Virtual Reality Engineering Workflow

BLIND
BLIND
BLIND

BLIND
BLIND

***Abstract*-Oil&Gas production systems are currently designed by means of complex computational modeling systems. Those systems involve several areas of structural calculus, oceanography, hydrodynamics, mooring systems, etc. The project of a new production unit is a lengthy, expensive, and conducted by diverse specialists geographically distributed. Due to the multi-disciplinary characteristic of those projects, collaborative visualization becomes a key component during the life cycle of engineering projects, especially those in Offshore Engineering. We present the integration process of an immersive 3D virtual reality visualization tool inside an integrated collaborative environment to be used by project engineers' teams during the execution and control of complex engineering projects. Such visualization system aims to improve the interpretation capacity and a better comprehension, especially tailored for the Offshore Engineering domain.**

***Keywords;* Three-Dimensional Graphics; Realism–Virtual reality; Graphics Systems; Distributed network graphics;**

1. Introduction

The Oil & Gas industry has increasing costs of finding and extracting hydrocarbons, especially in remote locations, ultra-deep water reservoirs or in hostile environments. The extraction of oil & gas reserves constantly faces the challenge of reducing costs of its components and activities, therefore, High Performance Computing, Visualization and Remote Collaboration technologies are being heavily used to improve productivity, leading to better cost-performance ratios.

Problem Solving Environments (PSE) [1] promise to provide scientists and engineers with integrated environments for problem solving in their domain, increasing their productivity by allowing them to focus on the problem rather than on general computational issues. Collaborative Problem Solving Environments focus on the development of a PSE coupled with collaborative environments to support the modeling and simulation of complex scientific and engineering problems.

Earth Sciences and Engineering are challenged to manage and interpret increasing amounts of data coming from the captured information of the environment or generated by computer simulations. The typical work of scientists and engineers consists in detecting features, measuring them, and finally generating a model that tries to explain those observed features. This visual approach to science and engineering is powerful, as the human brain excels at visually identifying patterns. As Edward Tufte [2] wrote more than two decades ago: "At their best, graphics are instruments for reasoning about quantitative information. Often the most effective way to describe, explore and summarize a set of numbers – even a very large set – is to look at pictures of those numbers".

Visualization and Remote Collaboration technologies help us to bridge the cost-productivity problem. High-end visualization systems are commonplace in the oil & gas industry. In former times, the industries have shown sensitive gains in efficiency and effectiveness when carrying out enterprise projects using Virtual Reality technologies. In the nineties oil companies were among the first to make industrial use of the so-called virtual reality centers (VRCs), equipped with immersive projection systems with large display walls (e.g., cave, cave-like, curved-panel, and powerwall), videoconference tools, among other solutions. Techniques such as three-dimensional geometric modeling, scientific visualization, immersive virtual environments, commonly used in VRCs, pushed the limits of teamwork activities in Geosciences and Petroleum Engineering.

The configuration of VRCs greatly improved visual communication and group collaboration in technical work sessions and decision-making meetings. The possibility of visualizing and manipulating virtual models in the VRCs has completely changed the way of working, notably for geologists and engineers.

VR visualization technologies enhance the content knowledge within any engineering design activity. When used in conjunction with collaboration, VR visualization provides valuable insights for better Decision Support with risk mitigation. Dodd [3] has mentioned that the next big management push is the empowerment of interdisciplinary teams with collaboration tools that include remote and immersive visualization on the desktop. Based on this, we emphasize that the combination of Collaborative tools and VR visualization constitutes a powerful component for any software solution for Large Scale Engineering Projects.

The next sections are organized as follows. Section 2 presents the related works that inspired the ideas to integrate a 3D virtual reality visualization tool inside an integrated collaborative environment. In Section 3 we present the conceptual model of the collaborative environment and how the virtual reality tool was transformed into a collaboration-aware application with the support provided by the collaborative infrastructure developed. In Section 4, we present different application scenarios addressed. Finally we present the conclusions and discuss possible future works in Chapter 5.

2. Related Work

In this section we present a few major works that motivated this research towards the immersive 3D visualization tool inside an integrated collaborative environment.

Visualization is an important component for many PSEs. For example, Parker et al. [4] describe SCIRun [5], a PSE that allows users to interactively compose, execute, and control a large-scale computer simulation by visually "steering" a dataflow network model. SCIRun supports parallel computing and output visualization, but originally has no mechanisms for experiment managing and archiving, optimization, real-time collaboration, or modifying the simulation models.

