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VIRTUAL REALITY IN TRANSPORTATION DESIGN

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IN
TRANSPORTATION DESIGN

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On ne voit bien qu'avec le coeur.
L'essentiel est invisible pour les yeux.

A. de Saint-Exupéry

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INTRODUCTION

Virtual Reality 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. The study of such advanced design systems have brought to the realization of an immersive environment in which new procedures for the evaluation of product prototypes, ergonomics, maintenance operations have been simulated. The positive and enthusiastic reply received from the industrial world has confirmed how these methodologies can be greatly useful in the phase of design, influencing the developing times and the quality of the industrial products.
The application of the realized environment to usability, ergonomics, concept design, maintainability verifications, design review, allowed to highlight the advantages offered by a design methodology: acting on the industrial product in 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. Moreover, during the application to the industrial case study, the designers of a new railway vehicle could take advantage of the developed methodology in the design phase, in particular in the planning of the new service systems, having the possibility to visualize and to interact with the model in real dimensions of the whole carriage.

Chapter 1 briefly introduces Virtual Reality and the common devices used in immersive experience. In Chapter 2 the development and the arrangement of a virtual environment for the functional, ergonomic and usability validation of equipment controls are described. Chapter 3 deals with the make up of a virtual showroom and work-through of a train model, showing VR application in phase of concept design and presentation of a new digital prototype, in more exhaustive way than simply technical documentation. Chapter 4 describes a complete Virtual Reality environment realized to simulate maintainability tests and manufacturing systems. An original VR architecture has been conceived in order to create a unique environment whose features are able to satisfy requirements both for Virtual Maintenance and Virtual Manufacturing tasks. In the Chapter 5 a methodology developed to execute maintainability tests of complex assemblies in Virtual Reality is described. Chapter 6 deals with the implementation in the realized environment of special features ad hoc for Design Review session, in particular applied to the planning analysis of a new train service systems.

The most important advantages deriving from the application of Virtual Reality techniques in product design is always synthesized by means the formula “developing time and costs saving”. This statement highlights the effective profitable consequences for a company of the introduction and the systematic application of VR in the development cycle of a new product. The possibility to design an alternative product solution just involving the creativity of a designer and spending costs of his working time and employed technologies, not saying even about design in “free time”, represents a revolution in terms of development, variety, quality of the product. However, another revolution it’s important to highlight nowadays is the *ecological mission* of the Virtual Reality. Such progress started with the explosion of informatics technologies, but its evolution in industrial application finds its important representation in this new design methodologies. Since the actual environmental situation stays at a dramatic point, not always well-known but sure easy visible every day in the modifications brought to the surrounding habitats, all new preserving technologies are welcome. Analyzing the complete process of development and production of a product, in every phase of this course several methodologies, allowing to reduce employed materials, environment impact, social consequences, are available. In the design phase, the role important is assumed by Virtual Reality. An illuminating mental experience is to imagine the realization of all the physical mock-up of all the alternative ideas which the designer wants to see and show, in order to solve his doubts and reach the best quality concept. The possibility offered by the VR to interact with such ideas in real time, in a more and more realistic way, seeming to have the real product of such ideas without touching any materials, any energy resources, represents a real revolution which necessarily has to be appreciated.

CHAPTER 1

VIRTUAL REALITY

1.1 HISTORY

Virtual Reality can be defined "the use of computer modeling and simulation that enables a person to interact with an artificial three-dimensional (3-D) visual or other sensory environment" [1]. The term Virtual Reality (VR) was coined by Jaron Larnier in 1987, but the history of VR dates back to 1960's when Dr. Ivan Sutherland invented the first Head Mounted Display (HMD) system for real-time graphics. Another more complete definition of Virtual Reality was given by Burdea et al. [2], "Virtual Reality is 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".
A first US patent relating to VR was the Sensorama Simulator in 1962, invented by Morton Heilig. This was a VR workstation with stereoscopic images, motion chair, stereo audio, temperature changes, odours, and blown air for wind effect, designed to "stimulate the senses of an individual to simulate an actual experience realistically."

Figure 1.1: Sensorama Simulator by Morton Heilig, 1962

Ivan Sutherland continued the work of Heilig developing his Head Mounted Display, to “augment” the vision of the user with the image generated by a camera controlled by the user movements [3]. This primitive device adapted the available systems, so it was heavier and much larger than current systems, provided with incorporated screen. The image generator developed by Sutherland was able to render scenes of only 200-400 polygons [2]. Huge progresses were made in polygons rendering, which are the main components of real-time VR or computer graphics determining the quality of the visualization.

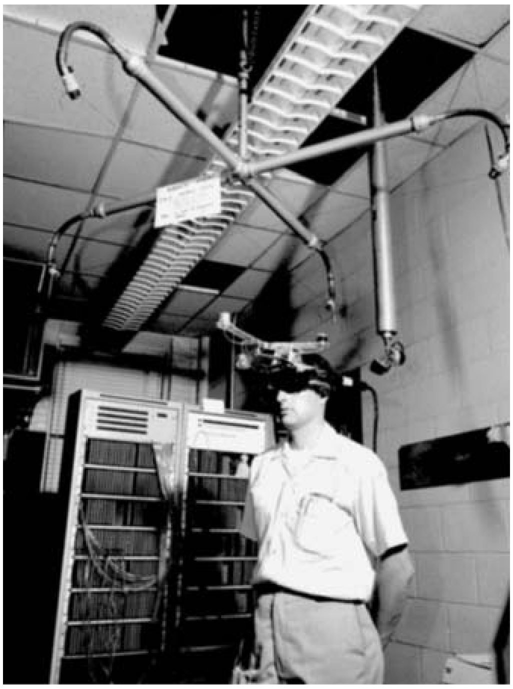

Figure 1.2: Early head-mounted display device developed by Ivan Sutherland at Harvard University, 1967

1.2 IMMERSION

The presence felt by the user allows him to behave naturally inside an artificial environment. There are different sub-classifications on levels of immersion. Single user and a computer monitor with stereoscopic vision are the simplest level of immersion. A large screen with wide field of view to visualize models in real scale with 3D stereoscopic view is referred to semi-immersive VR. The single user full-immersive level is equipped of a HMD with stereoscopic 3D vision and sound capabilities. A multi-user full-immersive set-up shall consist of an advanced visualization mechanism, Cave automated virtual environment (CAVE) developed by University of Illinois in 1992.

