Collaborative Virtual Environments for Sharing Product lifecycle

L. Brayda, L. Taverna, L. Rossi, R. Chellali

INTARO Group, Robotics, Brain and Cognitive Science Dept
Italian Institute of Technology
Via Morego, 30 Genova 16163
luca.brayda@iit.it

Abstract
This paper aims at presenting a general scheme of product lifecycle where Virtual Reality plays a central role at every step. We propose a framework where both manufacturer, customer, users and trainers share a virtual model of the product. Such framework allows us to emphasize that Collaborative Virtual Environments (CVE) are key-concepts for safety, time and cost reduction. We show that CVE is greatly useful at all steps of the product life. The design becomes co-design where customers and designers interact to achieve the optimal product. In the exploitation phase habitual tasks such as using and training are executed on the CVE platform. Last, dismantling strategies as well as their verification can be also tested on the same platform. Evidence of this framework is given with a real case study.

Keywords: Virtual Manufacturing, Virtual Reality, Rendering, Teleoperation, Telepresence, Haptics, Prototyping

1 Introduction

Virtual Manufacturing is a rather recent concept which has a great potential in industrial applications (Jayaram, 2001). In this discipline the advantages of Virtual Reality are carried out to the production process. While CAD-based software has already proved to help designers to clarify and present their projects in a more precise, concise and sustainable way, Virtual Reality is coming to a mature age, where not only designers can make use of a full-immersive experience in the production process.
CAD is related to professionals, while VR is for everyone.
In fact CAD allows the designer to achieve modeling and visualization of the product; however, it generally lacks to achieve a clear perception of the real dimensions of the product (Neugebauer et al, 2007. VR, instead, allows to go further: first, it provides immersive solutions, thus allowing a more realistic design review and supports a wide variety of simulation processes helping to validate or adapt the product; second, VR enables the designer to exploit other sensory channels, such as audio and haptics (Howard and Vance, 2007; Jayaram et al, 2007), without necessarily having an *a-priori* knowledge of the software environment, nor of

the model; third, it allows simulation and training, by applying physics laws to the (even partially built) model; fourth and last, it is scalable, as multiple virtualizations of a single real object can be accessed by several operators. To this regard, a distributed system customer-manufacturer has been proposed in (Wu et al, 2002), where cost functions of the whole job scheduling are analyzed as well. It has also been shown that VR can have a positive impact on market penetration of the manufactured products (Dépincé et al, 2004).

The purpose of this paper is twofold: first, we show that extending the use of VR to all the steps of the product lifecycle is beneficial, with a particular emphasis on designing, training and dismantling; to this regard, a related study about the combination of CAD and VR for all the production steps of car components (Gomes de Sa and Zachmann, 1999) has shown significant advantages. This because the use of VR shifts the researchers' attention towards a key component: *the interface*. Another related example is the study of cable harness design contained in (Ritchie et al, 2007), which confirms that well-designed interfaces are necessary to access the downstream processes and shows the advantages of VR over CAD. Second, we propose to use a Collaborative Virtual Environment (CVE) to allow all the actors of the production process to participate in the navigation (and possibly in the modification) of the virtual model (Mollet and Chellali and 2008): in this sense VR is the way operators can remotely and simultaneously act on the same, shared product and ultimately constitutes a footbridge between a professional designer and a customer, towards which the design process is opened.

Our motivation arises from the fact that in some applications (e.g. exploration of unknown or dangerous environments) there is a clear need of remotely manipulating products: while at one end of the remote link a human operator must be able to use the majority of the information (vision, sound, touch, temperature) normally available through the human body, at the other end a robot can be used to collect such information and close the action loop by executing the operator's orders. Industrial applications requiring particular complex design, long training (Gerbaud S. et al, 2008) and disassembly and dismantling process (Srinivasan et al, 1999; Srinivasan and Gadh, 2000) can then take advantage from Teleoperation (Zhai and Milgram, 1991; Kheddar et al,1998;Hickey et al,2000), and Telepresence (Yang and Chen, 2004), which allow to migrate real actions on virtual software platforms, and to act from the distance, instead of performing time-costly and risky actions directly on the product.

In this paper we present the concept and the skeleton of the CVE framework we are developing, and an example of its implementation. We present also some operating bricks of the whole system to show what is done, why it is done and how to use such bricks.

