THE USE OF 3D GRAPHIC MODELS AS A TOOL IN DESIGN AND ANALYSIS OF OFFSHORE SYSTEMS

Henrique Gaspar, henrique.gaspar@poli.usp.br
Escola Politécnica - University of São Paulo

Leonardo Fecchio, leonardo.fecchio@poli.usp.br
Escola Politécnica - University of São Paulo

Leandro Meili, leandro.meili@poli.usp.br
Escola Politécnica - University of São Paulo

Thiago Falcão, thiago.falcao@poli.usp.br
Escola Politécnica - University of São Paulo

Denis Taniguchi, taniguchi@tpn.usp.br
Escola Politécnica - University of São Paulo

Kazuo Nishimoto, knishimo@usp.br
Escola Politécnica - University of São Paulo

Abstract. *The recent advance of the graphical processing technology has allowed analysts to develop a more powerful tool in engineering post-processing. This paper discusses how 3D models have been used to represent, in a more realist way, the analysis done in the Numerical Offshore Tank (TPN) laboratory. These analyses have as output the dynamic response of many offshore components, such as floating units, mooring lines and risers, and offloading ships. This real-time 3D post-processing technology has given the engineers a better understanding of the ways offshore systems work and how their components interact between each other. Besides the needs that lead the laboratory to this level of 3D realism, this paper also discusses how this kind of tool allows the interactivity and makes the conception and analysis of an offshore project easier.*

Keywords: *3D Modeling, Post-processing, Offshore Design and Analysis, Real Time Visualization*

1. INTRODUCTION - 3D OFFSHORE MODELS

3D Models are being used in engineering, including in the offshore industry, since the 70's, when computers started to have enough graphical processing power to completely visualize a considerably large amount of information. Russo *et al* (2004) comment about the development of the technique, illustrating the process from the reservatory to the distribution. As time went by, computational mechanics became an useful tool in solving more and more complex engineering problems, demanding more complex 3D models to represent them. We could take finite elements method as a good example of that tendency, comparing the coarse meshes made in the past with the refined ones, containing hundreds of thousand to a million of elements.

We could give several others examples of the utilization of 3D models in pre-processing and post-processing when dealing with numerical simulation. This article was based on the work that was carried through in the Numerical Offshore Tank laboratory, a multiinstitutional hydrodynamics laboratory (Nishimoto *et al*, 2002). The laboratory makes use of several different computational mechanics models, such as the panel method, finite elements method, among others, to simulate an offshore system.

Simulations are held to validate the concept and design of new systems, as well as to analyze systems already in production. To achieve the goal of simulating the dynamics of an offshore system, the following entities must be present: platforms (hull and process plant), VLCC ships, mooring lines, risers, flex-joints, fair-leads, anchors, etc. Moreover, the simulation must take into account different environment conditions, such as wave, wind, and current. The result is a set of time series of the motion and forces with respect to each entity, and is visualized in a software developed by the laboratory called TPNView, that is further depicted in section 2.1

It is important to notice that this article delves into the graphical aspect of 3D models, leaving aside the ones used in numerical calculations by the simulator. The differences between them can be better explained describing the simulator in more detail. For instance, the panel method is among the list of methods available to calculate the behavior of a body under wave forces. This method allows the simulator to yield the body motion in its center of gravity. The data concerning the motion is afterwards used in the visualization software (TPNView). The panel method uses a different 3D model than the visualization software, allowing us to have complex models in the visualization, without compromising the numerical

computational performance. We also believe that the set of attributes that a mesh has to fulfill are distinct in each case.

Section 2.2 delves into the use of an unique data-set of models to accomplish the creation of videos and images, using 3D modeling applications available on the market, and also the real-time visualization of the simulation results.

The methodology of constructing a 3D model is subject of section 3, where we show the platform MonoBR as example. In section 3.5 we show various types of models, such as sub-sea system, AHTS ship and FPSO.

2. TPN - OFFSHORE NUMERICAL SIMULATIONS

There have been several developments concerning the simulation of the behavior of floating bodies under the effects of waves in the restricted boundary conditions, called numerical wave tank. The main feature of these model basin is to calculate full Navier-Stokes equations considering the viscosity and free surface conditions. However, the dynamic behavior of offshore structures in real ocean environmental conditions (considering waves, wind and current) is more complex and very difficult to simulate using full non-linear Navier Stokes equations. Moreover, in ultra-deep water, it is very important to consider an accurate mooring line and riser's dynamics in the analysis (Nishimoto, 2002).

The results presented in this paper were accomplished in the Numerical Offshore Tank (TPN). The simulator considers almost all physical phenomena acting on the floating bodies and mooring and risers lines. Since full non-linear solutions are not available, numerical, empirical and analytical models are being considered and integrated to it.

The potential time domain problem is solved by wave forces acting on the bodies and empirical models are used to simulate current and wind forces. To represent mooring and riser lines, the finite element model with more realistic hydrodynamic force models is used.

