VRTest:
a Virtual Reality sysTEm for tranSporTation design

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1. Introduction

Virtual Reality (VR) is a simulation technology that allows the designers to interact with the digital model of the product, before it has been physically realized, [Caputo 2004]. It can be defined as «*…a high-end user-computer interface that involves real time simulation and interactions through multiple sensorial channels: these sensorial modalities are visual, auditory, tactile, smell and taste*», [Burdea 2004]. VR techniques are relatively new, having endured a strong development only during the last few years, in correspondence of the progress reached by the computer science and the hardware and software technologies. Therefore, there have not been yet a great diffusion and application in industrial field, in spite of the constant decrease of the costs, and that can be found especially in the Italian situation, object of observation. Only large industries and corporations can afford to make an investment into VR in hopes of large returns. The current state of VR is generally not advanced enough for most corporate users to accept. Industry users want turnkey solutions that don't yet exist in such a young field. The possible benefits of VR are becoming more visible to industry users, but with the current state of virtual reality, the amount of development required is not always apparent or reasonable. Although limited tools are appearing that allow quick design of VR applications, the ability to design VR applications still often requires backgrounds in virtual reality and computer programming. This is experience that typical Information Technology or Research & Development employees do not often have and makes it difficult for many companies to be able to apply VR in their working processes without adding new personnel to their groups. Since companies need to justify their expenditures, they also can't easily spend tremendous resources improving the state of VR.

In the last years the researchers of University of Naples Federico II have made great efforts in order to make available VR technologies also to small Campania's industries operating in transportation field. These efforts have brought to the realization of a semi-immersive VR system, named VRTest, in which new procedures for the evaluation of product prototypes and manufacturing systems, can be tested in order to take into account the human factor both in the product design and in the process design. The VRTest has been founded by Campania Region with the aim of delivering advanced services and introducing new technologies into local companies operating in the field of transport. The positive reply received from the industrial world has confirmed how these methodologies can be greatly useful in the phase of design, influencing the developing time and the quality of the industrial products. The application of the realized environment to styling, usability, ergonomics, concept design, maintainability tests, assembly/disassembly simulations, design review, training, allowed to highlight the advantages offered by this design methodology: acting on the industrial product since the first phase of conception and thanks to the possibility to place the designer in front of the virtual reproduction of the product in a realistic way and to interact with the same concept, it allows the modification and the improvement of the product characteristics in real time with a remarkable saving of time and costs.

After a brief illustration of the VRTest laboratory, this chapter contains the description of the main activities realized in the VRTest in order to demonstrate how VR technologies can support and improve transportation design.

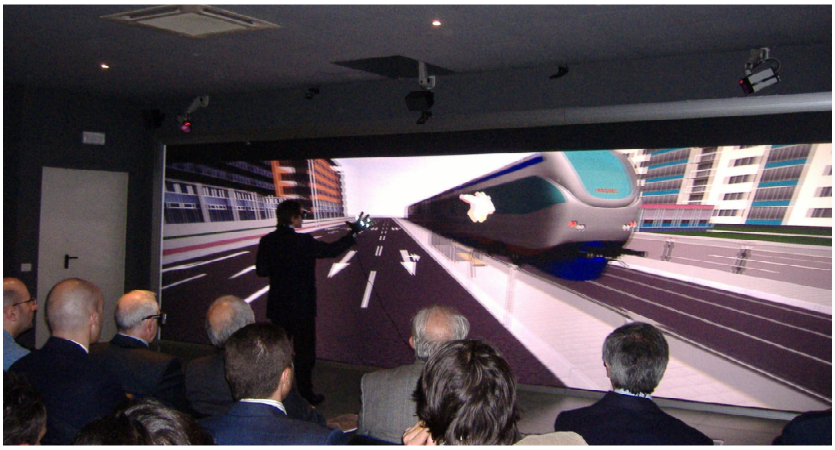


Figure 1. VRTest Laboratory.

These activities have been carried out in collaboration with the main Campania's industries operating in the field of transport like Firema Trasporti, Alenia Aeronautica, OMA Sud, Piaggio Aero Industries, with important Italian Research Centers like CIRA (Italian Center for Aerospace Researches) and Graphitech Foundation, and other Italian Industries like COMAU and European Industries like vrcom GmbH. These activities cover all the phases of the Product Development Process, from the conception to the marketing. In particular the main applications developed at the VRTest and described in the following sections deal with: styling, concept design, design review, virtual maintenance, virtual manufacturing, virtual training, marketing.