Paraview [6] is a kind of PSE for visualization that allows the interactive creation and manipulation of complex visualizations. Paraview is based on the notion of dataflow, and provides visual interfaces to produce visualizations by assembling pipelines out of modules that are connected in a network. However, both SCIRun and Paraview have important limitations which hamper their ability to support the data exploration process. First, there is no separation between the definition of a dataflow and its instances. In order to execute a given dataflow with different parameters, users need to manually set these parameters through a GUI — clearly this process does not scale to more than a few visualizations. Second, modifications to parameters or to the definition of a dataflow are destructive — no change history is maintained. This places the burden on the scientist to first construct the visualization and then to remember the values and the exact dataflow configuration that led to a particular scenario. Despite their limitations, SCIRun and Paraview show the importance of combining visualization with PSE.

In the Upstream segment of the oil & gas industry, the determination of optimal well locations is a challenging problem for Reservoir engineers since it depends on geological and fluid properties as well as on economic parameters [7].

Gruchalla [8] investigated the benefits of immersive VR for well-path editing. He reported speed and accuracy improvements of immersive systems over desktop system, based in a study with 16 participants who planned the paths of four oil wells. Each participant planned two well paths on a desktop workstation with a stereoscopic display and two well paths in a CAVE-like [9] Immersive Virtual Environment. Fifteen of the participants completed well path editing tasks faster in the CAVE environemnt than in the desktop environment. The better speed was complimented by a statistically significant increase in correct solutions. The results suggest that an immersive environment allows for faster and more accurate problem solving in a complex interactive three dimensional domain.

The Fraunhofer Gesellschaft VRGeo Consortium [10] is an oil & gas international consortium for developing visualization technology for Geosciences and Engineering applications in Virtual Environments. VRGeo has been presenting many significant contributions for the use of VR technology, especially in the area of Collaborative Work in Virtual Environments. Simon et al [11] presented a qualitative and quantitative study comparing usability and interaction performance for multi-viewpoint images, where a large screen projection-based stereoscopic display system is shared by a small group of people, each of them with its own viewpoint.

Another work was the VRGeo Demonstrator Project for Co-located Collaboration interactive analysis of complex geological surfaces and volumes in an immersive VR system [12]. They showed a new interaction paradigm allowing multiple users to share a virtual space in a conventional single-view stereoscopic projection-based display system, with each of the users handling the same interface and having a full first-person experience in the environment.

3. Conceptual Model

In this section we present the conceptual model of the CEE (Colloborative Engineering Environment), an integrated collaborative environment to be used by project engineers' teams during the execution and control of complex engineering projects, as is the case of the projects of deep-water floating production units in Offshre Engineering [13]. CEE allows an easy integration of different engineering applications providing team workers with means of information exchange, aiming to reduce the barriers imposed by applications with limited or no collaboration support.

In order to achieve its goals the CEE architecture is a composition of different Computer Supported Collaborative Work (CSCW) technologies to create a useful collaborative engineering environment. CEE is composed of a Collaborative Visualization Environment based on a Virtual Reality Visualization (VRV) tool and a Videoconference System (VCS); a Scientific Workflow Environment with a Grid Computing Infrastructure (GCI) support for executing large engineering simulations; and a Project Management Environment (PME) responsible for

