USING 3D MODEL AND AI TO PREDICT ATMOSPHERIC CORROSION - A SMART TOOL FOR DECISION MAKERS

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ABSTRACT

This paper focus on reviewing and offer a solution to manage the complex atmospheric corrosion process, a concern mainly for developed countries. A review of the main protective coating failure mechanisms is presented. Our objective is on gathering the main parameters for a maintenance/inspection management tool, by developing a field data collection processing that feeds a model for predicting coating failure.

The software developed by Vidya is merging the Industry 4.0 technologies since it uses the Digital Twin and BIM concept as it uses 3D models (inspection of the part inspected and / or pinch), Artificial Intelligence (predictive algorithms) and IoT (Internet of Things - communication with sensors wireless).

Through its algorithm, the software will outline an inspection and maintenance plan. It can predict costs, workforce and other variables to be considered for coating management.

Finally, after carrying out all the necessary calculations for the activities mentioned above, the software delivers the budget, productivity, the amount of paintings done and/or future paintings followed by several KPI for decision makers in all hierarchical areas organization select the best decision.

Key words: Coating, Industrial Painting, Inspection, Maintenance, Industry 4.0, BIM, Digital Twin, Artificial Intelligence, Prediction, Software, Management.

INTRODUCTION

According to NACE [1], the annual global cost thru corrosion is over 3% of GDR of an industrialized country. Part of this cost refers to atmospheric corrosion and costs to protect the equipment. It is estimated that near 50% of corrosion cost is related to protection against atmospheric corrosion [2].

Painting or coating are the most methods employed to protect the structure. The function of theses methods is to create a layer to protect the substrate surface that inhibit and isolate the contact to factors that must damage and create corrosion. In an industrial complex environment, for instance, FPSO, refineries, petrochemicals, mining, pulp and paper industry, the followed tripod is a challenge that technician in maintenance have to deal, during the asset management: corrosive atmosphere, a lot of different painting systems and a large number of components resulting in a large surface painted area.

These factors demand a proper management of resources to painting the plant. In this paper we propose to discuss a detailed model to approach this problem using the digital technologies with the objective to digitalize the management of painted equipment, optimizing the inspection and maintenance of industrial painting activities and supply information to operators to adopt strategies more efficient in integrity assessment.

To achieve all that, we propose the use of BIM (Building Information Modelling) as base to management the equipment in the plant, applying artificial intelligence (AI) to create and learn predictive models of degradation and also to optimize the maintenance activities to the big surface painted and sensors IoT (internet of thing) able to obtain data to monitoring in real time of main atmospheric corrosion parameters.

To operationalize this approached model, the software implementation was empowered of cloud computing technologies to process the computational twin model and propose the final solution in inspection and maintenance to all professionals involved at painted equipment management.

BIBLIOGRAPHIC SURVEY

2.1 Atmospheric Corrosion

Atmospheric Corrosion Atmospheric corrosion is a complex process, ruled for electrochemistry process and physics at a thin layer over the surface of the material with dynamic kinetic of different parameters that influence corrosion process [2]. The main factors that influence the atmospheric corrosion according to [2] are:

i. Time or humidity cycle;
ii. Air contaminants;
iii. Temperature;
iv. Others factors.

One way founded by engineers to specify materials and protection systems against atmospheric corrosion is the corrosion classification at aggressivity grades. A standard to classify atmospheric corrosion is ISO 9223-2012 [3].

2.2 Industrial Painting and Coating Failure

Knowing that adherence is the main recovering characteristic, the procedure of surface preparation and recovering application is very crucial. In addition , to each base material type, a different preparation method is necessary. To steel, countless surface preparation techniques, recovering application, inspection methods and quality control are able and must be specify properly to each situation by a qualified professional.

Even so, for diverse causes, the recovering systems fail at some points and at some moment it can compromise the substrate. A study conducted by Mark Weston *apud* [5] shows part of failures, near 46% is arising to applications errors at recovering system.

One of the most spread applied technique to protect metallic equipments and structures against atmospheric corrosion is the painting or the coating. Covering the metal works when the outer layer is adherent to substrate or metal base, the mechanical and chemical resistance to hold to severe weather, mechanical shocks and chemical agents in the environment. Therefore, they simply prevent the permeability of those corrosion agents cited above, such as humidity and/or the contaminants [4]. Lately the painting or coating is a layer to avoid the electrochemical contact between metal and the redutor agent in the environment.