2. VRtest Laboratory: hardware and software setup

The realization, in an immersive virtual environment, of all the above mentioned design activities, needs specific requirements: a powerful graphic and calculus system able to manage a great amount of data; a large screen able to visualize complex systems in full scale; projectors supporting active stereo; input devices allowing the protagonist of the virtual experience to easily navigate and interact with the virtual scene and other members of the design team to share such experience and review the design; software tools able to realize photo-realistic presentations of the virtual models on multiple displays, to track the real user in the virtual scene, to detect collisions among virtual object, to satisfy motion programming requirements, to realize kinematics simulation, 3D distance measurements, virtual markup, path recording and all the other tasks needed to perform manufacturing systems simulations; 3D audio output devices increasing the immersion in the virtual environment. In May 2005, the researchers of the Department of "Progettazione e Gestione Industriale" of the University of Naples Federico II have completed the installation of the Virtual Reality laboratory, [Caputo 2004], named "VRTest", realized for the Competence Regional Center for the qualification of the transportation systems. The laboratory is, to date, one of the most innovative in Europe respect of hardware components, screen dimensions and software availability. It allows developing products and complex systems and simulating their configurations and performances in virtual environment. Therefore, it represents the ideal theater for the immersive evaluation of concept of industrial products, complex assemblies and manufacturing systems that present large dimensions, figure 1. The main characteristics of VRTest are described in figure 2.

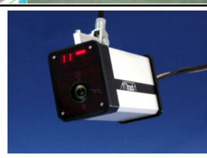
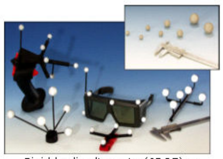
Graphics and Calculus System	Characterized by high performances and flexibility, and constituted by: - **SGI Onyx 4** with 10 CPU, 10 GB Ram, 6 graphic pipes, IRIX 6.5 Operative System; - **Cluster of 3 PC** with: 2 CPU Pentium Xeon, 4 GB Ram, Nvidia Quadro FX 3000G graphics card; Operative Systems Windows XP and Linux.	
Visualization System	**Powerwall** (7.5m x 2.4m) BARCO ACTCAD	
	3 DLP **Projectors** for active stereo BARCO Galaxy 6000 AL	
Tracking system	Optical, real time, wireless with 3 **ART TRACK** cameras; - it is immune from interferences caused by metallic objects and/or magnetic fields - it is able to recognize and track simultaneously 20 wireless sensors.	  Rigid bodies/targets (6DOF) or single markers (3DOF)
3D Input Systems	**Cyberglove** with 22 sensors, **5DT** with 14 sensors, **spaceball**, **flystick** e **joystick**	
Software	Virtual Design 2 by vrcom (Showroom, Assembly/Disassembly, Interior design, Lightsimulation modules, Developer Toolkit); CATIA V5 R16 P3 by Dassault Systems (all modules); Alias StudioTools R12; Classic Jack (Occupant Packaging Toolkit, Task Analysis Toolkit modules), TeamCenterVisualization 2005 and Unigraphics NX by UGS.	

Figure 2. VRTest characteristics.

Figure 3. Styling studies in automotive industry, (the 3D model of the car is courtesy of vrcom GmbH).

3. Styling

The VR applications in the "styling" consists of esthetic features evaluations according to the design requirements. Such a simulation tool allows to verify style surfaces on real size digital models: it is possible to control lights and shadows effects and even the reflections of the surrounding environment in which the vehicle is located, [Di Gironimo 2006a]. The majors automotive designers, such as Pinifarina Giuggiaro, use the VR for evaluations style without the realization of physical mock-up in real size, figure 3. Furthermore, the possibility of navigating in a virtual environment represents a powerful marketing strategy. In fact, demanding customers can choose among different layout configurations and interiors design of particularly products such as yachts, luxury cars, aircrafts. For example in VRTest laboratory we have evaluated style solutions for the furnishing of the the Piaggio Aero Industries P180 Avanti executive aircraft, [Di Gironimo 2004a]. Figure 4 shows how the designer, coming into the aircraft, can evaluate realistically interiors design layout, colors and materials. The designer can simply do this, just doing a virtual walkthrough.

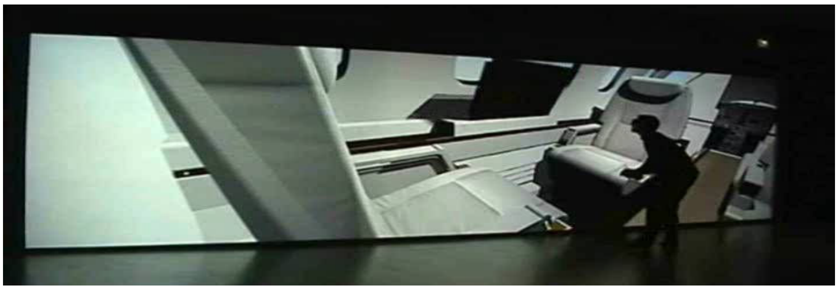


Figure 4. Styling studies in aeronautic industry, [Di Gironimo 2004a].

