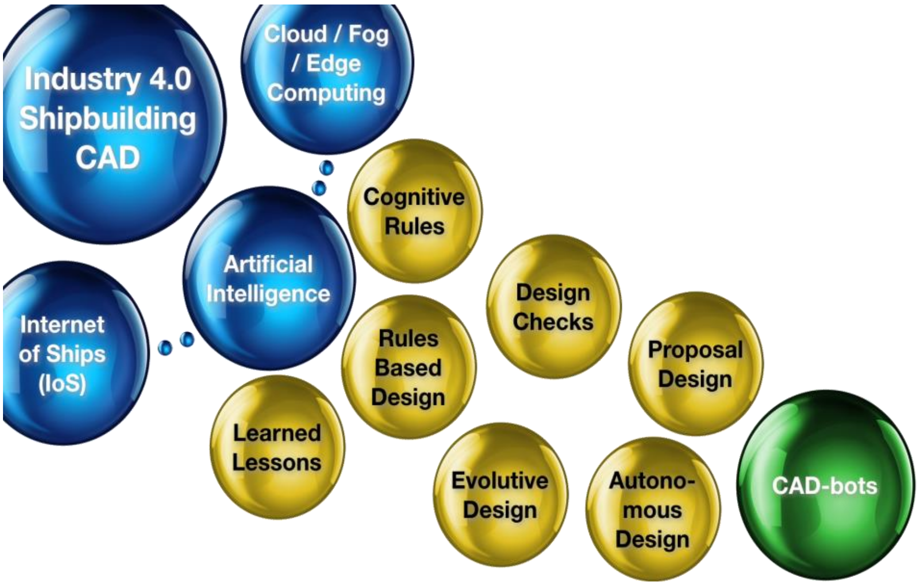

Figure 2. *AI* Evolution in the Shipbuilding *CAD* World [7]

3.1 First level AI CAD tools

AI applied to a *CAD* system should be based on the standard ways to control a design:

- Rules Based Design.
- Learned Lessons.
- Cognitive Rules.

First on the list, rules based design, it is the shipyard standards book of rules. These rules are the base of any dockyard design, and are the first one to be learned by our *AI* system.
To improve it, some other technologies can be applied, like Cognitive *AI,* which is the base of natural language processing in an *AI* solution.
This cognitive *AI* can be run over the shipyard standards book of rules, and with some user help, try to improve understanding in application of the rules from the *AI* tool.
All *AI* solution requires a specific time to learn the correct ways to apply the set of rules.
Next step, also based on natural language spelling, can be add the Learned Lessons to our *AI* solution, creating a mixed ecosystem of rules to be applied to the current design process.
And last step, but not less important, Cognitive Rules, these rules are deduced from the current design and also from production error input in the *CAD* system, like design incidences.

3.2 Second level AI CAD tools

With all first levels fulfill, second level steps can be applied:

- Design checks.
- Evolutive design.

First improvement applied in the *CAD AI* is the capability, in a non-highly intrusive manner, help user with the design, offering a list of design rule application failure to the current work.
This list, if is based on the second part of this tools, evolutive design, can not only the design issues, also offer an improved solution to user.
The bunch of solutions offered is based on the experience accumulated to similar issues found in the historic of the design improvements applied.
These steps generate Learned Lessons input in the *AI* system.
Second level tools requires a high level design knowledge to be trained faster, like a design checker role.

3.3 level AI CAD tools

Once the previous two levels have been accomplish their training, a third level of tools arise:

- Proposal design.
- Autonomous design.

First third level tool, proposal design, is one of the most required tool, in a natural language interchange: "Please, which are the best ways to connect this equipment and that pump?".
Based on the cognitive learning process of the *CAD AI* tools, the answer can be interpreted in machine language as route some pipe lines which connects both items and let me select the better one on my design criteria.
This last step also generate Learned Lessons input in the *AI* system.
Second third level tool, autonomous design, require a big bunch of approvals of the previous question, and based on them and in the *Piping & Instrumentation* (P&I) diagrams, can look for the best location for equipment items in the naval ship, as well as, create a piping solution of the system.
This step generate *Cognitive Rules* input in the *AI* system. These third level tools require months or years of training in the *CAD AI* tools, creating which can be named as *CAD*-bots, autonomous designers which, based on a simple input, P&I diagrams, can recreate a 3D accurate design, which accomplices which the most when not all design rules applied.