2.3 Industry 4.0

In this section, we call the attention for the Industry 4.0 concepts. Searching for specific points that can be used to asset integrity management and for industrial painting maintenance. Industry 4.0 or also called Fourth Industrial Revolution is in the current trend of automatization technologic application, communication and data exchange to the industrial process thru concepts of System Ciber-physics, Internet of Things (IoT) and *Cloud Computing*. The objective is digitalize production process creating a virtual model of intelligent factories. System Ciber-physics and sensors able of technology IoT integrated to the factory virtual model realize and monitoring and the operational in real time. *Cloud Computing*, process math models, algorithms and thru AI can determinate patterns able to optimize actions and decisions, co-operating to human activities in a productive environment [6]. The term Industry 4.0 came from a German´s government project of promoting computational modelling at manufacture sector [6]. The basics principles to Industry 4.0 [6] are:

i. Virtualization
ii. Decentralization
iii. Modularity
iv. Real-time operating capacity
v. Interoperability
vi. Orientation to services

These concepts are well widespread in the productive industry process in many sectors. However in others sectors a long way to implementation still need be crossed [7]. It is possible to expect that applying technologies from Industry 4.0 some evolution in the sector of Maintenance and Integrity Asset Management happens.

2.4 *Building Information Modeling* – BIM

Building Information Modelling (BIM) is a technologic method to parameter and digitalize a computational model to all life cycle of the engineering project. Literally, using BIM, a virtual model very precise of an engineering construction is create digitally [8] and can provide relevant information to all phases during life cycle of a plant, since project phase until operational and decommissioning. Besides that, in a BIM model all workers involved at project activities, construction and operational at engineering buildings could interact and take decisions in a way much more efficient.

Normally BIM models starts to be create with tools from CAD[1] project creating tridimensional models, exampled in Figure 1. Approx 80% of French ́s project companies use CAD 3D tools in there projects, according to [9]. However, is very important understanding that a 3D model of a building is not a BIM model in itself [8]. The computational model starts to be a BIM model when is parametrized with data and information related to all your components. It is important to emphasize that most cases, it is more important the information then the tridimensional view.

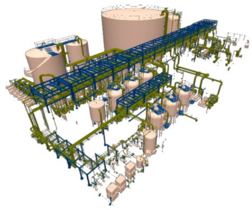

Figure 1: An example of tridimensional model created by CAD 3D tools that could be used at BIM

Eastman, C. [8] define BIM as a technology to modelling with a mix of production process, communication and analyse virtual models of engineering building. One of the benefits is that the model can be source of information centralized to all systems installed at the plant and assist it during operational activities [10] and maintenance. In addition, BIM can be the pattern to support the systems of monitoring and control at real-time the operation of the plant [8].

2.5 Artificial Intelligence

Nowadays the scientific community have giving attention to the dimension at research in Artificial Intelligence (IA), going deeper in a field called Learning Machine, that intend to create predictive models to complex systems using experimental data [11]. This domain knowledge study algorithms that allow the learning machine using a computer, this way improving the machine performance and to do some task. These algorithms have the capability to take decisions by math models that describe a structural relationship between variables involved in the problem using an objective function that has the job to quantify the solution quality. Some viewpoints of automatic learning also are intimately connected to mining data and analysing statistics [11].

[1] CAD is the acronym to *Computer Aided Design*

At this context the artificial neural nets are techniques very employed in algorithms that propose learning by data. The artificial neural nets is a computational technique that have a math model inspired in neural structure of intelligence organism that acquire knowledge through experience. Were developed, at the beginning in the 40´s by neurophysiologist Warren McCuloch and the mathematical Walter Pitts, however it has been forgotten because the low capacity to calculate in the computers at that time [12]. The peak in exploration of artificial neural nets was in 90´s supported by the development of Support Vector Machine and recursive neural nets, techniques that today made possible computers interpret words handmade in a graphical context, for example [13]. The field algorithms are the focus on research in Artificial Intelligence nowadays, and turn it more useful in diverse fields of science.

The coverage in Artificial Intelligence research is large, how can be observed in Figure 2, that illustrate a simplification in subgroups of algorithms and systems that compose this area in this science. Each component subgroup that today is named Artificial Intelligence can be merged to development in intelligent systems. In fact is common to found in literature, for example, an utilization of metaheuristic of optimization employed in artificial neural nets training, or *Convolutional Neural Networks* in specialized systems, what reinforce the idea that the field is modularized in parts that contribute by themselves.