The reminder of this paper is organized as follows: Section 2 shows how the product lifecycle would change when using VR at all steps; in Section 3 we discuss how the production steps can be exploited within CVE. Then, in Section 4 we provide a real case study, where VR models are derived from CAD models; Section 5 is dedicated to the use of robots for dismantling and Teleoperation in CVE. Finally, Section 6 discusses future research and perspectives.

2 The CVE Framework

In this section we show the advantages of adopting a CVE framework in Virtual Manufacturing. Generally speaking, a product lifecycle can be represented as depicted in Figure 1.

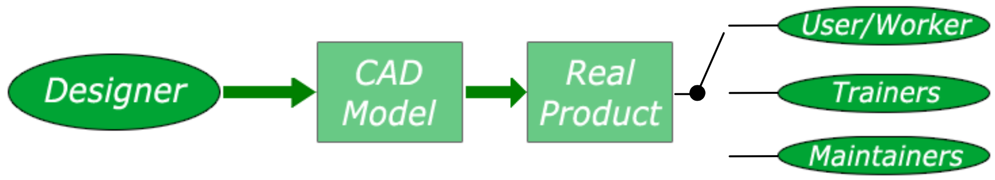

Figure 1: lifecycle of a product, without the use of Virtual Reality

In the first step, the designer builds a CAD model of the product; after that a refinement in agreement with the manufacturer is necessary. Once the CAD model is accepted and well understood, the real product is made. At this point the product can be exclusively accessed by users or workers, by trainers or maintainers. This is a clear limitation: training on new models of aircrafts, boats, learning the use of complex systems such as incinerators and blast furnaces, cannot be generally made while the whole production is ongoing.

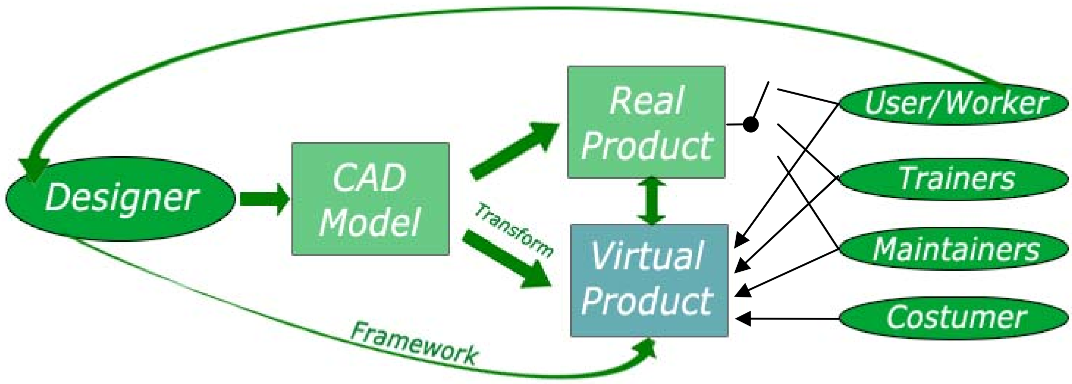

Figure 2: product lifecycle with the full use of Virtual Reality

A first paradigm of virtual-author and virtual mentor has been proposed in (Brough et al, 2007) to address this problem: it is clear that a simulation phase at this point is clearly a desirable option.
Figure 2 is showing the important role of VR if is used: a virtual model is generated by the designer, starting from the CAD model. The designer defines its framework (i.e. the hardware/software set up, the number and kinds of sensory feedbacks the other actors will use). At this point all the actors (user or workers, trainers, maintainers and the main customer, e.g. the company owner) can act simultaneously on the same virtual model. This considerably saves a great amount of time and pulls down costs.
The proposed scheme in Figure 3 is suggesting that VR is useful in all the steps of the product lifecycle:

- Design phase: VR can help the co-design process between customers, users and designers. This is a new concept, because traditionally no feedback is given from users to designers.

Instead of conceiving the product as something made *hierarchically*, VR would rather play in favour of working *circularly*. In fact, this framework implies to work with a fully interactive virtual prototyping.

- Exploitation phase: VR can help workers to be trained in a much safer and repetitive way: a virtual model can even be remotely accessed at home, in parallel, by all trained workers. This would greatly benefit time constraints.
- Life phase: VR can help to maintain a *coherent* model, i.e. modifications and transformations made to the product can be detected (even automatically) and reproduced on the virtual model and be ready to be known by all actors.
- End of life phase: designer and users can develop strategies to dismantle the system in the virtual environment. They can make use of specialized tools (robots for instance) to perform disassembly on the product elements.