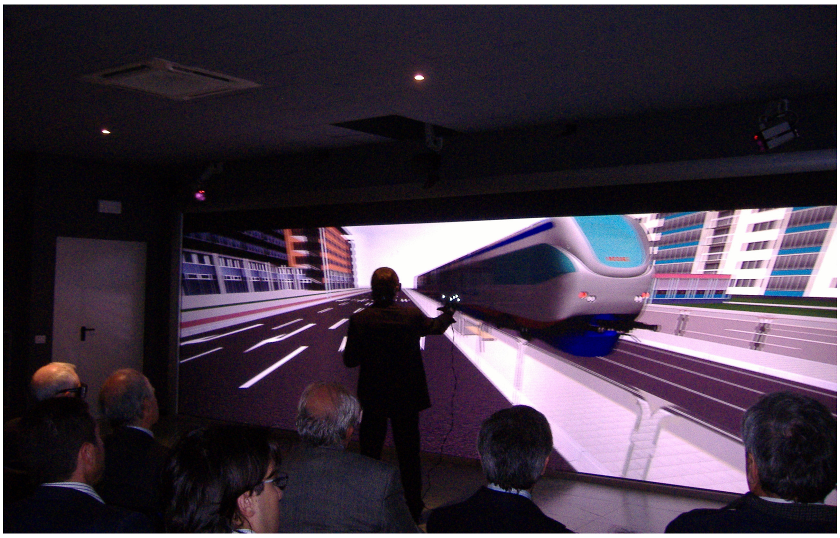

Figure 1.3: Semi-Immersive Multiuser Powerwall

Figure 1.4: Full-Immersive Single-User HMD

The choice of hardware for immersive visualization depends on the applications performed with VR. Individual systems have their own advantages and disadvantages respect to others; the cost factor also plays an important role in acquisition process. The least expensive system is a Cathode Ray Tube (CRT) monitor with stereoscopic capability and the most expensive a six walls CAVE system.

1.3 RENDERING

The graphical processing unit (GPU) has evolved from rendering few hundreds of polygons to today's NVIDIA Quadro FX engine being able to render more than 100 million polygons per second. Computers recognize models in the form of polygonal data. The demand for visualizing large datasets have ever been increasing, real-time rendering engines determine perception of the environment

by the user. The human eye-brain coordination requires at least 15 HZ (frames/sec) rate of rendering capability to make it realistic.
The graphics technology besides rendering also involves several factors which administer the immersive visualization. Frame lock and Genlock are the factors for multi-pipe and multi-channel advanced visualization techniques. Frame lock allows the display channels from multiple workstations to be synchronized, thus creating one large "virtual display" that can be driven by a multisystem cluster for performance scalability. Genlock allows the graphics output to be synchronized to an external source.

1.4 INTERACTION: TRACKING SYSTEMS

In-order to interact with a virtual environment special tracking input and output devices have to be used. There are several hardware available now than it was two decades ago. A tracker is a device used to transmit a change in 3D models position and orientation to virtual environment. Virtual reality applications typically measure the motion of the user's head, hands, or other body parts for the purpose of view control, movement and object manipulation [4].
There are various types of tracking systems available for full body motions and mostly used mechanisms are classified into:
1. Electromagnetic.
2. Ultrasonic and Inertial.
3. Optical.
4. Mechanical.

1.4.1 Electromagnetic

Electromagnetic tracker is used to determine the position and orientation of the user's head and hand. This system uses an emitter which emits electromagnetic field and detects sensor position within volume of the field. The coordinate value obtained from the sensor is transmitted to the VR system in form of signal and change is reflected in the 3D virtual scene. The performance is altered when used with large metallic objects. There are different vendors for the same technology with an option of wired and wireless tracking setup.

1.4.2 Ultrasonic and Inertial

Ultrasonic tracking system is a wireless non-contact position measurement device. This tracks the position using ultrasonic sound. This system has a transmitter, a receiver and an electronic circuitry. This system is a 6-DOF inertial motion tracking system based on hybrid technology. Inertial components aid to track both position and orientation, while ultrasonic range measurements are used only for drift correction purpose.
Calculations are performed by an internal processor for 6-DOF tracking data and it is delivered to host computer via serial or Ethernet connection. The advantages of this system is that it is simple, effective, accurate and low cost, but it is

restricted to working within a small volume, it is sensitive to temperature and depends upon line of sight.

1.4.3 Optical

This system was originally intended to capture the movement of body to create an animated sequence of movement. Optical systems use infrared video cameras to record the movement of a person. Reflective markers are placed on the body of the person who is being tracked and the systems process the data to produce a full body simulation. Since the system depends on the line of sight, the orientation of the cameras must be such to ensure that the markers are always visible. The positions of the markers within the camera images are identified by the software, and triangulated to compute their 3D position in space. If the 3D points are stored as a file they can be used at some later date to animate the joints of a computer-animated character to great effect. The applications determine the number of markers needed and what the rate required for the simulation.
Typically motion capture system needs a range of 60 to 240 frames per second (fps). The advantage of this system is that it is wireless and very precise (0.1mm tolerance) compared to others, but the disadvantage is that there is an internal latency for real-time applications and object occlusion for engineering purposes. At the beginning it was an effective tool for animators and a moderate interactive device for real-time engineering purposes with not good interface to commercial software's. Today optical tracking system is very effective for real-time tracking purposes due to a middleware (trackd), which allows this tracking data to be communicated with different software's for virtual prototyping. This system is also used in cave for real-time tracking.