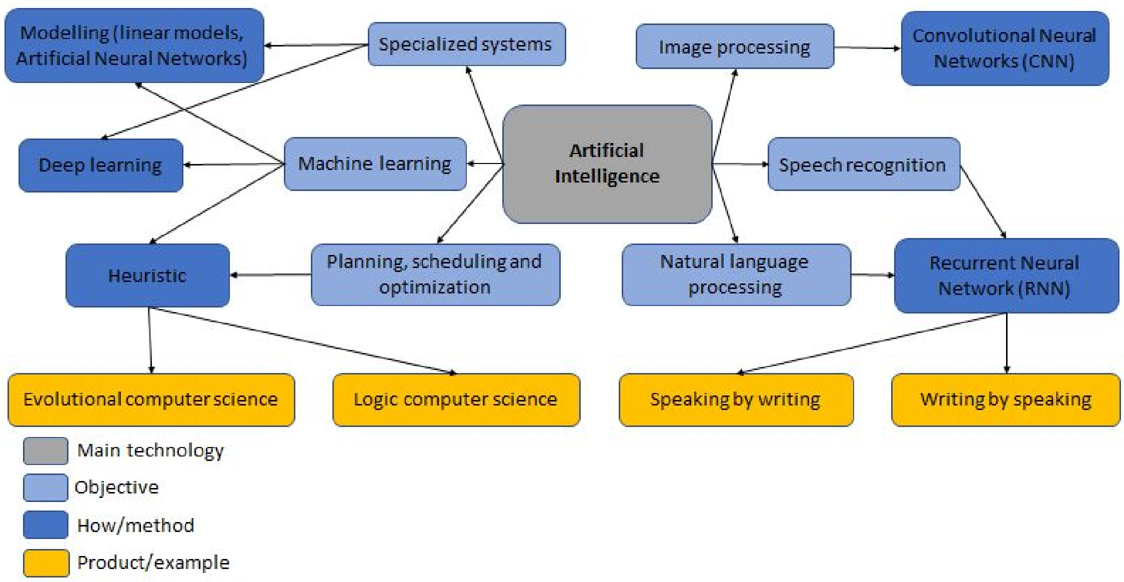

Figure 2: Examples of AI development

2.6 Digital Twin

Daily is increasing the concept of digital twin, since the popularity of the industry 4.0, companies are doing movements to become more digitized for the reason that is clear now that the economicity created by digital´s process is real. The reason for that is new technologies applied to collect information from the real facility to the digital model, for instance lasers, drones and high level data processing computers are getting cheaper

and the task to mapping a complex facility in a 3-D model or the digital twin can be done easier and cheaper.
The digital twin could be defined basically as a digital platform linked to the behaviour and performance in the past and at the real time following a key process that helps to optimize the business performance In our case the key process is the atmospheric corrosion.
At the industry 4.0 where sensors, artificial intelligence and 3D models are linked the digital twin is a possible tool to manage and predict a key industrial process. According to [14] the digital twin is able to identify intolerable deviation from ideal conditions thru any of many dimensions that the key process could be acting. That deviation is an identified opportunity to optimize the process; or the digital twin logical has an error; or is an opportunity to save costs, improve the quality or obtain better efficiency.
The observed deviation at the digital model may result in an action at the real facility. An opportunity at the real model can be done sooner, accurate and precisely, helping to fix and correct the asset, if that is the case before high consequent event.
The digital twin concept is new however it has gaining rapidly diffusion at the industry due the benefits. The tool to predict and manage the atmospheric corrosion developed is completely aligned to the digital twin concept, that it will be demonstrate further at this paper.

3. A NEW APPROACH TO MANAGE AND MAINTAIN THE INDUSTRIAL PAINTING

In this section we will discuss the main problems founded by professionals in industrial painting maintenance in complex process plant such as Paper and Cellulose, creating inputs to design a newly approach model to this type of activity.