3 Exploitation through CVE

Once the system is designed, its implementation, then its exploitation can start. In the following we explain how our CVE can handle both.

3.1 Preparation, achievement and exploitation

The design provides a quasi operational system: a virtual model where realistic physical behaviours as well as system's virtual representations are available. Thus the CVE can replace the real system for training sessions. Indeed, new workers gain access to the software platform through the Internet without any interference to the normal real lifecycle. This is particularly effective because the training phase may be done remotely and offline. We do not exclude that personnel may be even selected using the virtual training tools, thus leading to quantitative (and not only qualitative) evaluation of candidates.

In Figure 4 we show the CVE architecture. Both trainer and learners share the CVE through a client-server web-based application. All can interact with the virtual system using adapted I/O tools and exchange through video-audio server (Chellali et al, 2008).

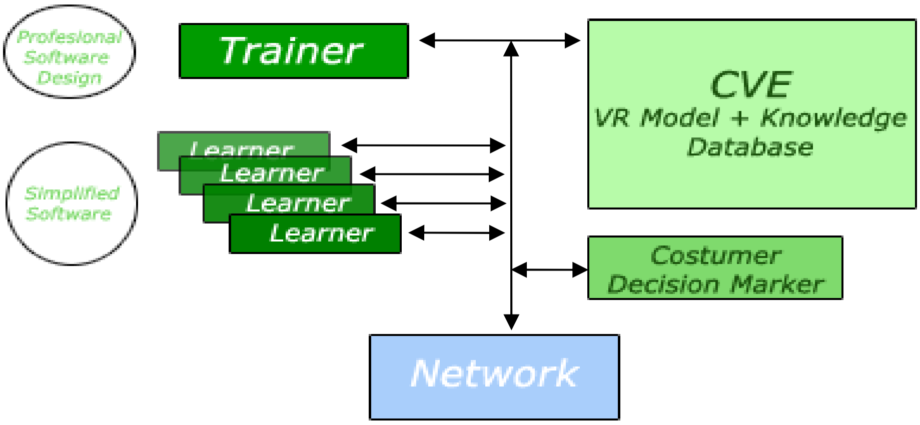

Figure 3: internet-based CVE addressing a training session. The same VR model is used by everyone, but interaction is experienced via potentially very different software platforms

It is obvious that training operations can be performed remotely, thus minimizing time and costs. In the developed CVE, learners can also gain access to real parts of the installation. Indeed, parts supporting automatic control, having sensors or needing visual inspection can be connected to learners to be tested or can fall under their control.

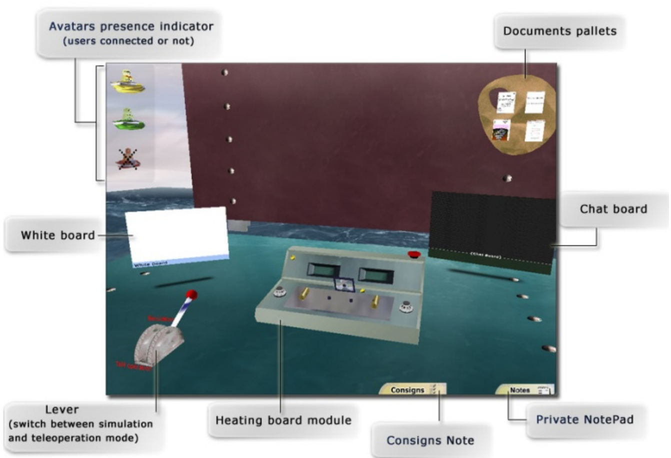

Figure 4: The training environment

In parallel and on the same platform, the customer can follow the achievement of the installation. This is evident in Figure 5, where the learner has simultaneous access to the virtual model of the real object (a heating board in this example), to usage documents and can communicate with the mates, all by being able to switch from simulation to teleoperation mode. Indeed and using the same principle (a web-based application), every step is stated by the manufacturer to let the customer know what exactly has been done and what remains.