4. AI CAD-BOTS

These *CAD*-bots are *AI* augmented cognitive bots which can perform automatically some design parts based on the lessons-learned and cognitive rules, but always fulfilling the complete list of the shipyard standards book of rules.
There is one exception, in the case of contradictory ones. At this point, *AI* tools, represented by the *CAD*-bots can offer designer which rules have a conflict and reapply approved rule to the previous design with reduced effort.
These *CAD*-bots can design and offer user a set of the most efficient solutions, helping in some complex design processes, like the study of the impact of deep design modifications, or even classification rule changes, augmenting user capabilities.

CAD-bots cannot solve all design problems, but their orientations is to do the most repetitive tasks as well as help in some design corrections.

5. AI APPLICATIONS IN MARINE INDUSTRY

The naval industry has always been very traditional and seems to be always in the tail of the implementation of the improvements that in other industries have matured previously. This fact has a reasonable explanation in the difficulty that the naval industry has to convert investments into profits. The naval industry is not friend of risks, especially when the simple fact of making warships is a huge risk in itself. On the other hand, the naval industry collects, to a greater or lesser extent, all the other industries and it may be thought that what is good for the others must also be good for it.

Focused on the shipbuilding industry, *AI* shall address important limitations among which are the lack of data or the confidentiality of the same. The marine industry has focused on immediate results, it is looking very quickly for a solution and does not store data and results in a systematic way that allows it to be used again in similar scenarios. The development of powerful algorithms requires that they can be applied in similar conditions with some recurrence. The data must be correctly structured and reasonably clean so that they can be used with advantage [10]. In the most successful cases there may be limited series of warships that have the same characteristics. It is difficult to find a systematic use of the data, but still there are interesting contributions that occur in the different phases of the life cycle of a naval project. However, it is possible to find a recurrent pattern in the characteristics of the steel parts of the ship. So *AI* systems can assess if they are correctly defined.

5.1 AI in marine design

The first stage of the lifecycle of naval artefacts is designing. We can find interesting approaches to the use of *AI* in this phase. And it must be said that some of them are quite old and date back to the time of the first explosion of *AI* interest. In 1989, the *Defense Advanced Research Projects Agency* (DARPA) of the United States promoted a workshop held at *Rutgers University*, New Brunswick, NJ to support research initiatives of hydrodynamic designs of naval ships. One of the objectives was to clarify the relationships between the hydrodynamic design problems of ships and the areas of *AI* research related to the design and analysis of complex systems [4]. Note that the results cannot be said to be very promising, since they concluded the need to acquire computational fluid mechanics analysis tools *CFD* and integrate them into the design processes and effective control of design processes, focusing on concurrent design and including approaches to explore feasible design space configurations and systematically recording and storing results. However, the expectations remained open and unspecified. Later approaches have been made to apply *AI* to the resolution of complex design problems through expert systems and the appropriate selection of them for certain problems such as structure dynamics or vibrations.

Where it is possible to find a greater variety of proposals is in the task of optimizing the designs using *AI* algorithms that analyse the design space of certain naval ships in which it has been made a systematic parameterization of the variables that allow to define different design alternatives. One of the examples can be found in the article, [16], for the application of *AI* to the design of cargo ships. However, it is not easy to find applications of *AI* to really systematic processes that are in real use, beyond purely academic or research attempts that have not finally materialized in the field of design. The reason can be found in the difficulty to develop these tools and the low return that companies and organizations derive from them.

5.2 AI in naval products and companies

It is possible to find some more tangible applications with a certain validity in the field of the operation of the ships, that is to say, the operation and the management of the transport. In this sense, the initiatives are much more numerous, although some are in phases of research or prototypes, others are in more advanced stages of implementation.

Thus, it is possible to find prototypes of unmanned vehicles that are used in very hostile environments and that require the support of *AI* This is well described by the MIT professor, Henrik Schmidt, in his course *Unmanned Marine Vehicle Autonomy, Sensing and Communications*. These types of artefacts in difficult environments, such as ice water, where communication is an impossible limitation, the role of *AI* is crucial, [11].