3.1 Modeling the Issue

As was possible to observed in the bibliographical survey, the effective use in painting and recovering to protection against atmospheric corrosion depends on different procedures, usually applying practise described in standards. Adopt forms to put in a procedure painting inspection tasks, painting failure analyses, surface preparation, recovering application, quality control and certify normally demands specific tools and well controlled process. This fact is the first attention point in optimization in industrial painting maintenance, what is proven by research in painting failure cause, cited in [5]. In industry there is the practice to document and to map in procedures however our experience evidence that there is a lot of obstacles to guarantee a well broadcasted information, application and inspection as they should be to technicians over the activities. Going beyond in a complex process plant we can enunciate a factor tripod that should leave in consideration in the industrial painting management during the operational phase. They are:

i. *Atmosphere corrosive;*
ii. *Painting system;*
iii. *Adding components and painted surface.*

Considering this scheme, the maintenance manager, responsible to industrial painting has the main function to decide which moment must occur the maintenance to each component, in a group of thousands, based on disponible material and labour resources and a pay yield analyses. Furthermore he needs to guarantee that his passive is not growing overtime and with taken maintenance decisions, in order to determinate moment in future there is not necessary the use of a big mount of resources bigger than acting in the equipment by punctual forms.

3.2 Approach Model Preposition

How was showed, the objective of this paper is propose a approach model to apply concepts of Industry 4.0 to be used in industrial maintenance, specifically in industrial painting, how a way to optimize the integrity management, maintenance activities and resource uses, turning it more efficient and integrated to productive process. The model proposed starts using BIM as technologic digitalization of industrial plants as a prospecting tool, inventory and asset management. To be a database that can be used since conception and design in engineering projects until maintenance and operational phases, the BIM should be able to save electronically all asset information. Additionally, how our intention is to endow the industrial painting maintenance with concepts from Industry 4.0, is worth a presentation briefly the interaction between BIM principles according to[15] matching the principles in Industry 4.0 according to [6] arguing that BIM has the potential to be a basic platform integrating technologies to operational and maintenance of complex industrial plants. *Table 1* shows in author's point of view the relationship Highly Related (HR), Related (R), and when no relation where identify (na).

Table 1. Interaction between BIM and Industry 4.0 principles.

Industry 4.0 BIM	Real Time Operation	Virtual-ization	Descentrali-zation	Focus on service	Modularity	Interoperability
Visualization	**R**	**HR**	na	na	na	na
Fast processing data to decision makers [(a)]	**HR**	na	**R**	na	na	na
Reutilization of data model to predictive analysis	**HR**	**HR**	na	na	na	na
Integrity and data centralization[(b)]	**HR**	**R**	**R**	**HR**	na	na
Automatic design drawings and documents generation	**HR**	**R**	**R**	na	na	**HR**
Cooperation[(c)]	**HR**	na	**HR**	**HR**	na	na
Fast creation and evaluation of plannings	**HR**	**HR**	na	na-	na	na

Communi-cation online, and electronic based on objects	**HR**	**R**	**HR**	**HR**	na	**R**

HR – Highly Related; R – Related; na – not applied

(a) Adapted from the concept "Fast generation of varies projects alternatives" from [15]
(b) Adapted from the concept "Data maintenance and design integrity" from [15]
(c) Adapted from the concept "Collaboration on the design phase and construction building phase" from [15]

Sach et all [15] define *Visualization* as a mechanism to design evaluation under a point of view static and functional. This function at BIM is highly related to principles of *Virtualization* of Industry 4.0. The model BIM is able to represent detailed in terms of visualization and information a building or factory. Another relation is *Operational in Real Time* because allow visualize datas and information confirm they are updating in somehow inside the computational modeling. Besides that, BIM´s model enable *fast information generation* to taken decision also *models utilization data to preventive analyses*, both related with real time *operation* of a computational model, what represents be the principles of Industry 4.0 more profited with BIM utilization. Soon after, it is observed that BIM is able to meet the verticalization principles in different aspects.

Once explicitly the interaction of BIM with industry 4.0, the model was implemented using the technology of digitizing plants as the prospecting tools, inventory and asset management. Once again they are listed in a single computational model, with this approach it is possible to automate activities for instance, area calculations and costs, through the correct parameterization of painting systems, environmental corrosivity and the quantification of the paint structure of each component of the plant.

BIM's main reason to be applied in industrial plant management is the converge in an unique platform providing solutions for the tripod of indicators mentioned in item 3.1, faced by the maintenance manager. In addition, the main existing facilities already have their electronic installations, the main source of information for the maintenance of the painting is already available, allowing the drastic reduction of the cost of implementing a management tool. In addition, it is proposed to parameterize the computational model BIM with the following information:

i. *Inspection parameters* - inspection procedures formalized and controlled by the computational model, capable of quantifying the state of degradation of the paint, allowing the maintenance of a permanent control of each component of the plant.

ii. *Maintenance parameters* - systems or paint schemes, as well as their costs and activities, accessibility and other relevant data. Our approach goes to a phase of creating predictive models of industrial paint failures able to learn thru data collected in inspections and maintenance.