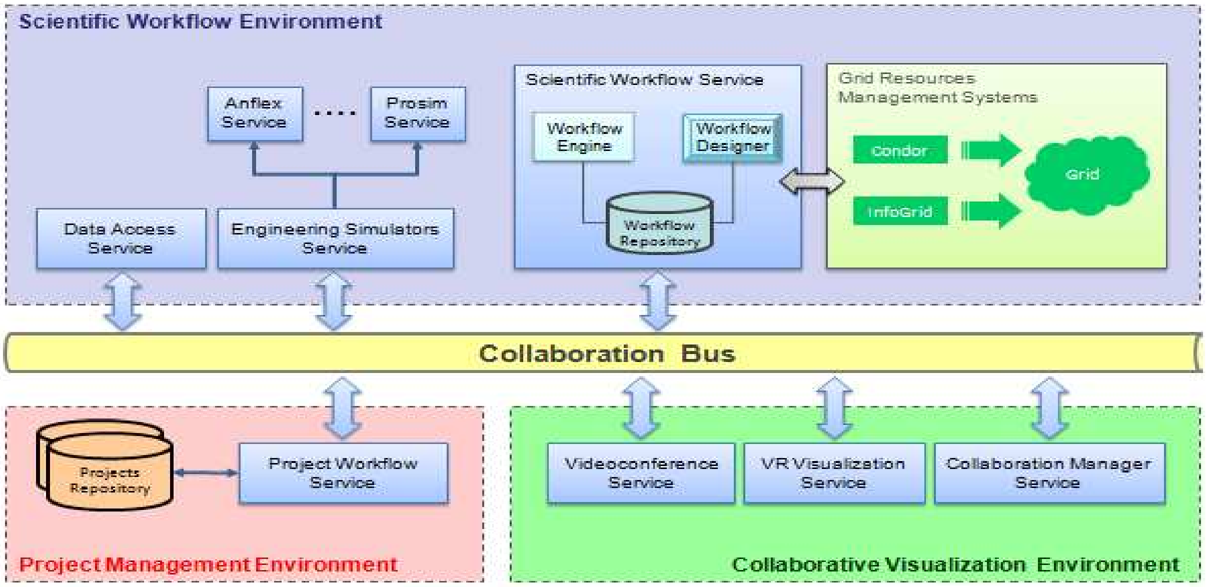

Figure 1: CEE Conceptual Model.

controlling the overall execution of the project and keeping track of all the information and different artifacts generated during project's entire life cycle.

CEE allows users to collaboratively solve their problems through the use of predefined scientific workflows or assembling new ones as necessary. Each workflow comprises a sequence of simulations, usually ending with a collaborative visualization supported by a VRV tool.

To achieve this, CEE was devised as an extensible platform, flexible and independent of system, allowing a transparent flow of information among different levels, systems and models. The challenges for building an effective and usefull CEE can be scrutinized according to the following aspects:

a) **Collaborative Work** – effective human-to-human interaction and communication for solving conflicts and enhancing group productivity should be provided;
b) **Virtual Reality Visualization** – high performance and scalability are important aspects of virtual environment architectures intended to support execution of large shared virtual worlds over long periods of time;
c) **Scientific Workflow Environment** – challenges related to the control of the execution of engineering simulations such as interoperability and distributed execution as well as data provenance [21] should also be provided
d) **Project Management Environment** – the ability to track all of the documents and artifacts generated during project's life-cycle. Multiple and different visions of the on-going project must be provided while users have different background.

The conceptual model (Figure 1) handles the above mentioned challenges creating specific services for them composing the CEE Service Oriented Architecture [22].

The Collaborative Visualization Environment is responsible for managing the user interaction. The Videoconference Service and the VR Visualization Service, work closely coupled with the Collaboration Manager Service to enable the creation of collaborative visualization sessions.

The Scientific Workflow Environment, was created to help the users build engineering workflows and seamlessly execute them in a Grid Computing Infrastructure (GCI). More generally, to support *distributed execution*, we use the interoperability characteristics of the ScWfMS and the distributed execution support provided both by the GCI of the CEE and also the support provided by the SOA backbone infrastructure furnished by the Enterprise Service Bus (ESB) [23].. For interoperability among applications it was developed a common format for data exchange among engineering applications.

The Engineering Simulations Service provides a Webservices interface [14] for remotely execute an engineering simulation program. Some of those simulators are, Anflex [15] a Finite Element riser analysis software, and Prosim [16] a coupled analysis software for the design of floating production systems.

3.1. Collaboration Manager Service

Collaboration Manager Service handles information about logged users in a collaborative session. It is responsible for the collaborative session management, access control policies, and behavior of each participant. One of the main components of the Collaboration Manager Service is the Session Manager, which is responsible to manage registered clients on the server and also coordinate the execution of the VR Visualization Service and the Videoconference Service when both are selected services to be used in a session. Collaboration Manager Service is also responsible for initiating the Java Messaging Service (JMS) Service Provider, in order to start the Collaboration Bus, the communication mechanism used by the users in the collaborative session.

VR Visualization Service is responsible for giving support for the Visualization Session execution and for supporting the creation of the Collaborative Visualization Session together with Collaboration Manager Service. The VR Visualization Service integrates BLIND [17] as the VR Visualization tool furnishing the necessary support.

Video Conference Service is responsible to control the evolution of a videoconference session that could occur simultaneously with a Visualization Session, characterizing a Collaborative Visualization Session.

A Service Coordinator in conjunction with the Session Manager is responsible for the creation and controlling of the Collaborative Visualization Session connecting any engineering simulations that wants to have its results collaboratively visualized.

The CEE-Collaboration Bus is created by the combination of an Enterprise Service Bus and a Message Oriented Middleware (MOM), with a Java Messaging Service™ (JMS) compliant implementation provided, in our case, by Apache-ActiveMQ [24].

MOM are based on the asynchronous interaction model, and provide the abstraction of a message queue that can be accessed across a network. More generally, MOM is a category of software for communication in a loosely-coupled, reliable, scalable and secure manner amongst distributed applications or system. The overall idea with a MOM is that it acts as message mediator between message senders and message receivers. Two types of channels are available, a Point-to-Point (i.e. a single channel per peer), available for peer to peer communications, and a public-subscribe (Topic) channel for group communications.