Another interesting field of application of *AI* is described in an article about the use of *AI* techniques for the detection of small warships, [15]. The approach is interesting because it raises a situation in which the naval ship is the subject of the observation, but can also be the owner of the application. Having on board systems with detection techniques of other warships, based on *AI,* opens the horizon of unmanned naval ships and their possibilities of realization.

AI also is being integrated into the combat systems of modern ships as essential to identify threats. Thus, the software STARTLE® of the company Dstl was selected by the Royal Navy for the management of threats and is described as a software that continuously monitors the ship's environment in a cut and medium range, processes the data it receives and through techniques of *AI* helps crews to make decisions. “It is inspired by the way the human brain works, emulating the conditioned fear response mechanism of mammals. It quickly detects and evaluates potential threats, the software significantly increases the situational awareness of the human operator in complex environments,” [9]. More recently the company Rolls-Royce has signed an association agreement with Google to use the latter´s machine learning engine to improve the company's intelligent awareness systems, [13].

It is also possible to locate *AI* applications in management systems for the exploitation of energy at sea or proposals of companies dedicated to energy in ships. Recently the company Eco Marine Power announced that it would start using the Neural Network Console provided by Sony Network Communications Inc., as part of a strategy to incorporate *AI* in various technological projects related to the ship, including the further development of the patented system of Aquarius MRE® propulsion (Marine Renewable Energy) and EnergySail®, [14].

One of the great references in the naval field is the marine area of Rolls Royce that is trying to promote the application of *AI* in ships in two lines: the intelligent management of assets that covers energy, health, data and fleet management and a second line of business of remote and autonomous operations. The latter includes intelligent detection or recognition, remote operations, autonomous navigation systems and connection with ships, [12]. As we can see on their website, not all lines of work are in operation, but some are in development.

5.3 The future of AI in marine business and industry

The exploitation of the marine business has an undeniable field of growth for *AI* There are many computer solutions that, based on the operating data of the different ship systems, can help manage assets in a more optimal way. The application of *IoT* to ships provides both data collection and the ability to act on assets to obtain their best performance, [10]. For this, it is necessary to have some essential elements. In the first place, we must have comprehensive solutions that cover all aspects of connectivity and integrate them in a coherent manner. It is necessary to have the signalling, connectivity and appropriate representation model based to provide interactivity with the end users. IBM with its program MAXIMO®

and SENER with FORAN® are developing a proposal that integrates reality model made during the initial design stage, with the solution of IBM to merge asset management with the power of data *IoT* obtained of sensors, devices and people to have visibility of them in real time. Have a model of the database in a single database, it allows obtaining virtual reality and augmented reality images on which the obtained data can be superimposed and compared with the technical performance measures expected for each element of the monitored warship. In this way it will be possible to act in the way that each situation advises.

Another interesting field of work for the future of *AI* is image recognition. In this sense and placing the focus on the marine industry, two fields of application appear. The identification of images in autonomous vehicles that can help the mission and the operation of them. Although it does not only have application in ships and unmanned devices, it can also be used in surveillance systems and detection of possible threats or risks in manned ships. Part of this is what one of the projects that have been mentioned above covers, [9].

The recognition of images through *AI* is also of interest in design stages. The need to have virtual models of the objects that are part of a project makes real models can be scanned and then try to be recognized to create the virtual model. This is of particular interest in ship revamping and retrofit. The need to have a virtual model from a real one in order to evaluate the possibilities of retrofitting, including the processes and manoeuvres necessary to carry out such operations. While cloud applications are able to work with that amount of visual information, they have not yet passed the threshold of identifying the elements that appear in the scene and converting them into analytical geometric representations or not, on which can obtain measurements or manipulate as a whole. An extension of this, can be applied to the component models that are used in the design stages by the *CAD* applications. Currently, it is increasingly common for components to be modelled in *CAD* that are obtained through external files that for the most part have been obtained for marketing purposes. These format are superficial representations of many faces that do not have a geometric and parametric representation. This, which is useful simply to see a model makes it useless or even a problem to carry out projects, since it is necessary to have metadata that only exist when the models have a formal geometric representation. That is to say, it is not the same to handle the six faces of a cube, that the cube in its totality. This limitation opens a field of action to *AI* programs that are able to recognize that certain faces form a determined surface, and in turn that certain surfaces form a certain solid. By the moment the available programs help the user, but it is finally the user who validates the conversion. However, *AI* programs can go on igniting this type of recognition that makes a human being to be more decisive each time.