At this context, it is proposed the usage of Artificial Neural Networks for the construction of predictive corrosive systems able to maximize the confiability in the industrial plants. In addition, the use of Artificial Intelligence in optimizing the overall cost for maintenance planning of plant components can be useful in assisting the manager.

Finally, the sensors equipped with IoT are able to monitor the main parameters that influence in the degradation of the paint during an operation phase in an industrial plant could be able to generate important data for the predictive models in real time, thus allowing the computational model to be run in real time providing even more accurate for operators.

3.3 Practice Implementation

Once the concept is developed, a practical implementation of the approach model described in this paper must be discussed. In these author's point of view, it would be feasible through Cloud Computing software. A cloud software would be capable of integrating a BIM model of an edification or an industrial plant, including:

i. A 3D render of the plant, containing diverse visualization filters;

ii. Artificial Intelligence model capable of predicting the degradations state of each component in the BIM model;

iii. Module oriented by inspection planning service, based on user configurable parameters in AI model predictions;

iv. Module oriented by cost optimization service, based on BIM model information and in AI model predictions;

v. Computational micro services powered by Artificial Intelligence innovations.

Such service has potential to optimize and to plan inspection and maintenance activities of industrial plant parts based on machine learning prognostications.

4. RESULTS

In this section it is presented the challenges, assumptions, and learned during the development. Also in the section 4.2 the solution itself is presented.

4.1 Development Steps

As mentioned previously, the first challenge had been the chosen of rendering at e-PMC software. During this development we faced a large number of possibilities. However focusing at the 3-D model files, it is usually heavy on data information, that push us to a rendering that analyses and process only the frontal espactrum, and according to the user movement at the model a refresh rendering is being processed. That makes the user experience smooth and pleasurable.

After this first barrier, it was demanded to create a predictive algorithm doing the process of input data from painting/coating degradation creating as a output an optimized painting plan scheme, that means, when each element should be treated, repainted, at the moment where an inversion at degradation curve happened, optimizing the painting plan. We called the predictive algorithm of CDS (Corrosion Degradation State curve).

Then the next step in the development chain was to think about how to input the data in the system. We reach the conclusion that the best way to insert the data in the system should be with qualify inspectors professionals via APP, paperless and wireless, allowing a fast *in situ* inspections. This option put us in front of some provocations, for instance, the solution to solve poor internet connection areas and find the correct element in the plant was to work offline. Downloading the Work Orders (WO) at the workstation the inspector goes to the field needless internet connection, uploading the collected data when returned to the workstation. However the biggest faced problem in the APP was how to manage offline the data from the 3-D model in a fast and reliable way, since this files are huge and demand a high processing rate to deal with it, not founded in mobile devices. The technical answer was the software extract images from the element selected at the WO, downloading it to the mobile device where the inspector can visualize the element to inspect at the field the correct element.

Following the development path it was noticed that the software prediction, the CDS, could be empowered by Artificial Intelligence, adjusting the degradation curve according to collected data from the visual inspections. Those real inspection information inserted in the software have a great value to a new prediction of painting/coating failure, calibrating the Corrosion Degradation State curve. However the CDS by itself showed to be not enough as good parameter to determine the painting/coating scheme, mainly for the mobilization time, that should be add in an optimized painting scheme. Many times elements with high CDS are far from each other. Recognizing the location problem and concerning about that we developed and added to the algorithm a logic cluster factor, where the local average CDS interact and the worst local element, higher local CDS and this interaction draw an execution painting/coating scheme.

At this point has been noticed the necessity of two modules in software, one to inspection, another to maintenance. Using AI a new, dynamic and optimized painting/coating scheme are produced at each inspection data inserted in the e-PCM. The division in inspection module and maintenance module brought some advantages, inspection WO and maintenance WO can be measured in different domain, key process, and a vary of indicators. This helps the decision maker to manage the resources (financial and workforce) for painting/coating in a fundamental based, graphic and better way.

In sequence the view from the available workforce had been thinked and added to the algorithm. The workforce labor is allocated, automatically at the calendar, creating a structured painting scheme, an execution schedule connected to Work Order planned to that period. Those WO are easily manually relocated, push forward or postergated by the authorized person to manage the Work Order and the software keep the manual changes and recalculate and build a new painting/coating scheme.