Figure 5. Different style solutions for the Piaggio P180 Avanti.

In order to carry out styling studies on the interiors of the Piaggio P180 Avanti, an immersive VR system has been employed, available at both CIRA and VRTest laboratories, driven by an in-lab-developed VR software, named ViRstPerson. Aiming at developing a realistic visual and interaction virtual environment, the ViRstPerson has been improved with some significant functionality, namely the real-time shadow generation and the real-time rigid body dynamics simulation for physically-correct object interaction, [Di Gironimo 2005a]. An other support to photorealistic presentation of industrial products for styling studies is given by *shader technology*; in fact it allows the programmers to have control over shape, appearance (such as colour, lighting, reflection) and animation of objects, in order to make very realistic real-time rendering. In [Di Gironimo 2006a] the authors have described the use of shader technology in Virtual Design 2 (by vrcom GmbH) for realistic presentation of train prototypes in VR, figure 1.

4. Concept Design

The early identification of the optimal concept is a critical task of the design process in order to increase the chances of satisfying customers. In [Di Gironimo 2006b] the authors have proposed an innovative approach for the quality evaluation of virtual prototypes of new industrial products (i.e. concept designs) by adopting statistical procedures. Following this approach, the optimal concept design is defined at the end of a process consisting of five phases: identification of the quality elements of the concept design, classification of the quality elements, generation and quality evaluation of product concepts and, finally, definition of the optimal concept.

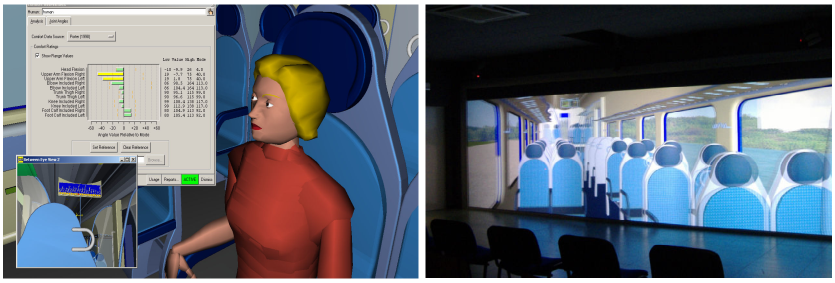


Figure 6. Ergonomics evaluation through virtual manikins and immersive visualization in VRTest of new concept solutions for a regional train.

Currently, VR environment offers the opportunity to evaluate the characteristics of different virtual prototypes by involving several experts and/or customers, overcoming the need for several physical prototypes. On the other side, the dynamics of simulation and the stereoscopic visualization in VR environment provides a more realistic and impressive interaction with virtual prototypes than in CAD environment. The proposed methodology has been fully exploited through two case studies: the choice of the optimal design for the interiors of a new regional train [Caputo 2005a], figure 6, and for the dashboard of a new minicar, [Di Gironimo 2006b], [Di Gironimo 2006c], figure 7. These studies demonstrate that the CAD software, integrated with ergonomic evaluation methodologies, statistical methodologies and VR technologies, make possible to concretize an idea for evaluating it and experimenting it.

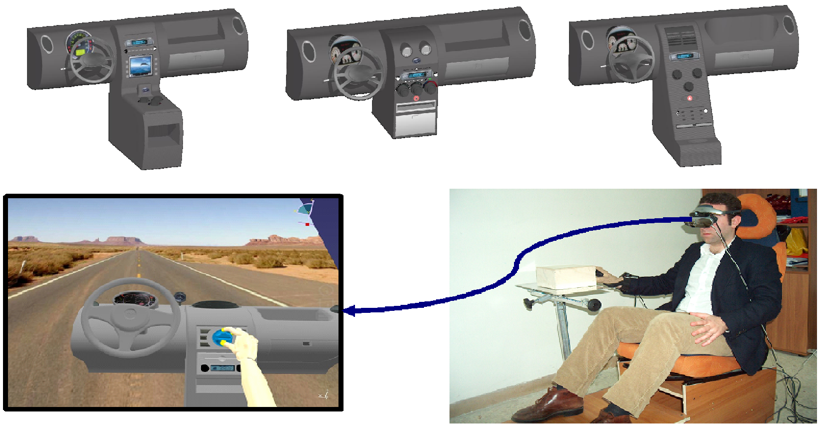


Figure 7. Quality evaluation of dashboard concepts in VR.