3.2 Maintenance and repairing

During its normal lifecycle, a product is subject to maintenance and to reparations. This undoubtedly leads to changes. For a precise follow-up, the resulting dynamic evolution must be stated and shared by all partners by keeping and updating the product's status. Unfortunately, this scheme cannot be fully and perfectly implemented. Mainly for large systems and due to the large number of developers and users, one cannot guarantee the reliability of the records of changes. The phenomenon is lesser for small systems but not excluded.

The Maintenance step may be split as well in its real and virtual parts, which are concurrent and complementary: once faults in the system are located and recognized, they can be remotely sent to the manufacturer (often coinciding with the repairer), which can visualize them on its own virtual model (issued from the Design step and stored). This greatly reduces time of intervention, potential dangers and costs. Faults location and recognition can even be accelerated by using the customer virtual model if sensors are placed on the product: a typical situation is the location of the escape of harmful substances. In addition, a simulation of intervention can be run within the CVE to verify its feasibility.
Figure 5 is given as an example. It shows some the capabilities of our CVE for a remote inspection task. We compare the supposed model and a live view of the remote world. An unexpected object (or event) appears: a metallic part bottom right for (a) and the white Lego part (b). Regarding the task model and the corresponding live view, an image processing system detects differences and signals it to operators. This approach is very helpful and signals potential modifications to be included within the up to date model.

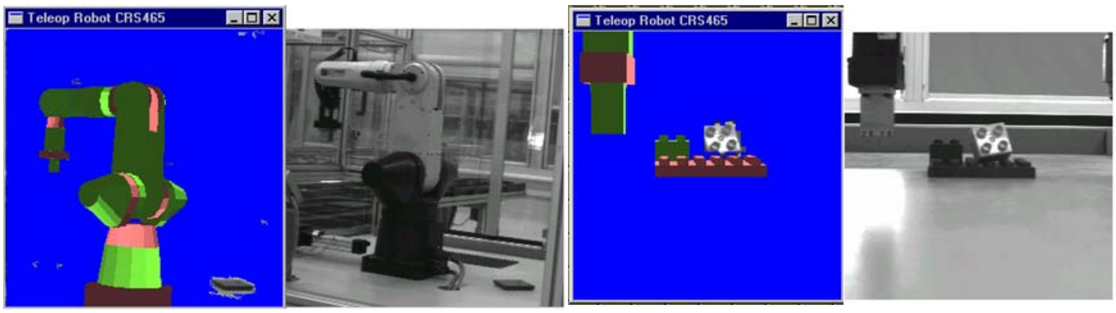

Figure 5: unexpected objects detection

3.3 End of life and teleoperation

The dismantling phase is frequently underestimated: the case of nuclear power plants is the most evident in terms of danger, as the lifecycle is very long (approx 40 years) and the procedures for dismantling must be handed down across generations.
As underlined in (Iguchi et al, 2004), when planning the maintenance and decommissioning of a dangerous work environment, high importance lies on balancing cost reduction and safety. While virtualizing procedures for safe decommissioning is a step forward, including such activity within a CVE framework would benefit the whole production organization because dismantling procedures can be learnt, tested, modified and reordered using a virtual, custom interface. The procedure would allow to better estimate and simulate different solutions for workload, safety checks, time and space constraints (interference or encumbrance avoidance).

To reach a very effective optimization of this process, the decommissioning phase should use data coming from the VR model, a 3D-CAD component database and, possibly, from a complete set of sensors. Moreover the scheduling of the decommissioning could be connected with software scheduling or project management software.
Once the virtual scheduling has been carefully planned, the tasks that have to be accomplished can be performed in a safe environment at any time, as frequently as necessary and at low cost.

4 Deployment of CVE on a case study

The Design phase is the first step of VR lifecycle, it is the *meeting point* between designer and user/costumer; in fact this critical point consists of creating a prototype by constantly evaluating and refining them based on user feedback.
An example of this cooperation is one of our current partnerships with the large manufacturing industry Ts Italia™. The project consists of modeling one of their large gas industry/deposits in order to permit navigation in this space and demonstrate how gas and liquids flow in the multitude of tubes and valves within the structure. This type of project will substantially improve the performances of TS Italia, as it may be used as a monitoring tool as well as being a tool for visualizing in real time all the many processes that occur within this large structure.