Finally at the development algorithm phase is was connected all cited above to the calculated area of the elements that is directly related to the among of painting/coating necessary at a specific time, and doing this it was possible to obtain financial planning to the painting/coating scheme that for some facilities has a big impact at the total maintenance budget. A accurate prediction will helps to manage the financial resource and act, buying the paint/coat or hiring more professionals to act at the right element at the right moment.

4.2 Software e-PMC

After more than one year developing the algorithm and the pilot test we reach the currently version for the software, to control, to manage and predict the atmospheric corrosion at complex facilities, completely emerged in the industry 4.0, Artificial Intelligence and Digital Twin concepts. This section will present details of the software, images and features how the user and the decision-maker can take benefits from the e-PCM platform.

Figure 3 illustrate that is possible to visualize at top left, the covered asset by the software, and a brief description below it. At the right side is possible to observe the asset and where is located itself. Georeferenced asset are valuable when the client have more than one asset covered by e-PCM.

Figure 3: Asset details

Once select the asset, at the homepage it will show in the left side, a list of content, for instance general dashboard, inspection and maintenance. In this particular case, the Figure 4 shows the default results when Dashboard is clicked, at the right side of the Figure 4 is showing indicators, total superficial area, area inspected and scheduled for a determined period to inspect and finally the area painted/coated and the area scheduled to paint/coat.

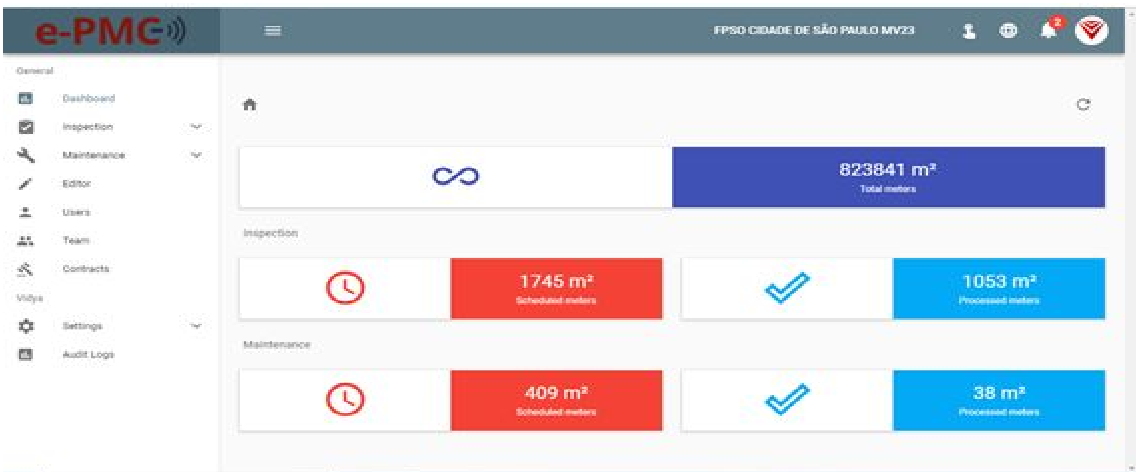

Figure 4: Dashboard

Figure 5 reveal performance indicators. At this case Figure 5 brings to us the average, minimum and maximum from inspection efficiency rates. This can be correlated at different time period, equips or even groups of equipments. Others key parameters are easily found at the Dashboard for inspection or maintenance, Work Order pending, scheduled or concluded.

Figure 5: Examples of performance indicators

When the user opens the inspection or maintenance window is possible to view a 3-D model from the asset, where he or she can navigate thru it for a better view, Figure 6. Rolling down at the same window is the Scheduler planning, showing the calendar and the equips available. At the top of the calendar are two option, one is Emit work Orders and Select Automatically. If the user wants to use the AI in the software than he or she would click in Select Automatically, doing this the software automatically will plot a series of Work Order at the calendar to be executed considering the degradation state, element size and equips available for the execution.