5. Design Review

After the concept phase of the design process, the VR is still extremely efficacious in the statement phase, during the which designers belonging to different competence fields have to interact in order to define and finally to deliver the final design. VR, in fact, gives the possibility to many people simultaneously to analyze and review the design, providing tools to highlight design lacks and to make modifications in real time. In this way, a variety of figures, not only designers, but also technicians assigned to the maintenance, can be involved in the analyses and in the evaluations, according to a concurrent engineering approach. From interaction among such different company figures indispensable indications can issue about the improvement of the maintainability and robustness of the final design.

An important experience in this area has been carried out in the VRTest in collaboration with Firema Trasporti; it deals with the development of an interactive environment designed to take advantage from the VR instrument during Design Review sessions. In particular, the system was implemented with the aim to offer an usable instrument to not VR expert users, such as workers assigned to the maintenance operations. Moreover, unlike the already available tools for Design Review, the environment was oriented to the study of complex systems with large dimensions, such as trains in real scale: with this aim, for example, the possibility to select any component of the assembly, directly pointing it in the scene, is given. The case study was offered by the demand of Firema Trasporti, to verify, in the preliminary design phase, the maintainability of components of service systems of a regional train, [Di Gironimo 2007a]. Particularly, the simulation interested the brake, the air-conditioning and the doors systems and was finalized to satisfy the required verifications of accessibility and detachability of such sub-assemblies with the usual tools, which the company maintenance shops are equipped with. In order to provide the instruments to carry on the described analyses, the following objectives have been pursued: exploring the scene in natural way by an user not necessarily expert of VR technologies; hiding the chassis and the furniture to show the only analyzed service system; highlighting every single element of the scene, showing in wire-frame mode or hiding the others; affixing markers in the virtual scene to note the critical points where to return successively; recording annotations; taking high resolution snapshots of the scene in real time; storing the

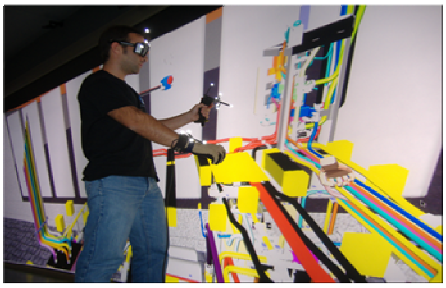


Figure 8. Navigating with the flystick.

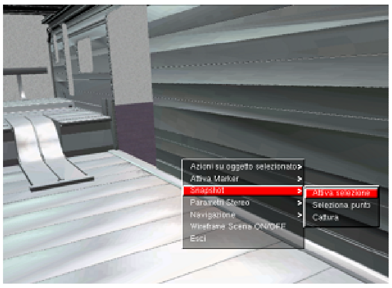


Figure 9. 2D Menu

whole virtual scene, complete with markers and annotations. The software chosen as simulation manager for this kind of application is *Virtual Design 2*, by vrcom. This software provides an user-friendly interface to handle all VR devices used in the VRTest laboratory. Moreover, the availability of a Software Development Kit allows to enhance and customize the basic functionalities of the simulation manager by developing new software modules, that are fully integrated with the underlying framework. The external module export many functions which can be triggered by certain events (e.g. a collision, the pressure of a key, a particular gesture of the virtual hand) as well as any other basic command. Such possibility gives practically infinite possibilities to program the Virtual Environment. All commands implemented in the virtual environment have been assigned to the buttons of a flystick in order to make independent the protagonist of the immersive experience, reducing at the minimum the necessity of a second operator at the control console. For the design review activities we have implemented the following functions: *navigation* (see figure 8), *2D Menu* (see figure 9), *selection* (see figure 10), *snapshot* (see figure 11) and *markers* (see figure 12); for a detailed description of these function see [Di Gironimo 2007a].

Figure 10. Selection.

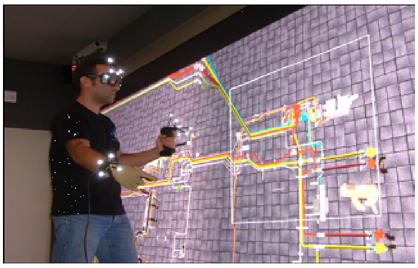


Figure 11. Selecting the snapshot area. Figure 12. Marker with annotations.

In particular, thanks to the markers, the user can signal particular objects in the virtual environment: in this case markers have been used in order to highlight the critical zones for the maintainability, destined to successive studies. The release of the marker takes place simply pressing one key of the flystick. The marker will appear in correspondence of the forefinger of the virtual hand in the shape of an arrow, figure 12. In this case the possibility has been provided to the operator to write and leave an annotation in correspondence of the marker. These annotations can be saved and loaded successively, for example for comparing different configurations of the analyzed assembly.