As the simulator uses full hydrodynamic equation, it takes a long time to calculate the simulation for floating bodies with several risers e mooring lines. Therefore, a cluster with more than 200 cores was built to run the simulator taking full advantage of parallel processing.

Another important feature is the post-processing of the simulation results. The entire 3D view of the offshore system is presented in a virtual reality room with stereoscopic projection (Nishimoto, 2002).

To achieve the scientific visualization of the simulated results, the construction of a precise 3D model is necessary, with correct geometry and dimensions. The post processing is subject of section 2.1. All the requirements of the 3D model can be found in section 3.3.1.

2.1 3D Real-Time Post-Processing

The visualization of simulations based on the real world in engineering, according to Nyland and Lastra (2001) is the quality of a quick comprehension and understanding in each case of study. In offshore case, this technique allow the visualization of the ocean environment in a scale which the analyst are accustomed, sensing what he would normally sense.

TPNView, a dedicated post-processing tool, was created as part of the TPN project, being responsible for the visualization of the numerical results (Gaspar, 2007). The need for a dedicated post-processing in the laboratory simulations generates a software capable of showing dynamically the behavior of the units and lines of the modeled offshore system.

The visualization is performed through a 3D environment using a 3D real-time computer graphics. The software is used as a tool for design and analysis, trying to be precise in the representation of the offshore system (Nishimoto 2004). All its components such as, platforms, its hull and plants, fair-leads and flex-joints, as well as VLCC ship, AHTS, buoys and other large structures are represented by 3D models, which are build using Autodesk 3D Studio Max and exported to TPNView's file standard (.DFX file). A discussion of this methodology can be seen in section 3.

The Software is considered to be the interface with the user of system TPN creating, from the results of the numerical simulations, a virtual scene where a human operator is immersed, and can not only visualize but also interact with the analyzed system. As this is the visible part of the results, the quality affects directly the decision of the analyst, who is using the calculus of the simulator as design tool (Nishimoto, 2004).

As the program is based on a three-dimensional environment, the visualization of the components of the offshore system is facilitated, becoming possible to observe the interactions between the components and undesirable movements. Thus, it is possible to view (three dimensionally) the structure relations in the system, allowing the detection of eventual collisions. The interface with the user was developed allowing the practical access to the data. It is possible, for instance, to simply observe the graph of the time-series of tensions in a line by the number and name of the line, or clicking on it while the simulation is presented. Examples of this type of analysis can be seen in section 3.5.

The development stages TPNView is coupled to the evolution of the computational capacity of graphical processing. The first version of the program, in 2001, needed great workstations to graphically process the amount of data that TPN generated for each analysis, through parallel processing (Nishimoto, 2004). With the increasing performance of the graphical cards, today is possible to have a version of the software in a personal computer, since the video card has support to the necessary functionalities. The software tends to become each time more realistic in the post-processing, allowing real-time visualization of a bigger number of polygons and more complex and detailed 3D models.

Another benefit of this type of tool is the creation of an efficient collaborative virtual reality environment in the offshore industry, bring together professionals from different regions, allowing the conjointly decision taking based in a common base analysis of the large amount of the data, i. e., the post-processing with the same group of 3D models for everyone in each offshore system simulation (Russo *et al*, 2004).

2.2 3D Movies and Images

The 3D models are also used for making animations. These animations can be inserted in many kinds of movies. In the offshore industry, there are mainly three types of movies that uses 3D models. The first one is the institutional movie, where is necessary to present the laboratory and/or institution that is connected to the project and technologies offshore. Many of the 3D models that are made for analysis, are later used for making institutional movies about the laboratory. Another type of a common movie is the marketing one, made for selling/showing some kind of product or tool. The engineering companies which work in joint projects with the university use them to apply the developed 3D engineering models and to sell a certain technology or know-how.

Another kind of utilization is as training tool. Examples are two current projects with partnership with the Brazilian navy. The first project, in 2003, was the docking of the aircraft carrier NAe Sõ Paulo. The 3D model used in the calculations is the same that was used for training the staff who would make the operation. Another similar operation was the transport of the submarine Tikuna, in which case a movie used during the training of the technician was made from 3D models utilized in the calculus.

2.3 Digital Mock-Up

Digital Mock-Up (DMU) enable engineers to simulate assemblies in real-time, replacing physical prototypes with virtual ones, using 3D computer graphics techniques. DMU also allows the design and setting of complex products, and to manipulate and position them on the screen, combining them to form single digital models, all without ever needing to build a physical model. After being assembled,users can collaborate on a more complete structure, evaluating the relationship between components from different designers and eliminating manufacturing and assembly problems at an early stage in the design process (Chadwick, 2004).