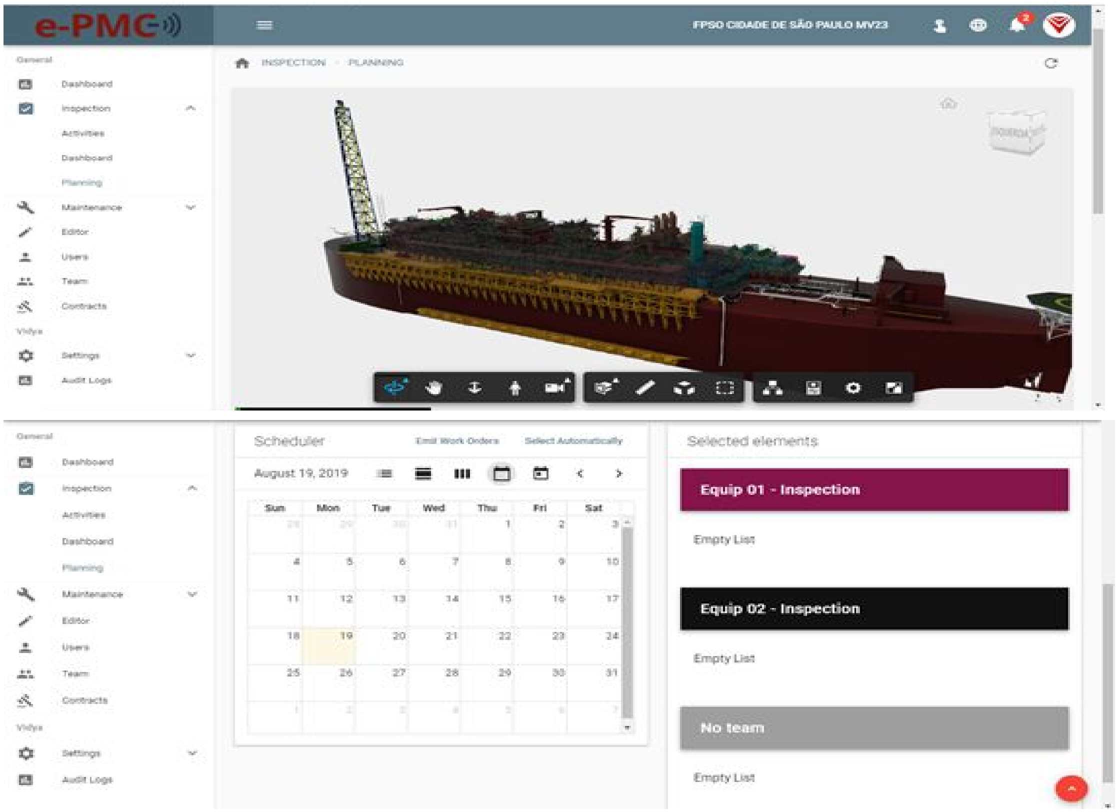

Figure 6: Planning Work Orders

After the implementation phase, all the information that the user needs to provide is the initial and the final date for work planning. The software using the predictive algorithm and the logic cluster factor it will bring the most efficient and effective planning for the period.

As a result the software put the orders in a list allocated at the day and the background color means the equip responsible for the WO execution. In Figure 7 we have three days selected, 21th to 23th Aug and the four color (grey, pink, cian and terracotta) indicates we have four equips to do the service during this time frame.

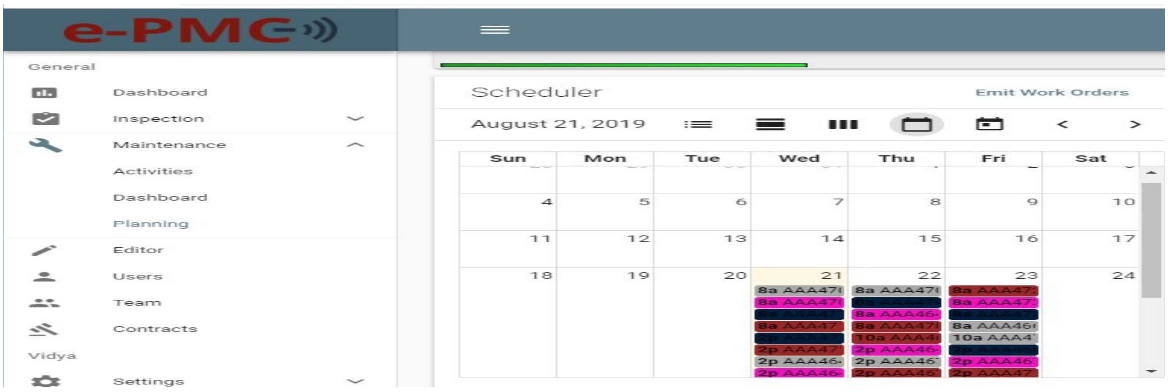

Figure 7: Scheduling optimized Work Orders

In the case the user chosen to emit the Work Orders manually, the user needs to select the element, the software will put the element in an available date as a first guess. If necessary to change the date the user can make it manually. In sequence the user should press Emit Work Orders. Those steps are possible in both structures, for inspection or maintenance.