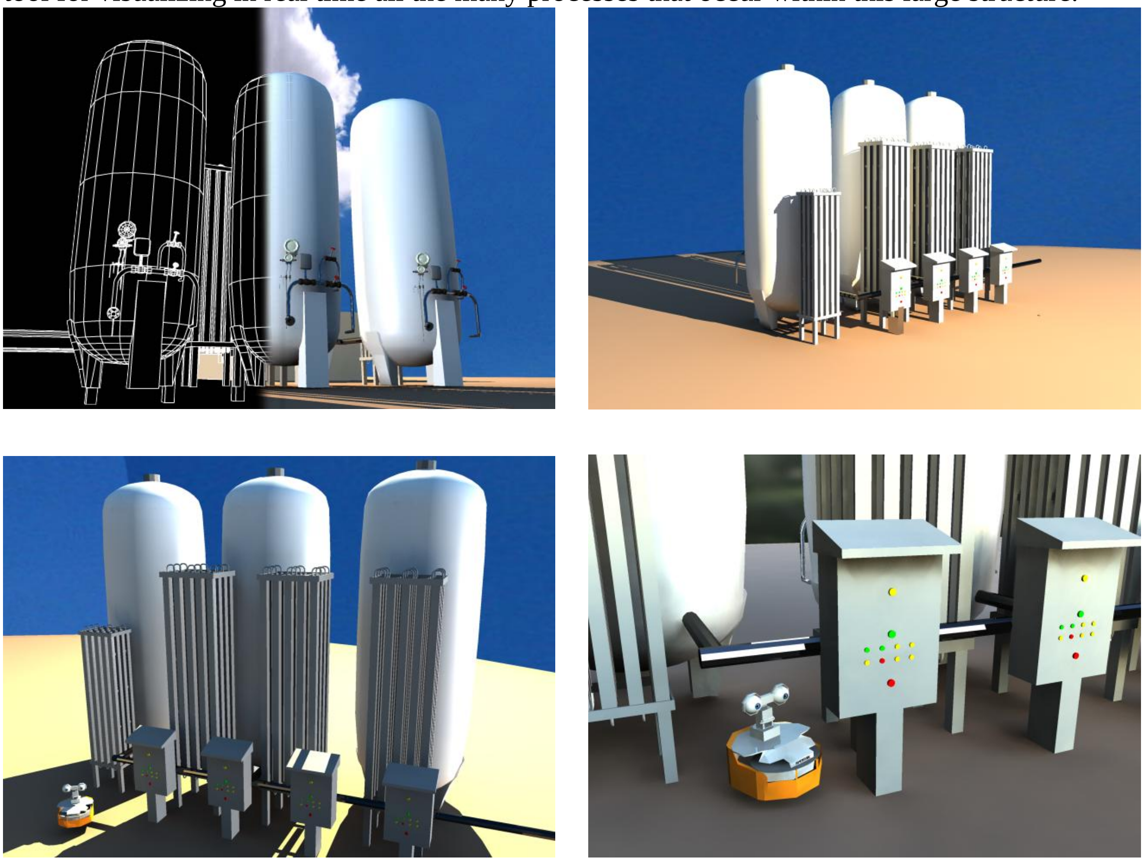

Figure 6: design step from CAD to VR and inclusion of a 3D model of a moving robot.

The realization of these objects is made by Maya™ software a powerful tool, including integrated 3D modeling, animation, effects, and rendering solution, which is able to recreate a very realistic model. Such model, if implemented with physical laws, can trigger user and designer to feel realistic sensation.
An example of the whole design chain is depicted on Figure 6: from top-left to low-right, the CAD model is recreated through a modeling process by the designer, transformed in the VR model and rendered; in addition, as it is shown in Figure 7, a VR model of the Sputnik robot (Dr Robot, 2005) is integrated. While fully virtualizing the whole pipe structure is already a good achievement, VR fields allow us to go beyond the purely visual model: the haptic arm Virtuose (Virtuose 6D35-45, 2007) can be used to feel the pipe structure and get haptic sensations once, for example, the model has been scaled one-to-one. This would greatly help the virtual training phase within the CVE mentioned in Section 3.1. In addition, sound feedback linked to the material and vocal explanations about the element state and function within the structure may be accessed by "touching" pipes.