This technology also is very utilized for the validation of offshore systems that still in the conceptual phase. The TPN utilizes DMU in the visualization and study of positioning settings of several components of an offshore system, such as platform, mooring lines, risers, etc. With 3D graphic models, is possible to modify certain initial parameters and analyze a new configuration of an oil field.

3. MODELING METHODOLOGY

The 3D modeling is used in offshore engineering as a tool for scientific visualization of numerical simulations. Thus, it requires accurate parameters to model an offshore system keeping the real measures of the desired design to be analyzed.

To construct a realistic offshore model, capable of being post-processed in real time and with interactivity by the user, three main stages must be followed during the modeling: precision of the input data, modeling in 3D software, and application of certain modeling techniques. The following subsections delve in to the details of these stages.

3.1 Input Data

The input data that is required for modeling are: main dimensions, overall shape, deck layout, riser and mooring line position, among others.

The offshore systems being analyzed have few variations, possibly been a common hull, a mono-column platform, a small boat or subsystems like buoys, pumps, etc. These data usually are taken from CAD drawings or a ship offset table.

The modeling of ship hulls requires a more complex data, such as details in cross sections. But platforms usually have radial symmetry, simplifying the measuring, and its later representation.

Additional references, like pictures of the real systems and machines are also used. This kind of image is generally used while making textures, and it is very important to reach the realism in the performed simulations.

The structures have many subsystems, like oil treatment and refining, mooring lines and risers, among others. While modeling them, the designer seeks a close representation to the reality.

Valves and pumps, do not need a great amount of detail, only the necessary to be recognized from far. It is not the size of the object that arbitrates it's detailing level because flex joints and fair-leads, that are much smaller than the platform, have a great importance in the analysis of the behavior of mooring lines and risers, and therefore more detail is needed, since they are observed very closely.

3.2 3D Modeling Softwares

The 3D modeling software builds the model that will be later exported to post-processing or digital mock-up, as shown in section 2.3. Each available software on the market, like Autodesk 3D Studio Max, Maya, Blender, etc, has different modeling features, and one can take several hours to mastering a specific feature.

Softwares like Multisurf, Microstation and AutoCAD are used for exportation of ship cross sections and platform hulls. CAD drawings are also used to turn a 3D model into the layout of decks and production plants.

Autodesk 3D Studio Max is the program adopted in the laboratory for 3d modeling of offshore systems. This software offers a wide range of modeling methods, associated to the abilities of the modeling team that encloses practically all the necessary techniques to shape an offshore structure. Also, it contains a software development kit tool (SDK), that allows the user to develop program codes inside this software. The DFX file export was created with this SDK tool, which transform the Autodesk3D Studio Max .3DS file in a .DFX file, utilized in TPNView.

3.3 3D Graphical Modeling Techniques

The construction of 3D models requires diverse techniques and many general detailing rules are applied, due to computer graphics limitations, looking for the best visualization performance, with the richest possible detailing level.

Two major techniques are detail level control and the use of texture maps.

3.3.1 Detailing Level

A model's level of detail (LoD) and the polygon density are direct consequence of the modeling method and, in fact, most rich representations of systems requires a lot more polygons, and it affects directly the graphic processing power needs, especially in real time visualization.

Systems that are observed from longer distances, where smallest details are often unnoticed, can use less polygons. Systems that are usually observed at short distances, with the attention of the user in every single detail close enough, require a more carefully modeling detail, and consequently a lot more polygons will be used.

That's why the modeling team has to be in deep conscience of the model usage to guide either efforts on building the most detailed model with less polygon usage. A common sense in detailing models with few or no polygon addition is the use of another modeling technique: the use of texture maps, discussed in section 3.3.2

A discussion about the level of detail in 3D environments based in the real world, and their problems, such as slow rendering, large demands of storage, resolution, etc, is discussed in Nyland and Lastra (2001). The computational discussion, with the codes and algorithms is observed in Pharr (2004) and McReynolds and Blythe (2005).

3.3.2 Texture Maps

During the detailing of 3D surface, as instance, the hull rugosity and weld lines, the addition of details in geometry is not always recommended, making the processing most complex. To solve this problem, texture map are used to simulate those surfaces properties (Azevedo, E., Conci, A., 2003). The two more usual types of texture maps are presented here:

Bump maps - are used to obtain effect of relief/rugosity in the surface of objects without the addition of polygons. Bump is a effect that modifies the light rays reflected in the surface of objects.

Opacity maps - allows the surfaces of the objects to vary its transparency of of 0 % the 100%. The great advantage is that using this type of texture is not necessary to create holes in the geometries, what diminishes the number of polygons in the model.

The figure 1 show an example of these both texture maps.

3.4 Design Stages

Next, we will follow each step for the complete construction of a 3D model.

The first part of the project is the hull assembly. It affects the hydrodynamical properties, viability and performance of the structure. Along with the mooring lines system and risers subsystems, they are the most carefully developed parts of the project.