The final feature from the software is the presentation of KPI for management of Work Orders. Figure 8 shows the information when the user click at Actives. Three columns are exhibited, at the left the pending WO, in the middle WO in execution, and at the right the completed WO. Those information are the result of daily communication between the tablet's user and the system, uploading the planning and downloading the executed Work Orders.

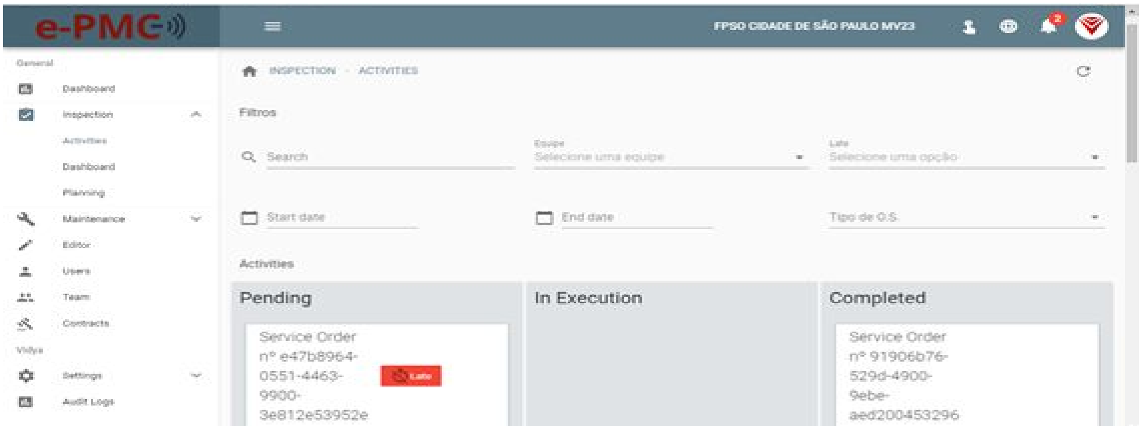

Figure 8: Activities view for pending, in execution and completed Work Orders

The software has a mission to be friendly, accurate and robust. The industry 4.0 claim for solution using data to optimize resources, improve the safety and increase quality. The e-PCM combine the industry demand to new technologies.

5. CONCLUSIONS

The objective of this paper was to expose a viable approach model to endow the maintenance of complex industrial plants such as Oil and Gas, mining, chemistry, paper and cellulose thru the Industry 4.0 conception, in special, dealing with maintenance problem in industrial painting, whose costs have a big importance in the total maintenance budget and in a lot of cases, still today they are executed under an incorrect or non optimized way and with a few or no previous degradation analyses, and the investment pay yield and activities optimization are neglected.

It have been possible to briefly formulate the problem of industrial painting maintenance faced by integrity manager inside industrial plants. It was realized a bibliographical survey refer to corrosion, industrial painting and your failures, principles of Industry 4.0 and also Building Information Modelling. Based on this knowledge was possible to create an approach model that conclude that BIM is the started tool to endow maintenance in a complex industrial plant using the principles of Industry 4.0.

Artificial Intelligence were applied at the CDS algorithm that will predict better with the collected data fixing the Corrosion Degradation State and using a logic cluster factor, based on the degradation of each element to optimize the workforce.

The authors believe that the software created are ideal and able to manage a big number of element for painting/coating scheme. During more than one years of test, the technology used has been shown to be robust enough, transferring and processing the data collected.

Managing has improved. Information about painting, for instance the area painted in the last year, that used to take couple weeks to be raised now can be done in the same day.

Finally, the authors suggest that the oil&gas, cellulose, mining or other complex industry, already have a tool to predict and manage painting/coating scheme covering the concepts for an industry 4.0, AI and Digital Twin. The author's purpose is not exhaust the theme but the opposite, giving start to discussion how to deal with problems in the productive process and also maintenance of this type of industrial plants throughout the use of Industry 4.0 principles.

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