1.4.4 Mechanical

These devices measure position and orientation by using a direct mechanical connection between a reference point and the target. Typically, a light-weight arm connects a control box to a headband, and encoders placed at the joints of the arm measure the change in position and orientation respect to the reference point. The lag for mechanical trackers is very short (less than 5msec), their update rate is fairly high (300 updates per second), and they are accurate. Their main disadvantage is that the user's movement is constrained by the mechanical arm [5]. An example of such a mechanical tracking device is the Boom developed by Fake Space Labs. Inertial tracking devices represent a different mechanical approach, based on the principle of conservation of angular momentum. These trackers use a couple of miniature gyroscopes to measure orientation changes. If full 6-DOF tracking ability is required, they must be supplemented by some position tracking device. A gyroscope consists of a rapidly spinning wheel suspended in housing. The mechanical laws cause the wheel to resist any change in orientation. This resistance can be measured, and converted into the yaw, pitch, and roll values. Inertial tracking devices are fast and accurate, and since they don't have a separate source, their range is only limited by the length of the cable to the control box or computer. Their main disadvantage is the drift between actual and reported values that is accumulated over time, and can be as high as 10 degrees per minute.

1.5 INTERACTION: NAVIGATION AND MANIPULATION

Besides motion tracking for whole body, hand-finger gestures are tracked with sensing gloves, such as 5DT Data Glove, Pinch Glove, Cyberglove, wich allow the user to interact with virtual objects present in the scene.
Moreover, there are several other interactive devices used in VR simulation for navigation such as 3D mouse, Joystick or Spaceball, Spacestick and Cubic Mouse. There is no standard approach towards VR techniques and devices. Directional sound, tactile and force feedback devices, voice recognition and other technologies are being employed to enrich the immersive experience The technology for haptics or sensorial reactions considering human factors is not yet mature for regular usage and also very expensive to afford for normal functioning.

1.6 REFERENCES

[1] Encyclopædia Britannica. 2006. Encyclopædia Britannica Online. Nov. 2006 <http://www.britannica.com/eb/article-9001382>.

[2] Burdea, G., ‘Virtual Reality Systems and Applications’ [Short Course], in Elctro’93 International Conference, Edison, NJ, 1993.

[3] "Head-mounted display." Online Photograph. Encyclopædia Britannica Online. Nov. 2006 <http://www.britannica.com/eb/art-87811>.

[4] Foxlin, E., 2002, “Motion Tracking Requirements and Technologies,” in K. Stanney (Ed.), Handbook of Virtual Environments, Erlbaum, Mahawah, NJ, pp. 163-210.

[5] Shneiderman, Ben, et al., “The Encyclopedia of Virtual Environments”, Virtual Reality and Telepresence Course, MD, 1993.

CHAPTER 2

ERGONOMICS AND USABILITY OF EQUIPMENTS CONTROLS

2.1 INTRODUCTION

In the following chapter the development and the arrangement of a virtual environment for the functional, ergonomic and usability validation of equipment controls are proposed.
In particular, the design and the realization of a mechanical simulator with four degrees of freedom (4DOF) are described, for the positioning, in the physical test environment, of a haptic device dedicated to the simulation of the physical behaviour of a knob. The 4DOF, appropriately integrated in a VR system made of a tracking system, a Head Mounted Display and a glove, allows to control with precision the position of the knob in the real space obtaining the perfect overlapping between physical and virtual models. In the work it is introduced a case study dealing with the investigation of usability of the controls present on the dashboard of a car. The tests have been carried out at the Virtual Reality laboratory (named "Vroom") of the Dipartimento di Progettazione e Gestione Industriale of the University of Naples Federico II.
The virtual environment has been realized according to the PRIN (Project of National Interest), involving, as Research Unit, the mentioned department The activities provided the set up and was developed at the *VRoom* Laboratory of the Department: first objective has been the study of the hardware and software systems suited for the virtual interaction of a digital object. The second objective has been to design and develop, in homemade and chip way, a physical test environment, which allowed any user/designer to execute the described usability tests.
Virtual Reality represents today an almost indispensable tool for the industrial design in order to reach an adequate quality level in reduced time. The development of an idea of industrial product passes through typical phases, such as the modelling of its geometrical shape as well as the production of test prototypes. Regarding to such products destined to interact with real users, by now usability and ergonomics verification became indispensable in order to assure to the final user a sufficient level of comfort.
Usability tests are traditionally executed on simplified physical prototypes simulating the functional characteristics of the final product. Thanks to Virtual Reality it is possible to overlap the geometrical design model to such physical test model, immersing user in a virtual environment in which feeling to interact with the final product.
Even if during the last few years the techniques of environment and products modelling had a continuous evolution, as well as the modalities to interact with their virtual representation, the physical prototype is still used to validate and verify design choices and functionalities, as, sometimes, the digital environment

does not guarantee the management of all phases of design and validation typical of the product development cycle.
However, use of the prototype demands human resources, financial and time investments, which often are deleterious for the competitiveness of the companies on the market: it’s necessary therefore to move the attention on alternative techniques and methods.
The technological evolution has lead to the employment of the virtual prototype (Digital Mock-up) as main instrument for the industrial design and not only. Using the approach based on the Digital Mockup, designers have the possibility to reproduce visual, audio and tactile sensations of the simulated environment, navigating inside the virtual model of the product, to analyze and to simulate its geometric-functional characteristics, and at last to reach a virtual validation of the design.
A virtual reality application generates a digital environment where user has the possibility to move in real time in a three-dimensional space, interacting directly with it. To move in real time means that user decides through the own actions, where to watch, where to go, how to behave. The graphics and calculus system elaborates instant by instant data relative to the transformation of geometry and space coordinates of the applied texture, according to the perspective changes and the movements lead by the customer.
The singularity of a VR environment stays in the possibility for the man of being able to interact with it in a natural way, as well as it were a real environment. A environment developed to allow realizing, by means of typical VR techniques and devices, subjective analyses of usability on the digital model of an industrial product should not transmit annoying factors, not due to the same product, that could negatively influence the judgment of the user/designer.
The necessity, for example, to wear quite invasive Haptic devices (which concur, practically, to percept tactile answers), generate a noise that avoid the customer to provide a valid judgment on the ergonomics or the usability of the analyzed product.
Therefore, in order to reach the described objects, an innovative not invasive Haptic system has been ideated and constructed, allowing the user/designer to estimate usability of equipment controls without disturbance factors. Tests have been executed which have concurred to optimize the calibration of the virtual environment with the physical mock-up, reaching, then, a definitive set up of the environment, judged suitable for the evaluation of equipment controls usability.
In order to test the realized environment an automotive case study has been considered. In particular, usability of a knob control of the air conditioning has been evaluated on a mini-car dashboard. Therefore, after modelling the dashboard in CAD 3D environment and realizing the virtual prototype by means of the application of opportune materials and texture, several tests have been executed in order to evaluate the usability level of the control.