The hull modeling is done by using existing surface functions on 3D modeling or CAD software. This method has, as input, the cross sections of the hull or an offset table, which represents the polygon vertexes that will make the hull. By interpolating these sections or points, this surface is built and can be exported to any other desired software to continue the modeling process. As mentioned before, the main goal is to use the best feature of each software.

After that, the deck can be built with CAD blueprints. The dimensions can be extracted or main parts can be imported from a bi-dimensional CAD file to a 3D modeling software. It is very important to state that there is a large gain of productivity when the software can exchange information between each other.

The platform subsystems will be placed on the deck and, as mentioned before, they may or may not follow the real

(a)   (b)
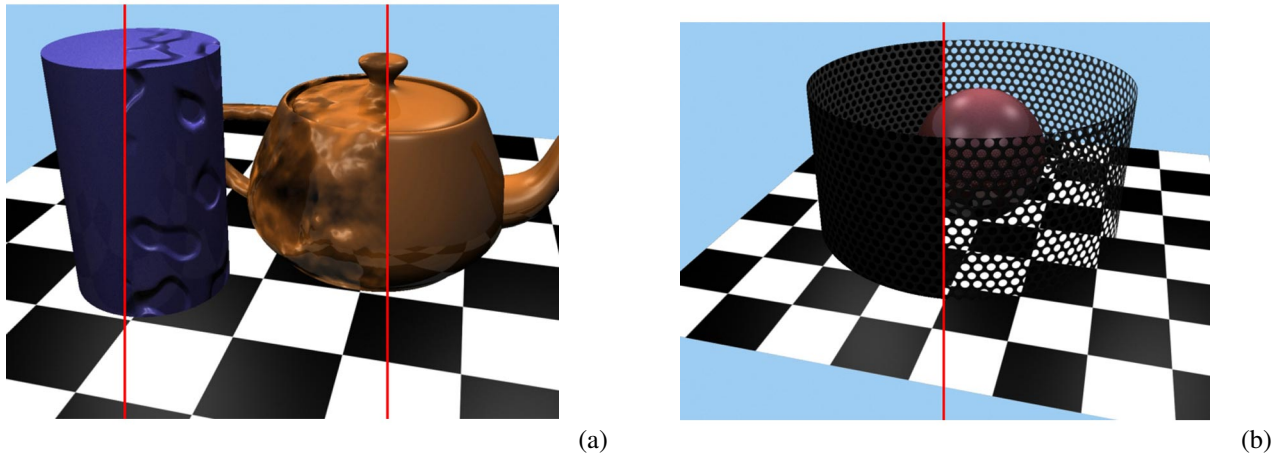
Figure 1. Example of Bump Map (a) and Opacity Map (b).

model. TPN has a generic systems library that allows time saving for the whole system modeling, without getting too different from the original project.

At last, the mooring points and risers lines are positioned on the hull. The position of these points are a important part of the project, as they will be re-positioned many times on the simulations. This process aims for the best performance of the systems on the analyzed environmental conditions.

During the whole structure modeling, the team concerns in the usage of parametric models in order to make big changes in short time. These parametric data are properties of the modeled object, such as height or radius, that can be changed quickly, but they can modify a lot of objects.

For instance, a system is designed to be analyzed from far. The objects in this model will certainly have few details, as this will not be noticed from far. They will have a low polygon density, so facets of a cylinder will be noticed but it will look smooth from far.

If the need of observing this system closely exists, it will be necessary to elevate the level of detail in order to show smooth surfaces. In this case, the same cylinder will have more faces, without the need of replacing the object with a new one. The number of faces parameter can be easily changed, adjusting the desired level of detailing.

The two cylinders in Figure 2 have 12 sides, but the difference between the dimensions does not allow us to see the sides of the cylinder on the right. Instances are objects that have been duplicated, but they have kept links with the original objects. If a parameter is changed on the original object, it will be changed on the instances.
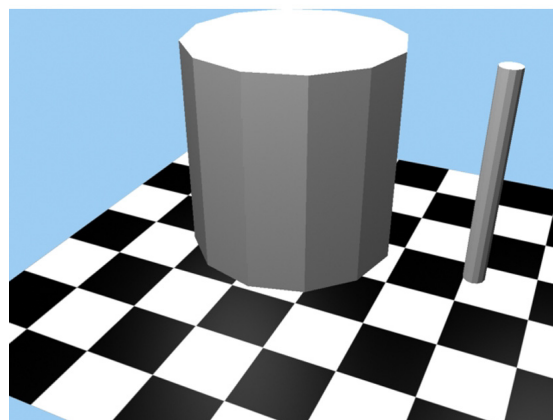

Figure 2. Two cylinders with same number of faces, but different aspect ratio.

Texturing is what makes the objects look real. By using pictures and images, it is possible to create materials that will generate different colors, metal shine effects, concrete surfaces and other properties. Some effects of texturing were commented on section 3.3.2

Finally, when the 3D model is ready, the visualization software executes the file and recreates it on a environment to simulate new conditions.