The realization of a naval project is something certainly complex, and not only by the transversality of it but also by the number of tools that must be handled and the limitations imposed by design rules or standards of various kinds: construction, security, etc. *CAD* systems provide more and more tools, but they are also increasingly complex to be used optimally. Along with this scenario, the marine engineering companies and the shipyards are faced with very demanding deadlines and staff or very young who, although they are familiar with new technologies, do not know the art of naval architecting and marine engineering or with very old people who are more reluctant to work with the *CAD* and with new capabilities. Therefore, it would be interesting to have a virtual assistant who can provide all the information necessary to do the job correctly. SENER and IBM are developing a project that integrates the cognitive abilities of Watson® with the functionalities of the *CAD* in the different stages of design.

The platform Watson® will have a corpus of information and data that will integrate everything needed to use correctly and optimally the FORAN® system Furthermore it also will include all regulations applicable to different types of naval ships, regulation of *IMO*, fighting against the pollution, safety regulations, etc. It can even integrate the design and work rules of the shipyards themselves in such a way that *CAD* users can make designs according to all the regulations and applicable standards at the different levels: administration, construction and ship-owners. The system will be trained to learn in order to give the correct information to each type of intention and will be able to learn and trained in different and new things that may affect the design. The integration can be done at different levels, completely decoupled from the *CAD* or coupled to it to perform certain operations in the *CAD*. It launches events that are captured by the listener system and this in turn links with the virtual assistant to provide the information or data that are linked to those operations. The interaction with the system may also be on demand or taking advantage of the natural language processing capabilities of the Watson® system. This project, see *Figure 3*, allows the capabilities of the FORAN® system to be increased to provide the cognitive and analytical capabilities of the Watson® system and make them available to the marine industry to put it in the field of *digitalisation 4.0*.