2.2 ERGONOMICS AND USABILITY IN AUTOMOTIVE FIELD

The process of development of a new industrial product has endured a mutation during the past century that has marked the beginning of an evolutionary phase still in full development. In the course of the years the customer has become the hinge around which the whole phase of product design rotates. Today, in fact, the study of a new product cannot leave out of consideration the satisfaction of the customer expectations as well as from the context to which such product is destined. All that has carried during the last few years to an always greater interest towards the application of principles of ergonomics and usability to the development of complex systems. In particular, in those fields, such as the automotive, which for technical and economic abilities succeed in meeting investments aimed to increase the satisfaction of the customer, the ergonomics is already recognized as an important phase in the planning process and development of a new product [1, 2, 3]. For example, in the process of design and development of a new vehicle one of first phases is to assure to the driver and the passengers comfort of the sitting and reachability, visibility and immediate understanding of use of the controls and the display present on the dashboard. Therefore, while some years ago the vehicles were only demanded to move from a point to an other in safety, today they are demanded to provide the same performances but in conditions of comfort [4, 5, 6]. The ergonomic design is based on a deep knowledge of the psycho-physiologic abilities and limitations of the man, in relation to the characteristics of work machines and environment. One of the main objectives of the ergonomic design is to assure the better level of usability to the final product. Norm ISO 9241 provides a definition of usability: "the effectiveness, the efficiency and the satisfaction with which specific customers reach specific objectives in determinate environment". The same norm asserts also that usability level is not an intrinsic characteristic of the product, as it is determined by the customer, the environment and the modalities of use of the product [7, 8, 9]. According with such principles, in the automotive industry main ergonomic requirement is to assure the comfort to the driver and the passengers, taking into consideration and optimizing factors such as habitability, reachability, visibility and postural angles [3, 10, 11]. The effectiveness of the employed methodology of ergonomic design determines the level of comfort, usability and, therefore, also of safety of the vehicle. The factors that mainly influence the ergonomics and the level of usability inside the vehicle are: disposition and shape of the controls that should be reachable and usable through simple and natural movements; the total aesthetic of the dashboard; the visibility of the driver, which depends mainly on the disposition and the shape of seats, glass surfaces, upright and the rear-view mirror; safety requirements that demand a configuration of the inside of the vehicle that minimizes the damages to the occupants in case of incident; the shape and the constitution of the seat that should minimize the fatigue of the driver; the type of stresses transmitted from the vehicle to the occupants. Some of such factors can be sure optimized in objective way by means of opportune software and instruments of analysis [12, 13, 14]. However, the optimization of other factors, such as, for example, usability of the controls or the aesthetic of the dashboard [15], cannot leave out of consideration the subjective evaluation of the customers, that must be put, therefore, in a position to interact directly with the product. As previously said, Virtual Reality can today represent an optimal, if not the only, instrument for realizing such subjective tests, during the phase of design when the only CAD model of the product available, and, then, before to construct some physical prototype. Many authors are experiencing different approaches in order to estimate the usability of industrial products in Virtual Reality [16, 17, 18]; the main limits are due to the technology that still not allow to obtain precise answers from the 3D input systems and above all from the systems of force feedback.

2.3 HARDWARE E SOFTWARE SYSTEMS

2.3.1 Hardware

In order to carry on the research activity the laboratory of Virtual Reality (named "VRoom") of the Dipartimento di Progettazione e Gestione Industriale (DPGI) of the University of Naples Federico II has been set up. The hardware system employed to analyze the case study object of the present activity is constituted by the following fundamental units:

- a Workstation provided with advanced graphics and calculus potentialities able to execute computational simulations in rapid time and to allow the visualization of complex assemblies with extreme precision and fluidity of movements;
- a double visualization system: a Head Mounted Display helmet for the stereoscopic vision which must be worn by the main user who lives the experience of immersive Virtual Reality, and a system of frontal video projection with two projectors for the passive stereo and a screen of medium dimensions (2,40m x 1,80m) in order to allow other persons interested to the design, to share the immersive experience with the main user;
- an ultrasonic tracking system having the function to find the position, the orientation and the movement of objects in the space and to generate a signal to send such information to the mainframe computer. In particular, for the operations described in the present work, the employment of a system, immune from interferences caused by metallic objects and/or magnetic fields and able to cover a 2,50 x 2,50 x 3 meters volume, has been preferred;
- a glove for the manipulation of virtual objects;
- a physic Seating Buck, constituted by a seat of a mini-car having two degrees of freedom (translation along the slide guides and rotation of the back) positioned, through the guides, on an opportune wood support handicraft constructed. In table 1.1 the characteristics visualization of the employed Hardware equipments are described in detail.

Table 2.1: *Hardware* devices used in the VRoom laboratory

Hardware	**DPGI**
Graphic Workstation	**IBM Zpro** Double Processor Intel Xeon 3.06 GHz, graphic card Nvidia Quadro FX3000, 256 MB video memory, Windows XP operating system.
Visualization system	**Head Mounted Display** *Daeyang I-Visor* with 800x600 resolution
	Frontal Video-projection System with two LCD projectors for the passive stereo, 3200 Ansi Lumen and 1024x768 resolution
Tracking system	**Ultrasonic *tracking* System** *InterSense IS-900PC-Tracker*
Gloves	***Cyberglove*** with 22 sensors by *Immersion Corporation*. ***5DT Data Glove*** with 16 sensors.