3.2. Collaborative VR Visualization Implementation

The CEE-VRV tool was adapted to be transformed into a collaboration-aware application with the support provided by the collaborative infrastructure developed. Figure 1 demonstrates how the applications were adapted to be able to send and receive messages from other clients.

3.2.1. Collaborative support

The adaptation follows the Remote Procedure Call mechanism, created in the former times, as an alternative for distributed computation. The process of adaptation was made in two levels. In the first level, a client-server paradigm was adopted where one instance of the visualization software acting as a server connects to other instances running as clients. The server creates a socket server and starts listening the port waiting for client connections, while the clients connects to the server.

For every new client connection, a thread on the server is created to deal with this new client, and the exchange of commands between that thread in server and the client can start. Although being a very simple implementation this synchronous communication mechanism is very limiting for collaboration purposes, because they require that the client and the server be available at the same time. Besides that there is no potential for developing loosely coupled enterprise applications without the use of multiple threads. We will present later the use of an asynchronous messaging mechanism as a powerfull alternative for a superior level of communication among the users.

A ComandSerializer component was developed to exchange commands that are in charge of transforming the application commands into its equivalent serialized form. This serialized form used the characteristics of the Lua language [18] that is fully integrated into the VRV tool used in the project (Figure 1). Another component of the solution is the RemoteCommandManager which is responsible to send and receive the serialized commands through a TCP/IP socket network connection. The flow of commands is depicted as follows:

a) Every command executed is sent to ComandSerializer that translates the command into a serialized form;

b) ComandSerializer, upon serializing the command, send it to the RemoteCommandManager whose job is to package the commands in an appropriate message format to allow peer RemoteCommandManagers to deal with those messages in an efficient manner;

c) RemoteCommandManager sends the serialized command package inside the message format, to all other RemoteCommandManagers that are connected;

d) The RemoteCommandManager peer upon receiving the message, checks the header whether it should process it or not;

e) ComandSerializer then receives the message from the socket, desserialize it and send it for execution in the Scripting Lua component;

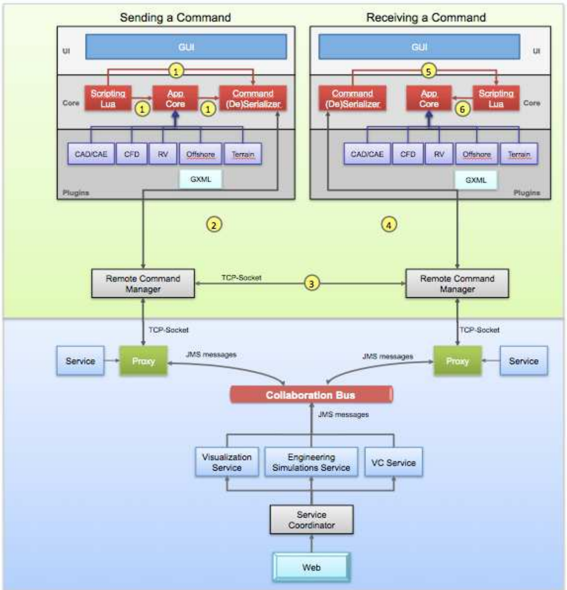

Figure 1: Remote Command Manager.

Following this procedure the commands are executed back and forth in the peers and we conclude the first level of collaboration with synchronous messages.

The second level of integration is a more powerful mechanism extending the types of communications that exists for Environ adding asynchronous communication, group and peer-to-pear communication mechanism provided by CEE Colaboration Bus. In this second level (Figure 1). the VR Service creates a local Proxy that talks to the Collaboration Bus and acts as a server for the VRV tool, therefore the VRV tool is now connected to a server socket on this proxy. This way, all collaboration communication is tracked by the Proxy that sends back those commands to the VRV tool. On the other side, every command sent by the VRV tool is resent by the Proxy to all users using a Topic created in the CEE Session in the Collaboration Bus or to specific users using its corresponding Queues also created for each user participant in the CEE Session.