5.6. Case Study

The implemented tools have been used in the Design Review sessions of the new train service systems with the participation of company designers and staff: thanks to the developed instrument the points and operations, critical for maintainability, have been highlighted and analyzed in successive sessions, figure 13. With this activity VR has been applied as an important support in the maintainability analyses of whole systems, even quite complex ones, such as those ones present in a railway carriage.

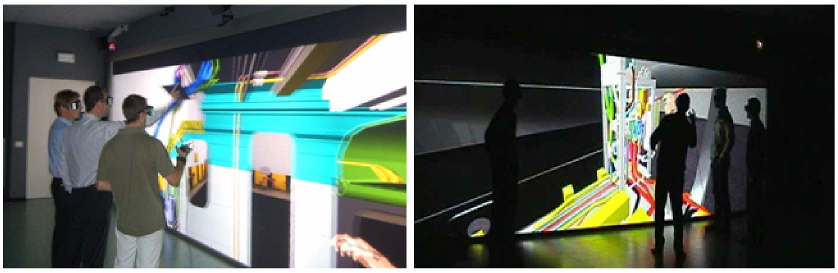


Figure 13. Design Review session.

With the aid of the virtual tools, in fact, it has been possible to carry on a preliminary maintainability verification of the whole service systems, already in design phase. During the discussion with the company technicians, the analysis has been concentrated on the only critical points, highlighting with markers those ones destined to successive and more in-depth analyses with Human Modelling tools. Markers have been saved with their positions and successively loaded on the new configuration of the system: in this way the process of critical review of the design and the comparison among the various reviews are easier.

6. Virtual Maintenance

When technical systems are not designed taking into account future maintenance operations, they imply high times and costs also for a simple replacement. For these reasons maintainability has to be considered a design characteristic and a competitive factor. Carrying out maintainability tests in Virtual Reality allows to take into account, the ability of the humans to perform maintenance operations since the first stages of the design process. In order to centre "the human in the design" when the design is still virtual, two approaches can be chosen: the use of virtual manikins and the direct manual interaction in immersive VR environment ("DIR.MAN.INT." approach). Virtual simulation of maintainability tasks by means of virtual manikins allows to: evaluate visibility, reachability and grasping of component parts during assembly and disassembly phases; calculate times and efforts needed for the execution of maintenance tasks; foresee the capability of the workers to support these efforts according to their anthropometric characteristics; highlight damage risks during each lifting and handling of component parts, [Caputo 2004b], figure 14. An added value to the analysis, carried out through virtual manikins, arises from the possibility for the same analysis to be standardized using appropriate percentiles, obtaining more objective results.

On the other hand, the DIR.MAN.INT. approach intends to allow the user/designer to directly interact with the elements of the product he is designing, with the aim to interactively carry on the maintainability analysis in VR through his own hands and arms, [Di Gironimo 2005a]. During disassembly, accessibility and manipulability analysis the designer becomes the protagonist of the analysis actions.

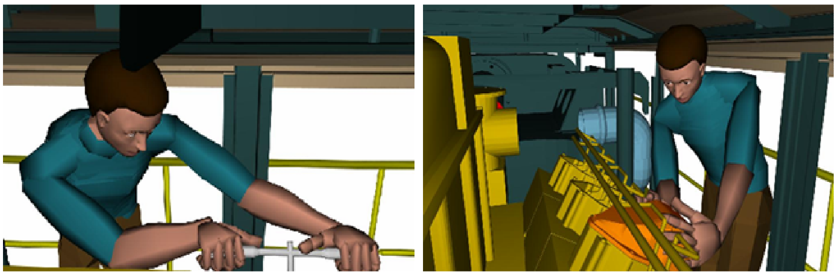


Figure 14. Maintainability analysis through virtual manikins,[Caputo 2004b]

These actions are not mediate through a virtual manikin but they are directly executed by the designer that wears some VR devices and is immersed in the VR environment. The evident advantage of the DIR.MAN.INT. approach consists in the immediate correspondence between the desired analysis and the relative action carried out. This correspondence makes the performed analysis natural, intuitive, and, consequently, quick. The main disadvantages of the DIR.MAN.INT. approach are innate in the subjective characteristic of the technique: in this case, in order to obtain more objective results, it is necessary to carry out a statistical analysis, through subjective tests on a representative sample of human population.

6.1. Methodology and Case Studies using Virtual Manikins

In [Di Gironimo 2004b] a methodology has been developed which provides the combined use of CAD systems and virtual manikins in order to optimize the maintainability analyses. Such methodology, called "EDIVE" (Ergonomic Disassembly In Virtual Environment), is structured in four phases (for a complete description see [Di Gironimo 2004b]): 1) analysis of the system; 2) disassembly analysis; 3) accessibility and manipulability analysis; 4) ergonomic analysis.