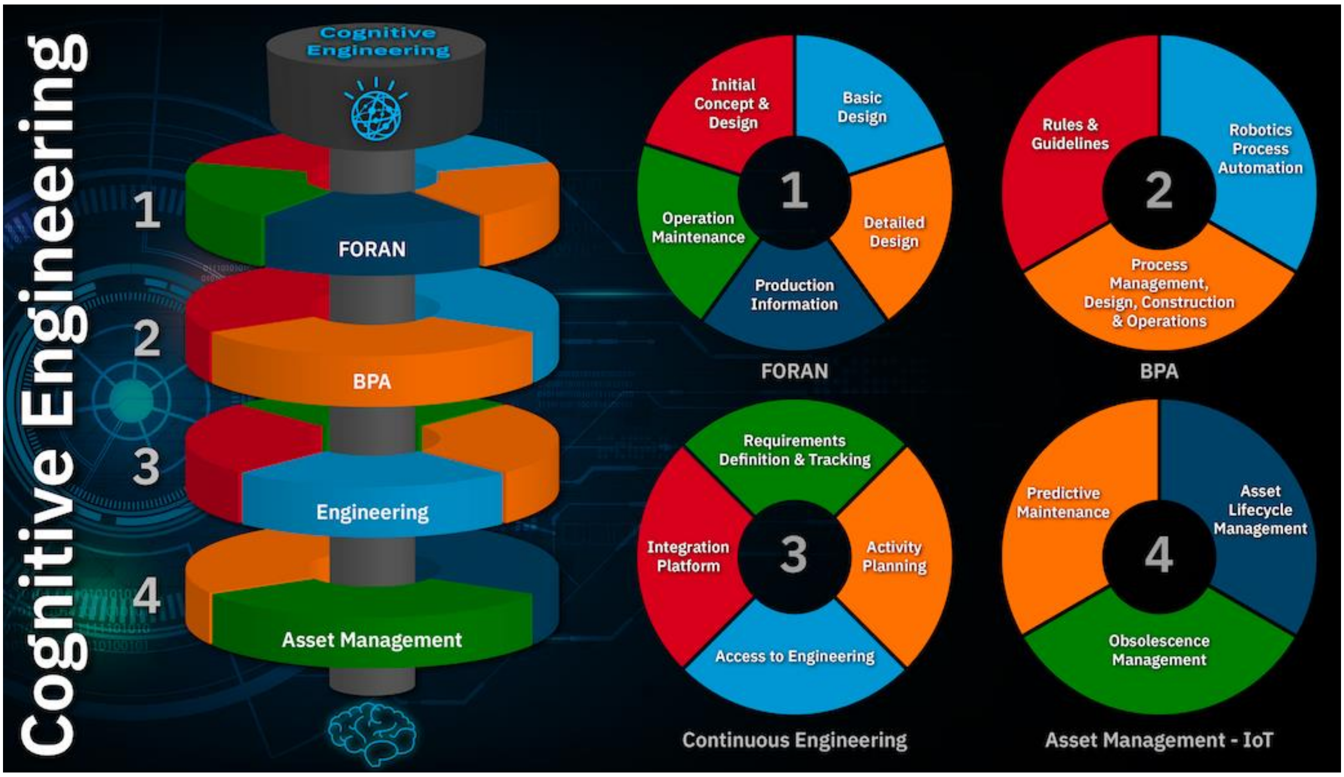

Figure 3. IBM Cognitive Engine in FORAN. Courtesy of IBM

As we have found possibilities of application of *AI* in the field of design, it will also be possible to see the realities of *AI* in manufacturing processes. Perhaps the first steps we will see in the ability of the machines to select the material of a manufacture. Machines that select clipping plates to take advantage of the material according to the remaining pieces or robots capable of organizing the movements of intermediate products in the workshop. The novelty of *AI,* will be that these machines and robots will not have to be programmed, but they will receive the data or the objects with which they have to work and they will know how to act. “In the future, robots will no longer have to be expensively programmed in a time-consuming way with code pages that provide them with a fixed procedure for assembling parts, we just have to specify the task and the system will automatically translate these specifications into a program,” [8].

6. FINAL CONSIDERATIONS

AI is one of the enabling technologies of digital transformation that has the greatest potential among those that make up the fourth industrial revolution. Knowing their characteristics and possibilities is essential to decide their application to certain processes and products, especially industrial ones and very particularly those related to the marine sector. It is important to identify the value that *AI* can contribute to the use cases where it can be applied.

AI automates the learning of repetitive tasks and the discovery of relationships through data. It is necessary to populate accurate and reliable data to *AI* systems as well as to provide sufficient information that is well structured and correctly tagged. The *AI* highlights the importance of the data.

It is necessary that those who use *AI* know how to make themselves understood and ask the right questions. The *AI* must be correctly fed, with questions and answers. An *AI* system is as intelligent as the individuals who prepare it.

AI adds intelligence to products, which means that it makes those technologies that incorporate them better, but we must not forget that it is these technologies that provide the core of value to work processes and methodologies.

The use of *AI* in industrial environments such as the naval one is just beginning. There is still a long way to go, in the field of design, optimization of projects, maintenance of data and results. Fields such as the recognition of images, for their conversion into models, the automatic intervention in the validation of the requirements, the optimal exploitation of the processes inherent to naval engineering, are still practically unexplored.

With or without debate, the truth is that *AI* is present day by day in our environment, and its development will be growing. We will see *AI* in applications that we would not have imagined weeks ago. Musical compositions that are the most listened to can be created with *AI* or the most curious and tasty cooking recipes, intelligent cars without a driver or the best doctor capable of correcting diagnosis and treatment. But in spite of all these advances, we will continue to need intelligent people, people who are smarter than machines and who are ahead of them, because there are capacities of the human being who can never be embedded in an artificial intelligence.

As a summary of this paper, the author would like to leave a final reflection for the reader consideration: if the brain can think, a *CAD* software could do it with AI.

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