3.2.2. Collaborative Visualization Session

The Collaborative Visualization Session is implemented with the help of a JMS and is controlled by the Service Coordinator in conjunction with all Proxies started on demand by each Visualization Service on a client machine that takes part in the session. The sequence of actions for the starting a Collaborative Visualization Session is described as follows (Figure 3):

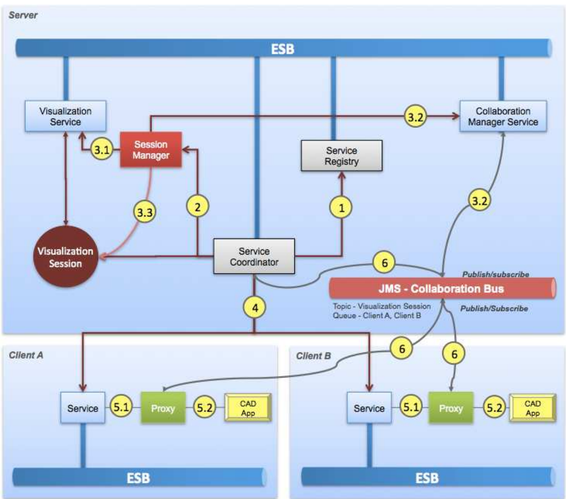

Figure 2: Starting a Collaborative Visualization Session.

a) Service Coordinator verifies in the Service Registry whether the client requesting the creation of the Collaborative Visualization Session supports the requested services or not;

b) Service Coordinator sends a request to Session Manager to create a Collaborative Visualization Session.

c) The Session Manager requests to Visualization Service the creation of Collaborative Visualization Session;

Session Manager requests to the *Collaboration Manager Service* the creation of session in the Collaboration Bus, then Session Manager requests the creation of Visualization Session to Visualization Service and finally send the sessionID of the session to the Service Coordinator;

d) The Visualization Service invokes the execution of the VRV tool on each participant creating the Proxy and passing the sessionID to it;

e) *Service Coordinator* receives commands from the *CEE Server* and sends to all participants (topic) or to an specific one (queue). Similarly, all participants can exchange commands among themselves using the *Proxies.*

4. Application Scenarios

First, we present the project of Collaborative Risers Analysis Workflow. Also, we describe the case of a Design Review Workflow of an engineering project where the support provided a collaborative visualization session for Design Review.

4.1. Collaborative Risers Analysis Workflow

Oil platforms use ascending pipes, called risers, to bring the oil from the wellhead on the sea floor to the platform's separator system tanks. The risers are connected to the platform using special connections called “joints”. To certificate the operation of the risers for their entire life cycle (30 years or so), simulations of the stress applied to the riser system are conducted based on meteo-oceanographic data about wind, tide and water currents. In order to avoid operational problems, simulations are made under extreme environment conditions to test against stress resistance.

The VRV tool adapted to use in the CEE is a tool designed to allow visualization of massive CAD models and engineering simulations in immersive environments (VR and Desktop). It is a system composed of a 3D environment for real-time visualization and plug-ins to import models from other applications, allowing users to view and interact with different types of 3D data, such as refineries, oil platforms, risers, pipelines and terrain data.

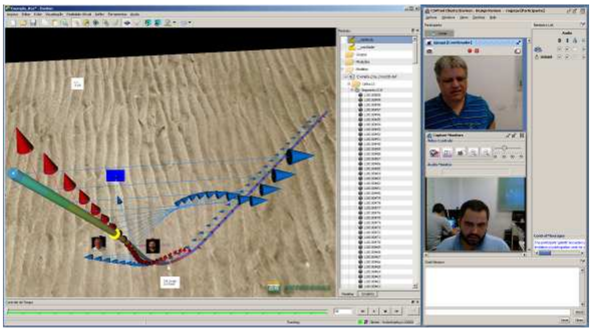

Figure 3: Riser Analysis (VRV tool + VideoConference).

Figure 3 shows a collaborative visualization session with the presence of two users, represented by two distinct 3D-cursors, visualizing the simulation results in their desktop with the support of a Videoconference using the *CSVTool*.

The blue arrow represents the water currents that actuate over the riser, while the red arrow represents the direction of the movement of the riser (i.e. instantaneous velocity). Observe that the greater the alignment of those two groups of arrows the greater the influence of the water currents in the final movement of the riser. For that situation we can see that there is no such alignment, which means that other environmental forces (winds and waves) have a greater influence in the final movement of the riser.

Two 3D annotations were created automatically, showing the extreme points (maximum and minimum values) of a selected force or strength in the riser. The third 3D annotation was created by one of the users to register some important observation made in this collaborative session.

Among other resources, it is possible to playback the simulation, examine pipes, sea waves and ship movements, and track elements in the risers that are subjected to extreme conditions (e.g., high stress values). It is also possible to select any element in a riser and examine it carefully; especially those elements in places subjected to great stress, such as the joints connection and the TDP (Touch Down Point). In Figure 4, the users are looking closely to the behavior of a selected element in the riser (green ring), they can also follow the movements of the element playing the simulation on the timeline bar.