Figure 15. Locomotive D146 by Firema Trasporti SpA, [Caputo 2004b].

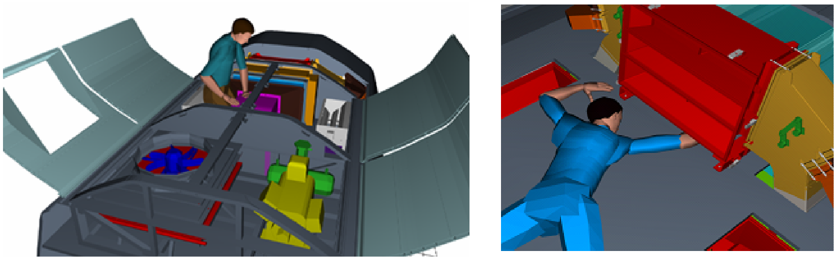


Figure 16. Maintainability analysis on the air-conditioning system of a train.

In [Caputo 2004b] EDIVE methodology has been applied on a already realized system, a locomotive realized by Firema Trasporti SpA, which needed a maintainability analysis of the engine components after a redesign for market requirements, figure 15. However, the great added value of EDIVE is when it is applied in the design phase of a system, that is when there is still time to point out and, therefore, to eliminate design mistakes that would make difficult or quite impossible some maintenance operations. In [Di Gironimo 2006d], an application of the EDIVE methodology to the main components of the air-conditioning system of a new regional train in phase of design at Firema, figure 16. The aims pursued through the application of EDIVE, have been: the improvement of the maintenance operations in terms of accessibility, demountability and manipulability of system components and subassembly; the improvement of the ergonomics of the postures of the operators assigned to the maintenance activities; the reduction of the maintenance time.

6.2. Methodology and Case Studies using DIR.MAN.INT. approach

In order to experiment the DIR.MAN.INT. approach for maintainability tests, and to develop a suitable usage methodology, in [Di

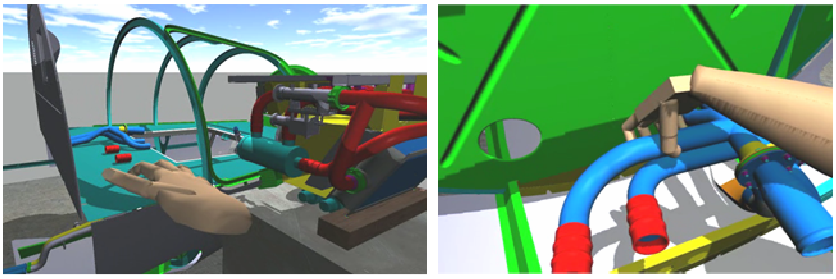


Figure 17. Maintainability tests on the air conditioning system of the P180.

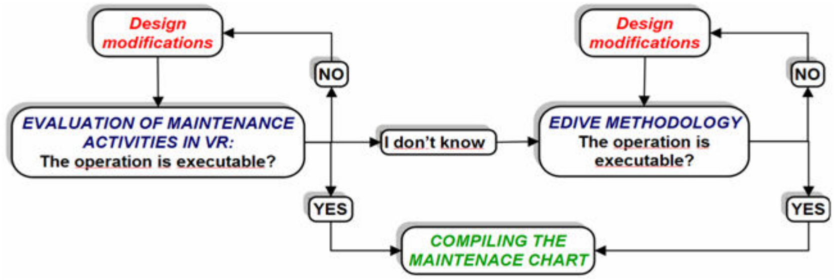


Figure 18. Methodology for maintainability test of complex assemblies in VR.

Gironimo 2005a] the software *ViRstPerson* (see section 3 of the present chapter) has been employed. In particular DIR.MAN.INT approach has been experimented on a aeronautic case study, namely the air conditioning and pressurization system of the Piaggio Aero Industries P180 Avanti executive aircraft, figure 17.

6.2.1. Complex Assemblies

Since EDIVE methodology results quite onerous due to the time needed for the set up of the simulations, it is not usable in case of maintainability analysis of complex assemblies, where maintenance tasks to execute are hundreds. In these cases many of the analyzed operations could be very simple and their feasibility could be easy verified, without recurring to the EDIVE methodology. In these cases the employment of DIR.MAN.INT approach, although it doesn't bring to objective results, allows to "filter" a great number of operations in order to limit more as possible the use of virtual manikins and offers moreover the possibility to simulate quickly several activities, figure 18. In [Di Gironimo 2006e], the authors relate a methodology to execute maintainability tests of complex assemblies in VR, analyzing and comparing 3 different approaches.