2.3.2 Software

In the first phase of the benchmarking it has been decided to investigate such software like CATIA V5 by Dassault Systems and Alias Studio 12 which include an integrated environment of CAD modelling and Virtual Reality. On the other hand, in the VRoom laboratory, previous activities of research had already been carried out which had seen the employment of Catia V5 [19, 20] and of Alias Studio 12 [15], both for the realization of digital models and for the successive analysis in immersive environment. In the second phase those software of Virtual Reality have been analyzed on which the authors they had already matured previous experiences, such as Jack [2, 3, 12, 15, 21, 22, 23, 24, 25] and Vis Mock Up [26] both by UGS. At last, other software have been analyzed for which a temporary licence was available, that is Amira VR by TGS, EON Professional with EON CAD and EON Icatcher modules and Virtual Design 2 (VD2) by vrcom. First of all, by the analysis carried out on the main systems of Virtual Reality present in commerce, it is not possible to identify which can satisfy any type of design requirement with any available hardware systems. The choice of the more suitable software for to the realization of the fixed objective has held in consideration the following parameters:

- Importing of the data from the generic environment of CAD modelling to the immersive environment of Virtual Reality;
- stereoscopic visualization (in active or passive modality);
- interface with tracking systems (in particular the Intersense IS900 system present in the VRoom);
- interface with 3D manipulation systems such as the gloves (in particular the Cyberglove and the 5DT present in the VRoom).

The results of the analysis are reported in the following table.

Table 2.2: Software analysis for Virtual Reality

	IMPORTATION CAD DATA	**STEREOSCOPIC VISION**	***INTERSENSE IS 900* TRACKING**	***Cyberglove* e *5DT* GLOVES**
CATIA V5	Direct from Catia Insufficient from other environments	**Supported**	**Supported** Other tracking systems are supported too, such as, for example, the ART and Ascension.	**Cyberglove supported** adding "*Virtual Hand for Catia V5*" plug-in, with considerable cost (about 10000 Euro). **5DT not supported**.
ALIAS 12	Direct from Catia Insufficient from other environments	**Supported**	**No** tracking systems **supported**	**Not supported**
JACK	Direct from UGS products by means of the .jt format. Possibility to use the main neutral formats	**Supported**	**Non supportato** VICON and Flock of Bird systems supported	**Cyberglove supported** **5DT not supported**
VIS MOCK UP	Direct from UGS products by means of the .jt format. Possibility to use the main neutral formats	**Supported**	**No** tracking systems **supported.** Navigation can be performed with a Spaceball	**Not supported**
AMIRA	Possibility to use the main neutral formats (suggested WRML)	**Supported**	**Supported** by means of the TrackD software	**Cyberglove e 5DT not supported.** Only the *Pinchglove* supported
EON	Possibility to use the main neutral formats. EON CAD software contains a direct converter from the	**Supported**	**Supported**	**Cyberglove e 5DT not supported.** Only the *Pinchglove* supported

	most important CAD systems.			
VD2	Possibility to use the main neutral formats.	**Supported**	**Supported**	**Cyberglove supported** **5DT supported**

After the analysis VD2 has resulted the software better answering to the exposed requirements. However, the carried out experience has demonstrated how such software was not supported from the workstation present in the Vroom laboratory. Consequently, having been the dashboard already designed in CATIA V5environment, the same environment has been decided to be used also for the immersive visualization.

2.4 THE FOUR DEGREE OF FREEDOM SIMULATOR: *4DOFSYSTEM*

In the Virtual Prototyping and in the applications of Virtual Reality the need to integrate the prototype, element of the virtual world, with the product, element of the real world, can be perceived. In order to satisfy such requirement the design and the realization of a device have been lead, able to allow immersive simulations in virtual environment on the prototype, such as ergonomic evaluation and usability tests of the product, assuring the perfect overlapping between virtual environment and physic test environment.
In particular, a support with four degrees of freedom has been designed, three translations and one rotation around an axis. For the execution of the research activity, such system has been integrated with a one rotational degree of freedom device, in order to execute the ergonomic and usability validation of knob control systems. The system also is characterized with a volume that allows the integration with a sitting system, *seating buck*, for the execution of ergonomics tests inside an automobile. The 4DOFsystem has been designed and realized at the DPGI laboratories of the University of Naples Federico II. *4DOF* is the acronym of Four Degree Of Freedom, base of departure of the idea and the design. The development of the design, executed with the software CATIA V5, at first has taken in account the only technical and functional requirements and, in successive analyses, the overall dimensions for the particular applications, the cost of materials and their availability on the market. Movements and rotation had to be mechanically controlled and sufficiently precise. The structure had to be light but at the same time resistant, not expensive but functional, the mechanical control of the movements had to be prepared to be provided with an eventual future motorization. The first approach to the problem allowed to sketch the structure in a simple way without limiting the imagination. The result has been a functional and also aesthetically valid structure (figure 1).