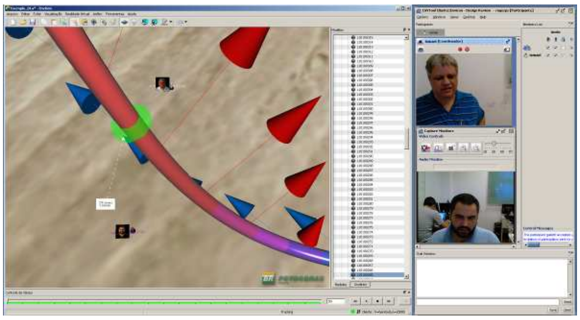

Figure 4: Closer look on an element of the riser

At the end of the session both users will have all the information attached to its local copy of the model. This information represents the state of the collaborative visualization session and can be persisted in a file that can be loaded again in the future to reconstitute the scenario that was analyzed.

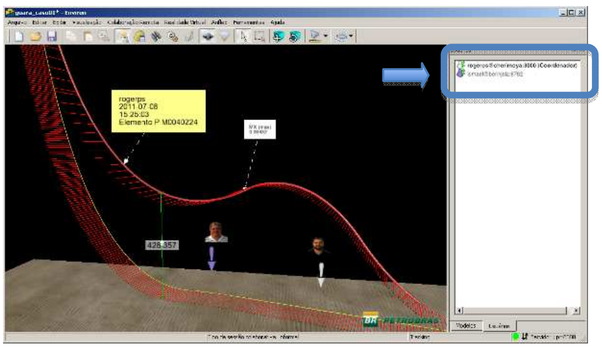

Figure 5: Users in a collaborative visualization session.

Figure 5 shows another collaborative visualization session now with another set of risers. The picture shows the white 3D annotations created automatically, and two other annotations created by each user, making comments about different elements in those two risers.

Observe that in the users tab, we have the awareness mechanism showing information about the status of the user (online, offline) and its role in the session (coordinator or participant).

In Figure 6, we show an engineering project where the users want to study the movement of a buoyant, the usage of the buoyant is to reduce the stress that are submitted to the risers, , especially when there is a great fluctuation in the platform movements due to strong environmental conditions (wave and winds). Through the use of the buoyant we can decouple the movement of the platform hull and the movement of the riser system. Engineers can monitor the distance between the buoyant and the platform and also can observe the behavior of different forces on the risers.

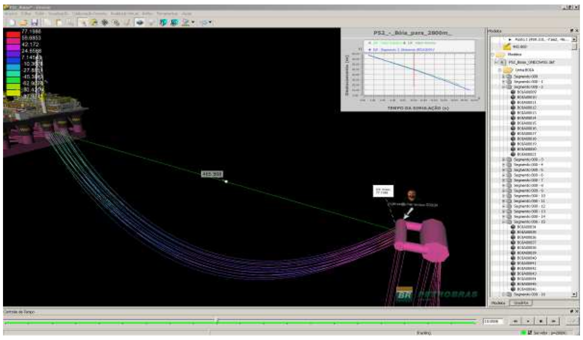

Figure 6: Users monitoring the behavior of marine buoyant

4.2. Design Review Workflow

Design review is the process of checking the correctness and consistency of an engineering project, and making the necessary corrections to it. CEE is very helpful in this process, for instance to assess the safeness of different emergency escape pathways in case of an emergency in the plant.

The Design Review workflow is a simplified version of the riser analysis workflow, where the workflow engine invokes Service Coordinator to create a Collaborative Visualization Session with the support o Video Conference Session according to the user's choice. In this session the users manipulate engineering artifacts and create 3D annotations and make 3D measurements in the model.

Object manipulation is an important resource in design review. The ability of moving, rotating and scaling objects is important for various purposes such as joining different models in a scene, viewing hidden portions of the model, planning the placement of a new piece of equipment on a plant, and simulating a maintenance or intervention operation in a process plant are also valuable tools. Moreover, integration with a CAD database is useful to allow user to create annotations on the model emphasizing critical parts (Figure 7). It is also possible to show comments attached to objects, which can be used as recommendations for project management..

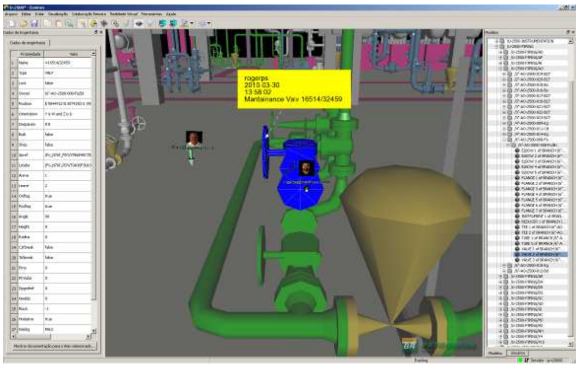

Figure 7: Maintenance plan enriched with annotations.