The development of this 3D modeling techniques has the same kind of benefits for offshore design observed in Jones *et al* (2006), and their discussion about interactive 3D environment for ship design, such as: "*reduced time to an agreed conceptual design solution; reduced re-view and offline resolution of design issues and trade-offs; reduced occurrence of issues being missed; better solutions found i. e. that give good results on potentially conflicting parameters; better exploration of the solution space and requirements space*".

3.5 Step by Step Example of the Methodolgy

This section shows a step by step of the methodology commented in 3.4 As example is shown the MonoBR case. More information about this type of platform, such as it's main dimensions and other configuration details can be found in Torres et al (2004).Figure 3 shows the drawing in CAD of the MonoBR platform's hull. At right, is observed the 3D model constructed in 3D Studio Max of the structure in wire frame.

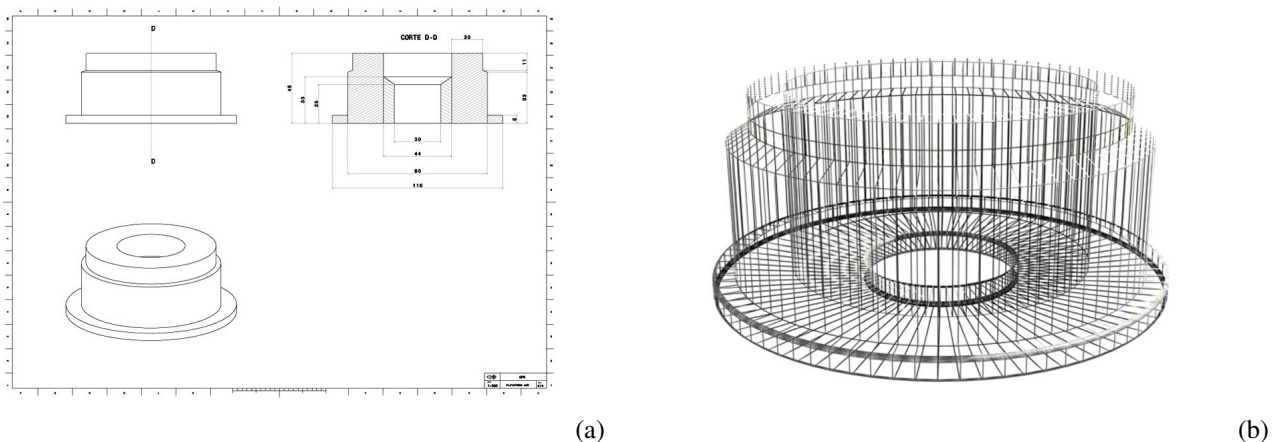(a)   (b)

Figure 3. Image (a) shows a CAD drawing of the MonoBR platform hull. Image (b) is its model in 3D wire frame modeled in 3D Studio Max.

With the wire frame ready, a surface is building having a basic material. After this process, the textures are applied, As it is shown on the Figure 4 .

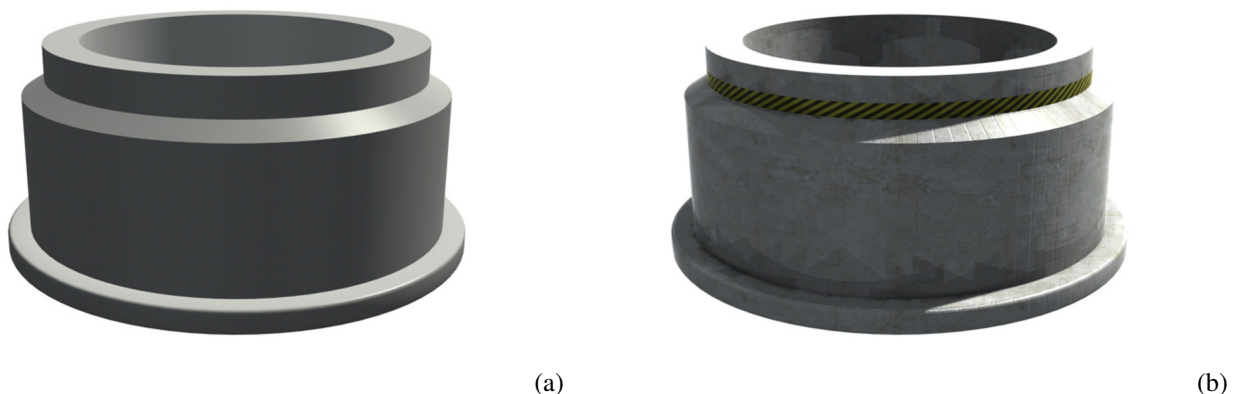(a)   (b)

Figure 4. Image (a) shows the platform surface model. Image (b) is the same model with textures applied.