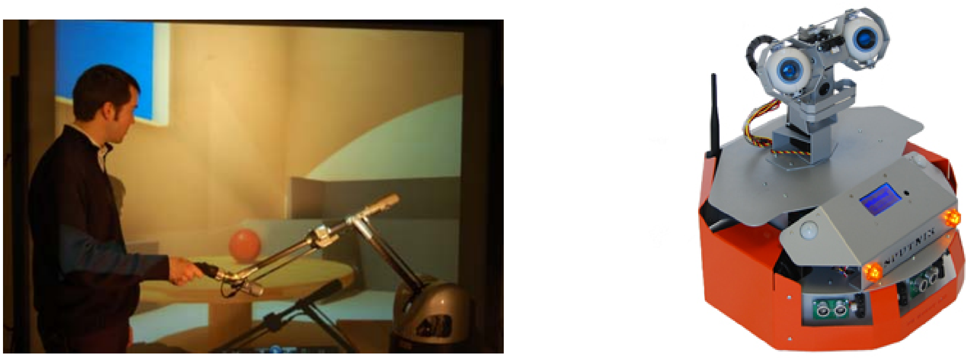

Figure 7: Robots used for teleoperation within CVE: the Virtuose haptic arm can reproduce the touch, while the self-moving Sputnik robot performs stereovision and distance estimation.

5 Manufacturing, maintenance and beyond

In this section we discuss some off-topic arguments that are beyond the original aim of this paper but directly related to the virtual manufacturing. In particular, we see how VR can be successfully used during the post-production phases, from the deployment to the end-of-life. The two main aspects that we could underline are the maintenance and the decommissioning of the final product. Thinking about big industrial plants and dangerous environment VR could really be used not only to save money but, first of all, to save human lives. We can easily imagine a gas or radiations contaminated environment where the maintenance is a life-threatening activity. While the DEXUS system described by Iguchi uses avatars to train humans in a virtual environment, in a life threatening situation the VR model of the plant and the teleoperation of a mobile robot may be the only ethically acceptable solution to some kind of emergency situations. For example, within the scope of the analyzed case study the Sputnik robot can be used to perform surveillance on the pipes structure. The collection of visual data can be processed within CVE to keep track of the model changes. Finally, as stated in Section 3.1, all actors can be informed of (or alarmed about) the new structure evolution. Without going that far, ordinary maintenance could be done using these technologies, VR + teleoperation + robotics. In this case it is clear that the VR model is useful not only during the manufacturing

phase but also during the entire lifecycle. Specifically, during the phase-out a dismantling phase may be necessary.
In this scenario the VR model is sold and evolves *with* the product: it clearly justifies its cost not only during the design process but could be considered as a benefit for the customer that can reuse the same model as a tool to run properly the real product.
Other examples could be proposed: a similar but much more complex, more and more difficult and expensive problem is oil extraction. In 2000 ABB designed a subsea platform named SUBSIS (SUBSIS, 2000). It's easy to imagine such an automatic plant designed with the aid of a virtual reality model, the plant could also be completely remotely operated and maintained using the same model and some sort of mobile robot designed to fit the structure and move in such a factory.
Again, the novelty is represented by the combination of VR models and teleoperation of mobile robots. In this case all the dangerous work during the maintenance and eventually decommissioning of the industrial plant is done by one robot, or a team of mobile robots, equipped with a set of interchangeable tools, suited for the specific task.
The proposed scenario is not science-fiction and is based on well-known technologies. The key points are the safety procedures involved in such a project. Telecommunication protocols and fault tolerant hardware and software give us, today, the capability to face every possible problem could occur. Nevertheless the topic has to be deeply investigated and accepted by the customer.

6 Conclusions

We proposed a scheme that is able to handle the whole product lifecycle. In our Collaborative Virtual Environment all actors of a product lifecycle can exchange information, based on the same virtual data: as such, a CVE constitutes a bridge from professional to end-user representation, being able to be remotely used and offering a prototyping platform based on iterative co-design. Mutual feedbacks between users/workers, designers, trainers and customers make the production process *circular* rather than *hierarchical*: in this sense our new approach allows to extend the use of Virtual Reality from the very beginning to the end of life of a product. More specifically, VR is a very powerful tool to alleviate training, maintenance and decommissioning costs, where risk assessment and safety can be first simulated, then implemented. In this sense the virtual model becomes part of the product and evolves with it, allowing real-time monitoring, possibly automatically performed via a sensor network.
This leads to optimal results in terms of ergonomics, economy, time-to-market etc…A real implementation of some bricks of a CVE was provided: we built a virtual model of a large structure of gas and liquid containers. Ongoing work is focusing on integrating virtual models of robots, able to give audio-visual information and haptic feedback, which can be fused in the same virtual environment as avatars of real robots, thus operating on the real structure. The purpose we plan to achieve is performing teleoperation and telepresence mainly for maintenance and dismantling of dangerous worksites.