Figure 8 shows some measurements taken for planning the movement of a large tank on production unit. Users create 3D annotations to guide the maintenance process and can also create an animated path showing the entire operation.

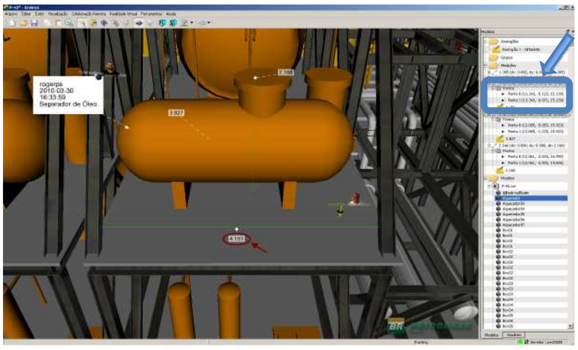

Figure 8: Measurements in 3D in a CAD model.

4.3. Virtual Guided Tour

In the Virtual Guided Tour, a user follows the movements of another user, sharing the same view of the model.

Figure 10 shows another collaborative visualization session. The pictures show both users following a 3D path passing through important points and at the end an annotation is created to mark some important event on the platform, maintenance or commission of new equipment could be programmed.

During VR Collaboration three types of sessions may exist: Informal, Classroom and Lecture. So for each type of session the user has a status that is determined according to its role (coordinator or participant). In a Virtual Guided Tour the coordinator is in a state that he sends camera movements and must ignore any camera movements from the other users (SendOnly), while all the other participants are in a state that they can only receive commands and cannot send any camera movements (ReceiveOnly).

The awareness mechanism shows the icons of each user with 2 green lights, one for input and another for output. When changing to a Classroom or Lecture collaborative session the state of the coordinator and participant changes accordingly, as shown in the Figure 9. Observe that the awareness mechanism changes the icons of each user accordingly, the coordinator change its state to SendOnly (upper arrow green, lower arrow red) while the participant change its state to ReceiveOnly (upper arrow red, lower arrow green).

It is also possible to request the coordinator role, but only in a Classroom collaborative session, in a Lecture session this possibility is forbidden.

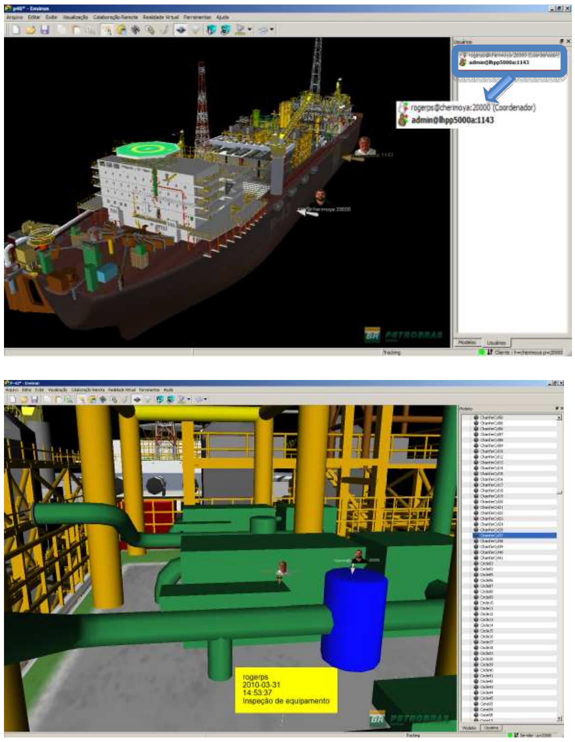

Figure 9: *Virtual Guided Tour*

5. Conclusions and Future Work

A collaborative environment was developed to optimize the execution of Large Engineering Projects such as Offshore Engineering projects. Upon the integration of VR technologies into the workflow of the team workers we expect to improve the use of VR in oil&gas projects. It is clear that visualization resources improve the quality of engineering projects, but users do not want to spend their time preparing the content to be visualized in other system, which requires knowledge in another domain, like an immersive multi-projection environment. The creation of an integrated environment that simplify the daily job of the engineers, from running simulations on a Grid through visualizing its results on an immersive environment or on a desktop, provide increasing team members productivity allowing them to focus on the problem at hand rather than on general computational issues. From the VR and Visualization point of view, the solution approach treats them as first class tools, exploring their potential for facilitating information exchange and common understanding of complex problems.