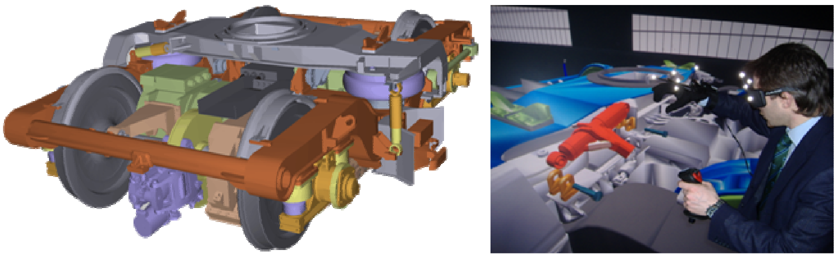


Figure 19. Virtual Maintenance task on a railway bogie.

This methodology has been applied to a case study offered by the Firema Trasporti SpA relative to the analysis of feasibility, in virtual environment, of the preventive and corrective maintenance operations of a motor bogie of a railway vehicle, figure 19, [Di Gironimo 2006e].

7. Virtual Manufacturing

To date, the VR is largely used to develop new methodologies for the design of automated assembly lines, in order to realize innovative products whose manufacturing process is the more possible automated. The virtual simulation environment allows either to evaluate the best workplace layout configuration, which minimizes the lead time in the line production, or to optimize the automation level and the human component for each workplace. This means it is possible to carry out kinematic simulations of robots and ergonomic evaluations of operators in order to compare the results of these simulations with safety requirements. In manufacturing environment many software packages have been developed for virtual applications. These packages provide important functions that can be used to develop and create virtual manufacturing environment and to address process planning, cost estimation, factory layout, ergonomics, robotics, inspection, factory simulation, and production management. Virtual Manufacturing can be realized with the integration of different software tools, each dedicated to simulate three main production environments: robotized work cells, manual work cells, hybrid work cells, [Caputo 2006a], [Di Gironimo 2006f]. Several experiences in the aeronautic, automotive and railway field have been carried out in the VRTest laboratory. Figure 20 shows two snapshots from the simulation of the assembly process of the SKYCAR aircraft carried out in the VRTest in collaboration with OMASud SpA. In [Di Gironimo 2006g] we have conceived an innovative assembly cycle of railway vehicles that can

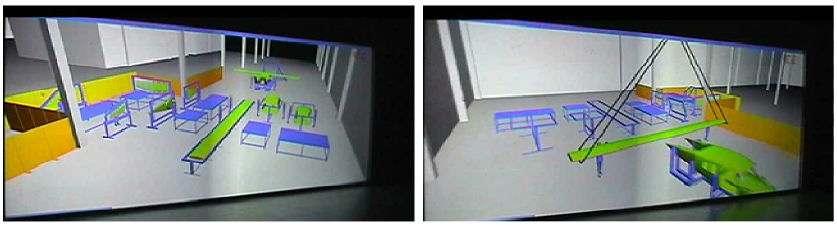


Figure 20. Study of the SKYCAR aircraft assembly process.

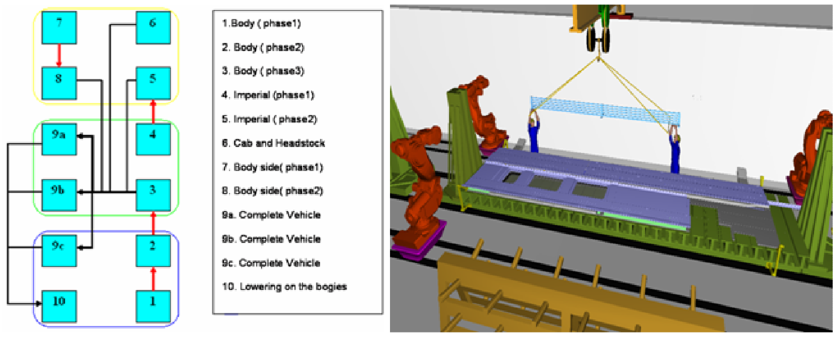


Figure 21. Innovative assembly process of a modular train; on the right the proposed configuration layout; on the left the lowering of the baggage rack in the workplace 7 dedicated to the assembly of the body side module.

improve the manufacturing process. The developed simulation environment has allowed to evaluate different workplaces layout configurations of the train assembly cycle. The best workplace layout configuration has been detected in order to minimize the lead time in the production line and to optimize the automation level and the human component for each workplace, figure 21. The study has allowed to underline the critical points on which the designers have to focus their attention in order to define an innovative solution able to assure clear advantages in terms of feasibility and saving time and costs.