Figure 5 shows a part of the platform, with the fair-lead models already attached to it. The figure shows a 3D model of the platform process plant, which will be attached to the hull later. Having separated files of each part of the offshore system makes the file storage and management easier at the moment of the construction of the offshore system.

At last, the Figure 6 shows the same platform 3D model and its subsystems on two different usage cases. The first one, on the left, shows a 3D render for movies and images. On the right, the same model in a 3D render in real-time on
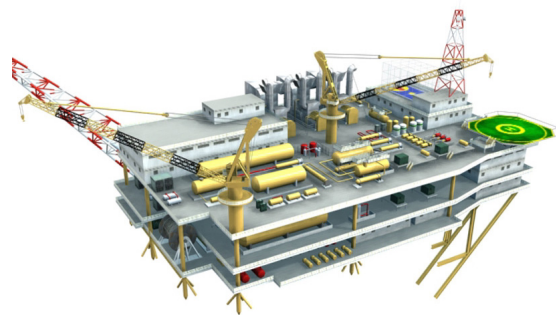
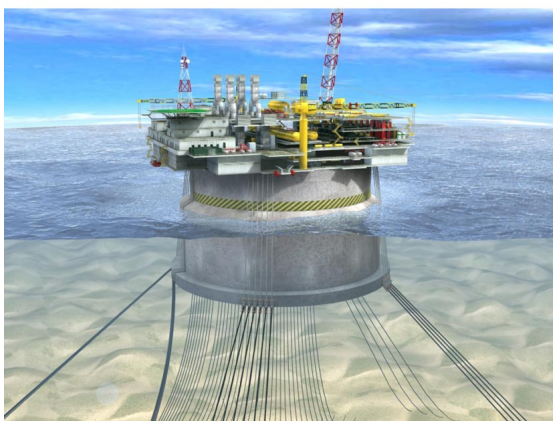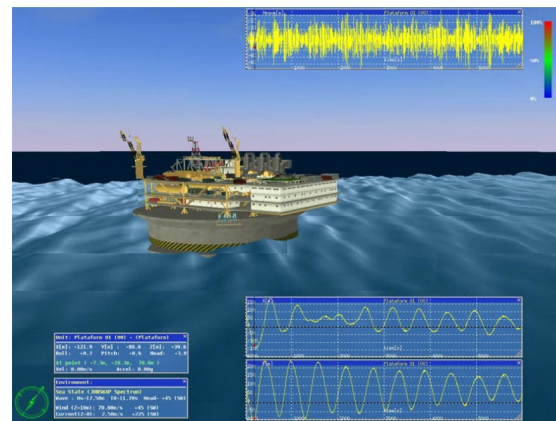(a)   (b)

Figure 5. Image (a) shows a detail of the platform 3D model with its fair-leads. Image (b) is a deck model with the process plant that will be attached to the model.

the 3D post-processor TPNView.

(a)   (b)

Figure 6. The images show two final results of different usages of a 3D model. Image (a) shows the platform and its environment. Image (b) is a screenshot of the TPNView software, with a 3D model being rendered in real-time, allowing plot and simulation data analysis.

4. EXAMPLES OF 3D OFFSHORE MODELS

Here is shown a series of offshore structures 3D models done at TPN over time. The methodology adopted is the same shown as shown in 3.5.

Figure 7 shows two final results with different usages of 3D modeling of a FPSO model. In image (a) is possible to see the unit and its environment. Image (b) is a screenshot of the TPNView software and the plot and data analysis.

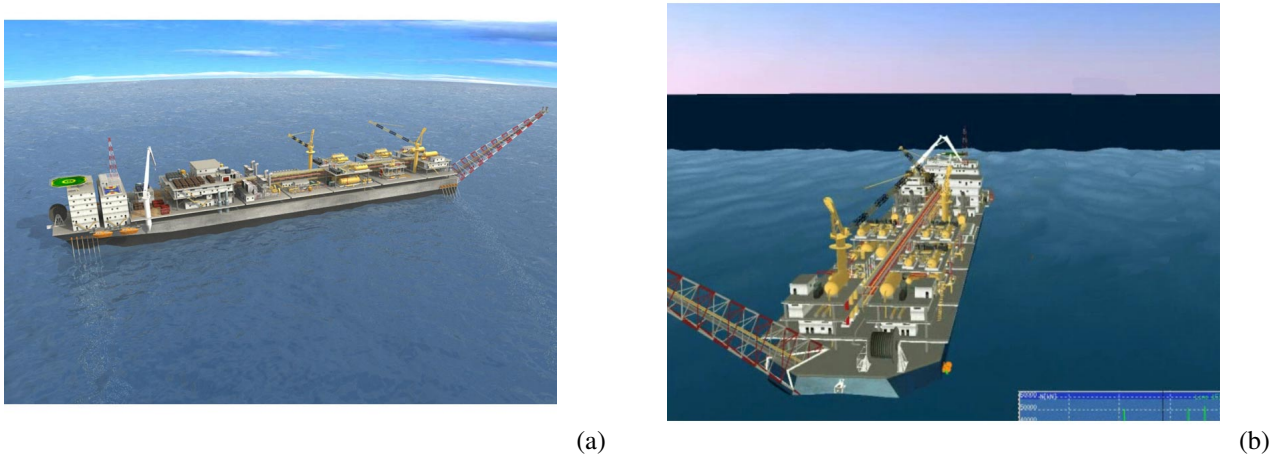(a)   (b)

Figure 7. A FPSO render utilized in movie (a) and TPNView real-time post-processing (b).