Although this work is focused on a solution for Offshore Engineering projects, we believe that the proposed techniques could also be used in other areas. There are many important Petroleum Engineering activities [19] that would benefit with the implementation of the current CEE implementation, such as: collaborative real-time visualization, walkthrough and fly-over offshore facilities modeled with massive CAD models; project of ultra-deep water riser and mooring systems; Controlling and monitoring of the construction process of large production units, among others.

References

[1] E.N. Houstis, E. Gallopoulos, R. Bramley, J.R. Rice. "Problem-Solving Environments for Computational Science". IEEE Computational Science and Engineering, 4(3): 18-21, 1997.

[2] E. Tufte. "The Visual Display of Quantitative Information". Graph Press, Cheshire, Connecticut, 1983.

[3] E. J. Dodd. Visualization and Collaboration for the On Demand Upstream Petroleum Enterprise. IBM technical reports, Toronto, Canada, May, 2004.

[4] S.G. Parker, M. Miller, C.D. Hansen, C.R. Johnson. "An integrated problem solving environment: The SCIRun computational steering system". In 31st Hawaii International Conference on System Sciences (HICSS-31), pp 147-156, 1998.

[5] SCIRun. http://software.sci.utah.edu/scirun.html

[6] Paraview. http://www.paraview.org

[7] H. Klie, W. Bangerth, M. Wheler, M. Parashar, V. Matossian. "Parallel well location optimization using stochastic algorithms on the Grid computational framework". In Proceedings of the 9th European Conference on the Mathematics of Oil Recovery (ECMOR IX), 2004.

[8] K. Gruchalla. "Immersive well-path editing: investigating the added value of immersion". In Proceedings IEEE Virtual Reality, VR04, 157–164, Chicago, USA, 2004.

[9] C. Cruz-Neira, D. J. Sandin, T.A. DeFanti, R.V. Kenyon, J.C. Hart. "The CAVE: Audio visual experience automatic virtual environment". Communications of ACM, 35-6, 1992.

[10] The VRGeo Consortium Project.http://www.vrgeo.org

[11] A. Simon and S. Scholz. Multi-Viewpoint Images for Multi-User Interaction. In Proc IEEE Virtual Reality Conference, VR '05, pp. 107-113, March, 2005.

[12] A. Simon. "First-person experience and usability of co-located interaction in a projection-based virtual environment". In Proceedings of the ACM Symposium on Virtual Reality Software and Technology, VRST'05, Monterey, November 7-9, 23–30, CA, USA, 2005.

[13] T. Moan. "Marine Structures for the Future". Internal Report 2003-01. Centre for Offshore Research & Engineering National Univ of Singapore, NUS, 2003.

[14] W. Lee, S. McGough, S. Newhouse, J. Darlington. "A standard based approach to job submission through web services". Proc. of the UK e-Science All Hands Meeting, pp. 901–905. UK EPSRC, 2004.

[15] M. M. Mourelle, E. C. Gonzalez, B. P. Jacob, 1995, "ANFLEX - Computational System for Flexible and Rigid Riser Analysis", Proceedings of the 9th International Symposium on Offshore Engineering.

[16] B. P. Jacob, N. F. F. Ebecken. "An Optimized Implementation of the Newmark/Newton-Raphson Algorithm for the Time Integration of Nonlinear Problems". Communications in Numerical Methods in Engineering, vol. 10 pp. 983-992, John Wiley & Sons, UK/USA, 1994.

[17] BLIND REVIEW

[18] R. Ierusalimschy, L. Figueiredo, W. Celes. "Lua – an extensible extension language". Software: Practice and Experience, 26(6), 1996.

[19] C. L. N. Santos, G. G. Cunha, L. Landau. Use of VRML in Collaborative Simulations 149 for the Petroleum Industry. Proceedings of the 34 th Annual Simulation Symposium, SS01, 2001.

[20] BLIND REVIEW

[21] Y. L. Simmhan, B. Plale, D. Gannon. "A survey of data provenance in e-science". SIGMOD Record, vol. 34(3), pp 31–36, 2005.

[22] R. High, S. Kindler, S. Graham. "IBM SOA Foundation: An architectural introduction and overview". IBM developer Works, Nov, 2005. http://www-128.ibm.com/developerworks/webservices/library/ws-soa-whitepaper/

[23] M. Endrei, J. Ang, A. Arsanjani, et al. "Patterns: Service-Oriented Architecture and Web Services", IBM RedBooks, April 2004. http://www.ibm.com/redbooks.

[24] ActiveMQ, JMS Provider. http://activemq.apache.org/