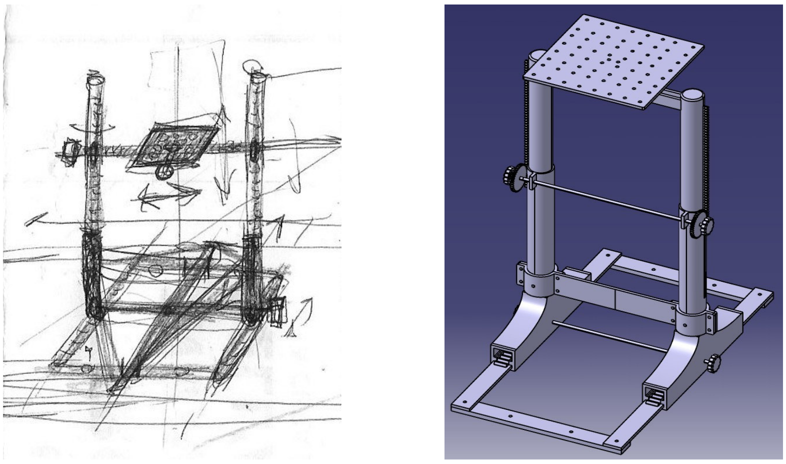

Figure 2.1 – Ideation and first design solution of the *4DOFsystem*

The functional validity has been verified with the DMU Kinematics module of Catia dedicated to the simulation of the mechanisms animating any parts of an assembly.
The first design solution would have involved the creation ex novo of some components of the support, while others, like cogwheels and racks, would have need excessive costs for their purchase or realization. The support had also to contemplate the eventual possibility of motorization of the movements, in a near future, which revealed quite complex due the structure represented in figure 1, considering the excessive weight and the constructive peculiarities of some parts. Also the overall dimensions were excessive and not adapted to the best positioning of the structure in presence of a seating buck, fundamental in some simulations. Therefore, the first design were modified. In order to reach a precise movement in the space, along the three directions, the system cogwheel-rack, present in the first design, has been replaced with a screw-female thread system, which assures more precise movements, is easy to find in commerce and sure is the simpler system to motorize. With these bases, the project has been carried out (figure 2), always trying to optimize the workings. In particular, all workings except cut or perforation were avoided, for which a simple hacksaw for aluminium and a column drill have been used. The final project has been the synthesis of a problem which involved different aspects: from the resistance to the lightness of the structure, from the cost of the materials to their availability, from the functionality to the simplicity of realization. All the degrees of freedom have been submitted to the functional verification, by means of the DMU Kinematics module of CATIA, which allowed to define, simulate and analyze the different cinematic mechanism of “the virtual” structure; such results have been therefore totally found with those obtained on the real support.

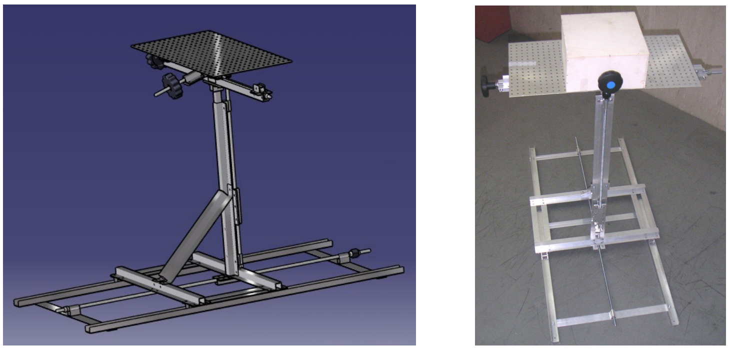

Figure 2.2 – Definitive design solution and realization of the 4D*OFsystem*

In order to carry out the evaluation tests of the usability in VR on a generic knob of a car dashboard, a method to obtain the perfect correspondence between real and virtual knob has been developed. In fact, the glove used for the virtual interaction is an optimal instrument for the manipulation but it does not give back any answer to the contact with the virtual bodies, since it is not equipped with a force-feedback device. The original idea contained in the present activity was to overlap perfectly the physical knob with the virtual one; in this way the user interacting in the immersive environment with the virtual knob, touches at the same time the real one which gives back the perception of its presence. In order to guarantee always the perfect overlapping of the physical knob with the control involved in the simulation, the solution of a problem of inverse cinematic has been necessary: once assigned the position of one point of the slab, in a reference coordinate system, calculate the movements of the degrees of freedoms that identity the configuration of the system for which the point assumes the required position. Mechanics of robots allows a simple resolution of the examined problem, schematizing the *4DOFsystem* as a Cartesian Robot with three translational axes, being the fourth degree of freedom a rotation fixed around one of the translational axes. The problem of inverse cinematic has been resolved considering an absolute tern positioned in a point of the 4DOFsystem, in particular with the origin coinciding with an extremity of the base. The problem can be resolved positioning the absolute tern in any other position of the space, for example, coinciding with a particular point of a seating buck. In this case four terns have been considered, one absolute and three relative to the translation along axes. Schematizing the 4DOFsystem the terns are positioned as in figure 3:

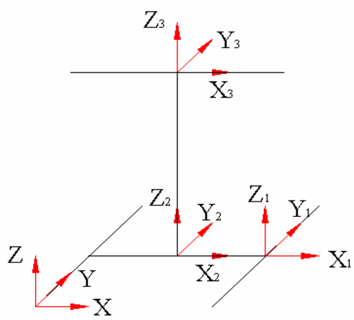

Figure 2.3 – The reference coordinate systems chosen for the solution of the cinematic problem

The problem is resolved calculating the **X** vector providing the movements of the *4DOFsystem* along the three axes, being the vector **M = [X, Y, Z]** the required position of the point of the slab.

$$\mathbf{M} = \mathbf{T}\,\mathbf{X}^{\mathbf{T}} \qquad (1)$$

The T matrix relative to the configuration of the examined system has the shape:

$$\mathbf{T} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix} \qquad (2)$$

Multiplying both members of the (1) to $\mathbf{T}^{-1}$:

$$\mathbf{X} = \mathbf{T}^{-1}\,\mathbf{M} \qquad (3)$$

Adapting the (3) for the examined tern:

$$\mathbf{X} = \mathbf{T}^{-1}\,(\,\mathbf{M} - \mathbf{X_0}\,) \qquad (4)$$

where the vector $\mathbf{X_0}$ provides the position of the origin of each tern respect to the absolute one. The cinematic problem of the slab position has been solved [9].

2.5 USABILITY TESTS

As previously asserted, the present study has been finalized to the evaluation of the usability of controls in virtual environment. Such activity has been carried out by means of a series of tests lead on a representative sample of the customer population. In order to simply demonstrate the validity of the method, a generic knob of an automotive dashboard has been modelled to carry out the experiments on a central control. The dashboard, the controls and the relative accessories have been ideated and, therefore, designed on the base of real overall dimensions and mechanisms. In particular, the virtual knob of the dashboard has been realized with the same dimensions of the real knob, which has been placed on the simulator of the four degrees of freedom, the 4DOFsystem. To the assembled product texture and CatMaterial, created ad hoc, have been applied, since the resulting realistic effect provides to the user an highly immersive perception (figure 4). The validity of the immersive test much depends on the correct collimation of the two environments, virtual and real. What mainly interests is the correspondence between real knob and virtual knob, center of the usability test.