Figure 8 shows two examples of sub-sea structure. Image (a) is the subsurface buoy (SSB) and image (b) is the sub-sea manifold structure.

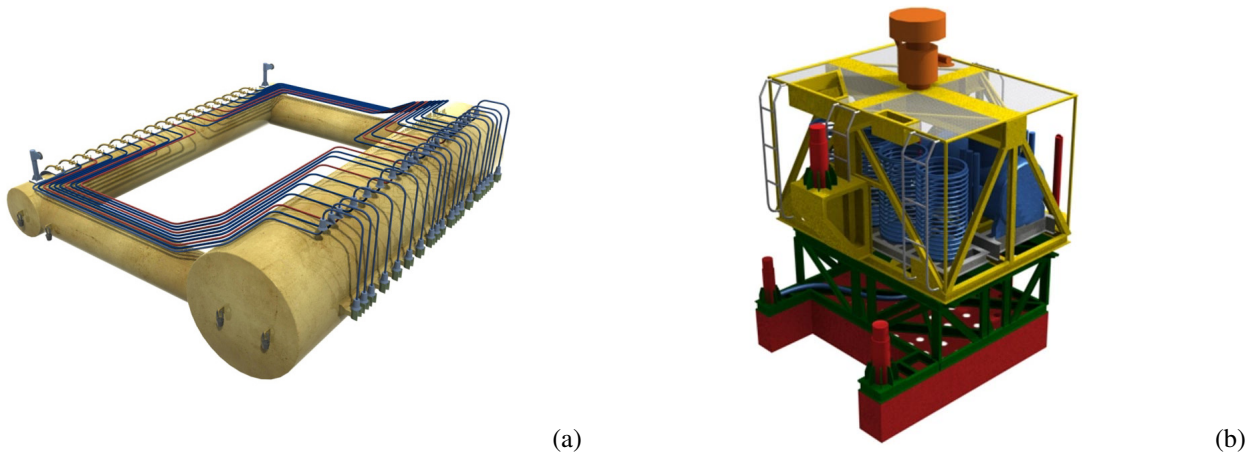(a)   (b)

Figure 8. SSB buoy (a) and a sub-sea manifold (b).

Figure 9 shows two examples of 3D model analysis done by TPNView. Image (a) is a TLWP platform being analyzed. Image (b) is a detail of the connections lines with a FPSO of the same system.

At last, Figure 10 shows in image (a) a AHTS modeling. Image (b) is a screenshot with a complex system post-processed by TPNView, with three structures and their respective mooring lines and risers.
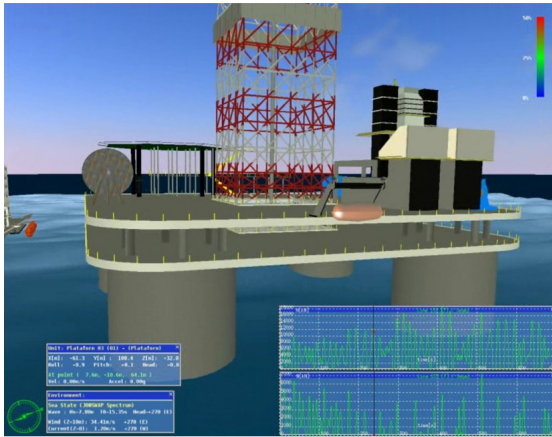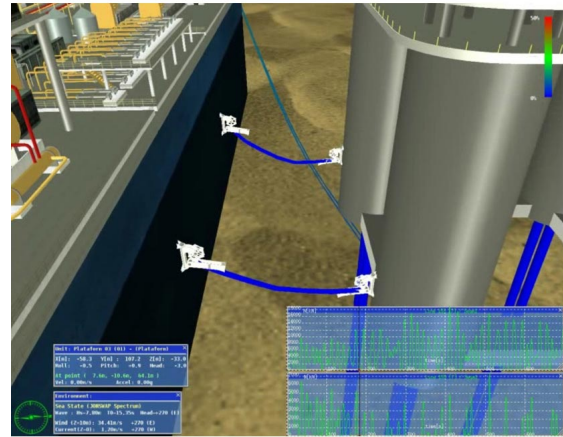
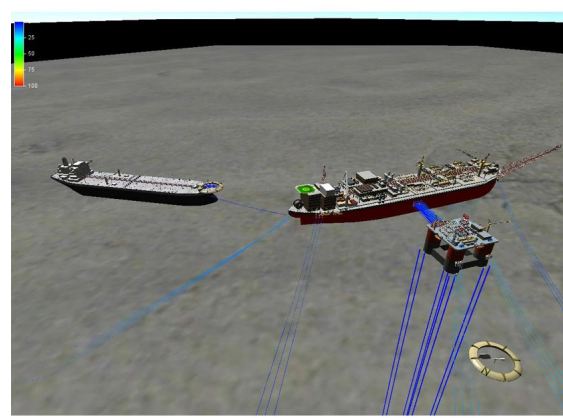(a)   (b)