In [Caputo 2006b] we have developed a methodology for studying, in a virtual environment, the ergonomics of a work cell in an automotive manufacturing system. The methodology is based on the use of digital human models and VR techniques in order to simulate, in a virtual environment, the human performances during the execution of assembly operations in a manual work cell. The aim was to define the optimum combination of those geometry features influencing human postures during each assembly tasks. We have analyzed a case study

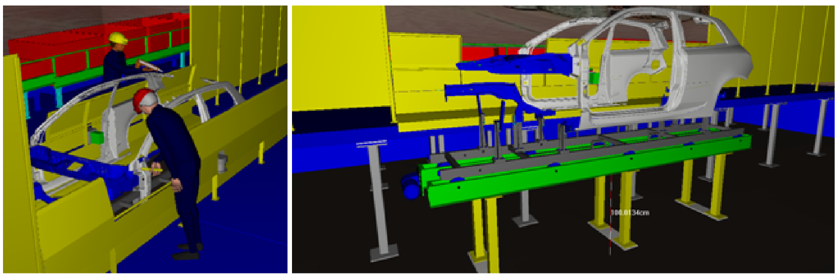


Figure 22. Ergonomic optimization of a body welding work cell.

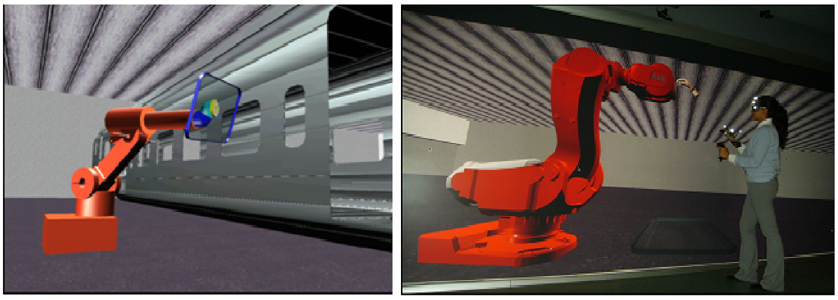


Figure 23. Human Robot Interaction within a manufacturing system in VR.

proposed by COMAU, a global supplier of industrial automation systems for the manufacturing sector, regarding the optimization of a body welding work cell, figure 22.

Finally, in [Di Gironimo 2007b] we have described a framework which helps designers verify the results of robotic work cell simulation in a Virtual Environment. In particular we have developed a prototypical VR system for the support of robots planning tasks, reuse of animation events, and the implementation of customization tools for animation elements and their behaviours. The system is also able to direct the focus of the observer to interesting events, objects and time-frames during robotic simulations in order to highlight the Human Robot Interaction within the manufacturing systems, figure 23.

8. Virtual Training

Another important VR application is the virtual training. The strong point of training based on the use of VR is the high degree of interactivity that it is possible to obtain in a virtual environment.

Figure 24. AVIRA, a Virtual Training system for aeronautic industry.

In fact, unlike the traditional methods based on classroom lessons that only allow a passive participation of the users to the training, VR allows the students both to visualize in a realistic way the contents of the lesson and to interact with the represented objects. According to that, thanks to the collaboration with Alenia, we have elaborated an innovative virtual training methodology, called AVIRA, specifically dedicated to the worker with composed materials, figure 24.

9. Conclusions

This chapter mainly has the aim to offer a vision of the potentialities, still not adequately expressed, that the simulation technologies based on the VR can produce in order to improve transportation design. The costs to be sustained for the employment of the VR in the design are notable as well as the plant costs and the management due to the continuous demand of updating of the structures and the operators. For this reason the applications concretely realized to date are related to industrial compartments such as the automotive and aeronautical industry that are able to sustain the costs. Finally, notice that the design methodologies based on the VR produce others two positive results. The first one is that they offer the unexpected liberty to the designer to invent new solutions different among them and from the traditional, because the tool that they have available allows them the contextual experimentation. The second advantage is that the design with the aid of the VR necessarily require the meticulous and punctual analysis either of the functional requisite, or of the project parameters, or of the constrains. These considerations, that spring not only from the necessity to model and to simulate the objects, but also from the simulation and the experimentation of their functionalities and their employment, determine a knowledge more deepened and detailed of the project. A such advantage, would already represent an appreciable result. To date, the modeling and the simulation activities based on information technology represent an important tool to achieve optimum outcomes in the industrial design. These tools realize in the VR their most efficacious and powerful synthesis, because VR, better than any other instrument, realizes the right essence of the designing which consists, essentially, in conceiving and realizing innovative ideas in order to satisfy real requirements of the society where we live.

10. Acknowledgements

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