7 References

Brough, J. E. et al. (2007) Towards the development of a virtual environment-based training system for mechanical assembly operations. *Journal on Virtual Reality 11, 4* 189-206.

Chellali R. et al. (2008) SyTroN: virtual desk for collaborative, tele-operated and tele-learning system with real devices – In *Proceedings of Edutainment 2008*, Nanjing, China

Dépincé P. et al. (2004): Virtual Manufacturing : Tools for improving Design and Production. In *International Design Seminar - CIRP International Design Seminar*, Caire, Egypt

Gerbaud S. et al. (2008) GVT: a platform to create virtual environments for procedural training – In *Proceedings of IEEE VR 2008*, Reno, USA

Gomes de Sa A., Zachmann G. (1999), Virtual reality as a tool for verification of assembly and maintenance processes, *Journal on Computers & Graphics* 23, 3, 389-403.

Hickey S. et al. (2000) Telereality - the next step for telepresence. In *Proceedings of the World Multiconference on Systemics, Cybernetics and Informatics* (VOL 3) (SCI 2000), pp 65-70, Florida.

Howard B and Vance J. (2007) Desktop haptic virtual assembly using physically based modelling *Journal on Virtual Reality 11, 4* 207-215

Iguchi et al. (2004) Development of Decommissioning Engineering Support System (DEXUS) of the Fugen Nuclear Power Station, *Journal of Nuclear Science and Technology* ,41(3), 367-375

Jayaram S. et al. (2001) Assessment of VR Technology and its Applications to Engineering Problems. *Journal of Computing and Information Science in Engineering 1(1):*72–88

Jayaram S. et al. (2007) Industry case studies in the use of immersive virtual assembly. *Journal on Virtual Reality 11, 4* 217-228

Kheddar A. et al. (1998). Fitting teleoperation and virtual reality technologies towards teleworking. In *Proceedings of 4-th French-Israeli Symposium on Robotics* (FIR'98), pp.147-152, Besançon, May 13-15.

McCorkle D.S and Bryden K. M. (2007) Using the Semantic Web technologies in virtual engineering tools to create extensible interfaces *Journal on Virtual Reality 11, 4* 253-260

Mollet N., Chellali R. (2008) Virtual and Augmented Reality with head-tracking for efficient teleoperation of groups of robots, accepted for publication for Cyberworlds2008

Neugebauer et al. (2007) Virtual reality aided design of parts and assemblies *International Journal for Interactive Design and Manufacturing 1* 15-20

Ritchie J. et al. (2007), Cable harness design, assembly and installation planning using immersive virtual reality *Journal on Virtual Reality 11, 4* 261-273

Sputnik robot (2005), by Dr. Robot manufacturer: http://www.drrobot.com

Srinivasan, H., and Gadh, R. (2000) A Non-interfering Selective Disassembly Sequence for Components with Geometric Constraints,'' *IIE Journal of Design and Manufacturing*

SUBSIS project (2000), http://www.abb.com

Virtuose 6D35-45 (2007) from Haption SA: http://www.haption.com

Srinivasan, H. et al. (1999) Virtual Reality for Design and Manufacturing. *Appliance Manufacturer Magazine*., No. 5, pp. 23–25.

Wu S.H. and Fuh J.Y.H. and Nee A.Y.C. (2002) Concurrent process planning and scheduling in distributed virtual manufacturing. *IIE Transactions, Volume 34, Number 1,* 77-89

Yang X. and Chen Q. (2004). Virtual reality tools for internet-based robotic teleoperation. In *IEEE Proceedings of the 8th IEEE International Symposium on Distributed Simulation and Real-Time Applications*, pages 236–239, Washington, DC, USA

Zhai S. and Milgram P. (1991). A telerobotic virtual control system. In *Proceedings of SPIE,* vol.1612, Cooperative Intelligent Robotics in Space II, Boston, 311–320