(a) (b)

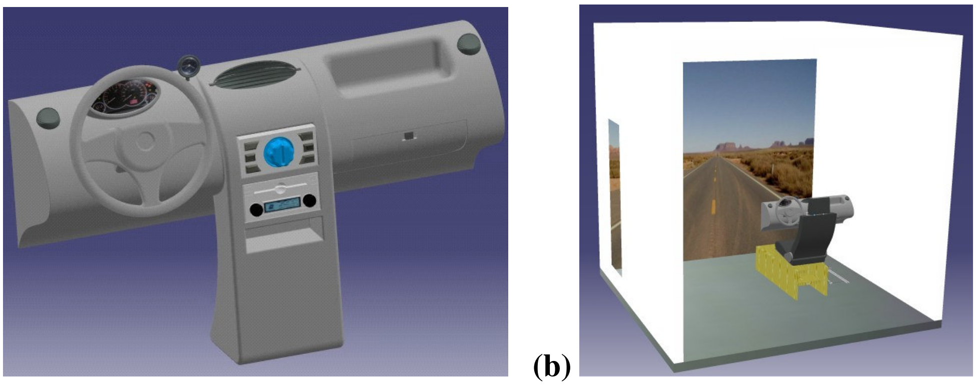

Figure 2.4 – (a) The dashboard modeled for the tests; (b) Virtual reproduction of the VRoom laboratory

In order to reach this objective, the room of the DPGI laboratory has been reproduced, based on the effective measures, in which the seating buck and the 4DOFsystem have been placed and to which the dashboard has been overlapped. Thanks to the constraints system present in Catia, it has been possible to configure the room with the correct positions of the sitting system and the simulator. Such constraints have allowed obtaining the coincidence between the two systems. The positioning has happened by steps: during the execution of the tests precise indications have been asked to the user. These information, with the opportune arrangements, such as the calibration of the CyberGlove sensors to each single user, allowed the better registration for two environments, in order to guarantee the adequate repeatability. The resolution of the problem of inverse cinematic previously described allows, moreover, the repositioning of the real and virtual simulators respect to a global reference system placed in any point of the laboratory, calculating and applying the opportune movements to the translational joints. The test of usability of the dashboard knob has been realized considering the procedures described in literature. Such test represents a first approach to the ergonomic evaluation in immersive virtual environment, supplying a base for successive analyses on the usability of equipment controls [27].

The test has been executed in two sections; in the first it has been asked the customers to estimate the perception of the virtual environment: level of immersive sensation, correspondence between real and virtual knob, coincidence between the rotations of real and virtual knob. Each user carried out the test of interaction with the product seating on the *seating buck*, which the 4DOFsystem had been placed on side. For the test the helmet and the glove have been worn, calibrated for every single user. To each person it has been asked, therefore, to execute some operations of manipulation with increasing level of difficulty: in order to acquire familiarity with the virtual environment the wheel and the drawer have been used; at last, the interaction with the knob has been required. Such test has been repeated many times until reaching an optimization of the virtual environment configuration.

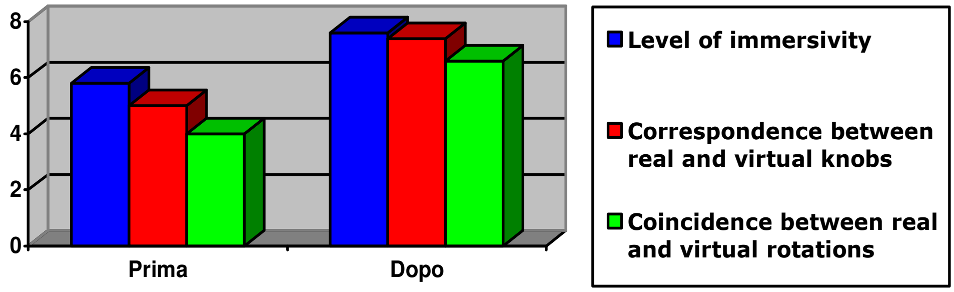

Figure 2.5 – Comparison between the judgements on the virtual environment, before and after the registration tests.

Objective of the first phase, in fact, has been to obtain a precise registration of the position of the dashboard so that, when the user grasp and rotate the real knob, at the same time the virtual hand reaches and rotate the correspondent virtual knob. The indications, obtained from the execution of the tests, have conducted to the first result, which has been to establish the better registration of the test environment. The histogram showed in figure 5 testifies such improvement.
In the second phase the analysis of the usability of the knob has been dealt with. User has been invited to concentrate on the visibility and the reachability of the knob, without looking away from the road: the presence of the road, visible thanks to a texture applied on a surface large as a screen placed in front of the dashboard, allowed increasing the level of realism of the simulation (figure 6). The histogram of figure 7 evidences the good result obtained for the perception of the knob, to confirm the validity of the simulation system used as instrument for the usability tests. Noteworthy is that some judgments felt the not perfect adaptability of the glove to the various dimensions of the user hand. In particular, this problem was found for hands of small dimensions, for which the fingers do not succeed to activate the sensors correspondent to the last phalanges.