Figure 9. TLWP platform (a) and detail of connection of TLWP with FPSO (b).

(a)   (b)

Figure 10. AHTS (a) and Complex Offshore System (b)

5. CONCLUSION

Through the present work, the following conclusions can be summarized:

- 3D models can be used for many goals. TPN uses them mainly for offshore system analysis. Although the same model can be used in institutional and training movies and images and digital mock-ups.

- The use of 3D model enables significant time saving in offshore system models constructions to be analyzed. This feature is possible due to the use of the numerical simulator TPN. This gain happens in the design system analysis and also in the working systems. Another advantage is the use of separated and parametric files, allowing the change of a dimension without demanding the re-built of the whole structure.

- The polygons optimization and texture maps is also another significant advantage, as there is time saving on the real-time post-processing done by TPNView.

- Also, the engineer has a large variety of possible simulations, changing dimensions, environment conditions and mooring lines settings. The developed post-processor with 3D models allows the analysis of these options, interacting with the environment, during the design phase of a system and the troubleshooting of a working offshore system.

- With this type of tool is possible to obtain a better understanding of the whole offshore system, with the possibility to visualize all their principals components as 3D models, allowing a realistic interaction, leading all the professional involved with the project to taking decisions based on a common base of models analyzed and post-processing of the data.

6. REFERENCES

Azevedo, E., Conci, A., 2003, "Computação Gráfica: Teoria e Prática", Ed. Campus, São Paulo.

Chadwick, D., 2004, "Digital Mock-Up", CadUser, Vol.17 No 11.

Gaspar, H. M., 2007 "Metodologia de Análise Estrutural e Pós-processamento a partir de Simulações do Comportamento de Sistemas Oceânicos", MSc Thesis, EPUSP.

Jones, B. S., Naef, M., McLundie, M., 2006, "Interactive 3D Environments for Ship Design Review and Simulation", 5th International Conference on Computer Apllications and Information Technology in Maritime Industries, COMPIT.

McReynolds, T., Blythe, D., 2005, "Advanced Graphics Programming Using OpenGL", Morgan Kaufmann Publishers, San Francisco.

Nishimoto, K. and et al., 2004, "Tanque de Provas Numérico", FINEP Technical Report.

Nishimoto, K. and et al., 2004, "Desenvolvimento do Sistema de Visualização Científica em Realidade Virtual para o TPN", FINEP Technical Report.

Nishimoto, K., Donato, M., Maseti, I. Q., 2002, "Numerical Offshore Tank: Development of Numerical Offshore Tank for Ultra Deep Water Oil Production Systems", Congresso Nacional de Transporte Marítimos, Construção Naval e Offshore - SOBENA, Rio de Janeiro.

Nyland, L., Lastra, A., 2001, "Visualizing the Real World", Computer Graphics and Applications, IEEE, pp. 6-10, vol. 21, issue 5.

Pharr, M. (editor), 2004, "GPU Gems 2 - Programming Techniques for High-Perfomance Graphics and General-Purpouse Computation", Addison-Wesley, Upper Saddle River.

Russo, E. E. R., Raposo, A. B., Fernando, T., Gattass, M., 2004, "A Realidade Virtual na Indústria de Exploração e Produção de Petróleo", in "Realidade Virtual: Conceitos e Tendências - Livro do Pré-simpósio SVR 2004", Ed. Mania de Livro, cap. 11, pp. 179-201, Rio de Janeiro.

Russo, E. E. R., Raposo, A. B., Fernando, T., Gattass, M., 2004, "Workspace Challenges for the Oil & Gas Exploration & Production Industry", Conference on Construction Applications of Virtual Reality - CONVR, pp. 145-150, Lisboa.

Torres, F. G. S., Cueva, M., Nishimoto, K., Malta, E. B., 2004, "Projeto HidrodinÃ¢mico de uma Plataforma do tipo Monocoluna-MonoBR", Congresso Nacional de Transporte Marítimos, Construção Naval e Offshore - SOBENA, Rio de Janeiro.

7. Responsibility notice

The authors are the only responsible for the printed material included in this paper.