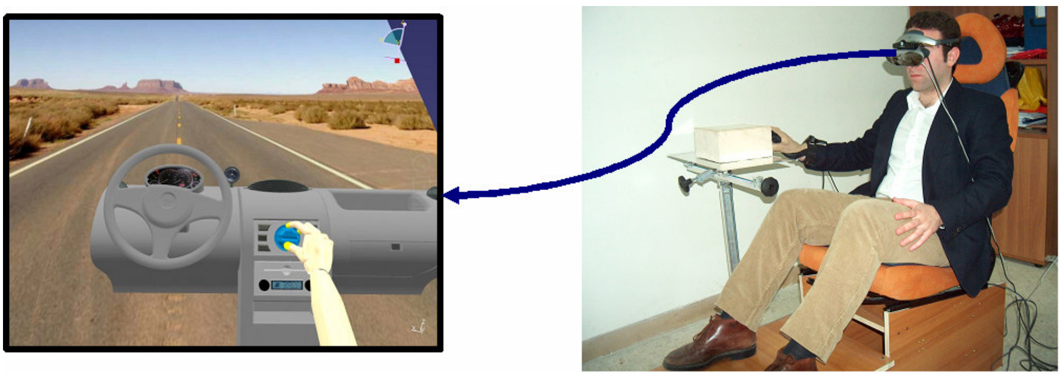

Figura 2.6 – Virtual Manipulation of the control during the test; on the right side user on the seating buck, on the left what user is watching

Figure 2.7 – Global judgement expressed in the tests

2.6 CONCLUSIONS

The importance progressively acquired by the Virtual Reality is such as to bring modifications to the classical mould of the design and a continuous improvement of the phase of virtual prototyping, instrument by now able to reduce the costs and shorten the product realization time. The executed tests have demonstrated how the realized immersive virtual environment results appropriate for evaluations of control usability. In particular, thanks to the constructed simulator, it is possible to perceive the tactile sensation of the virtual knob, judging the interaction with this control.

It turns out obvious, in conclusion, how the development of a interactive virtual environment represents, with an aimed activity of development, an useful instrument for the validation and the ergonomic analysis of controls.

2.7 ACKNOWLEDGEMENTS

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2.8 REFERENCES

[1] BRIDGER R.S., “*Introduction to Ergonomics*”, Eric M. Munson e James W. Bradley, 1995.

[2] DI GIRONIMO G., *“Studio e sviluppo di metodologie di progettazione ergonomica in ambiente virtuale”*, Tesi di dottorato, Università degli studi di Napoli Federico II, 2003.

[3] CAPUTO F., DI GIRONIMO G., MONACELLI G., SESSA F., “*The Design of a Virtual Environment for Ergonomics Studies*”, Proc. of XII ADM International Conference, Rimini, 5-7 September 2001.

[4] BADINI BUTI L., "*Ergonomics between Research and Application*", SAE 95A1025.

[5] BANDINI BUTI L. "*L'industrial design ergonomico*" in Ergonomia n. 5, Moretti & Vitali Editori, Bergamo, 1995

[6] RIZZO R. "*La sicurezza degli impianti industriali*", Edizioni Scientifiche Italiane, 1998

[7] MICHELLONE G., LEVIZZARI G., "*L'evoluzione veicolo guidatore*", in IF, Gennaio 1999

[8] ROHMERT W. "*Physiological and psychological work load measurement and analysis*", in "Handbook of Human Factors", Wiley & Sons,1987

[9] BANDINI BUTI L. "*Ergonomia e progetto*", Maggioli Editore, 1998

[10] KROMER K. H. E., "*Modelling the human-equipment interface*", in Automotive ergonomics edited by B. Peacock and W. Karwowski, Taylor & Francis, 1993.

[11] NAGEL K., "*Comfort evaluation as ergonomic tool with application to interior concepts of vehicles*", SAE 1999-01-1921.

[12] DI GIRONIMO G., MONACELLI G., MARTORELLI M., VAUDO G., "*Use of Virtual Mock-Ups for Ergonomic Design*", Proc. of 7th International Conference ATA, Florence, May 23th - 25th, 2001.

[13] PORTER J. M., CASE K., FREER M. T. AND BONNEY M. C., "*Computer-aided ergonomics design of automobiles*" in Automotive ergonomics edited by B. Peacock and W. Karwowski, Taylor & Francis, 1993.

[14] PORTER J.M. AND GYI D.E., "*Exploring the optimum posture for driver comfort*", Int. J. Of Vehicle Design. Vol. 19, No. 3, pp. 255-266.

[15] DI GIRONIMO G., LANZOTTI A., VANACORE A., "Concept Design for Quality in Virtual Environment", Accepted in Proc. of QMOD 2005 "Quality Management for Organisational and Regional Development", 29 June – 1 July 2005, Palermo, Italy.

[16] BRUNO F., DE NAPOLI L., MATTANÒ R. M., MUZZUPAPPA M., "Valutazione dell'usabilita' di Prodotti Industriali in Ambiente Virtuale", Atti del XVI Congreso International de Ingenieria Grafica, Saragozza, June 2-4, 2004.

[17] BRUNO F., DE NAPOLI L., MATTANÒ R. M., MUZZUPAPPA M., "Usabilità di prodotti industriali: un approccio basato su tecniche di Realtà Vistuale", Atti del Convegno Nazionale XIV ADM - XXXIII AIAS "Innovazione nella Progettazione Industriale" Bari, 31 Agosto - 2 Settembre 2004.

[18] COLOMBO G., DE ANGELIS F., PASINI N., "Sperimentazione su dispositivi per la prototipazione e la realta` virtuali", Atti del Convegno Nazionale XIV ADM - XXXIII AIAS *"Innovazione nella* Progettazione *Industriale"* Bari, 31 Agosto - 2 Settembre 2004.

[19] DI GIRONIMO G., LEONCINI P., PATALANO S., "Realizzazione di un "Walk Through" all'interno della cabina passeggeri del Piaggio P180 Avanti:

confronto tra due ambienti di visualizzazione e sviluppo", Atti del Convegno Nazionale XIV ADM e XXXIII AIAS "Innovazione nella Progettazione Industriale", Bari, 31 Agosto - 2 Settembre 2004.

[20] LEONCINI P., DI GIRONIMO G., ALLOCATO A., "Interazione realistica per verifiche di manutenibilità in realtà virtuale", Atti del 4° Convegno Tecnico Scientifico di MIMOS (Movimento italiano di Modellazione e Simulazione), Torino 25 - 27 Ottobre 2004.

[21] CAPUTO F., DI GIRONIMO G., PATALANO S., BIONDI A., MAIONE R., LIOTTI F., "Use of ergonomic software in virtual environment for the prevention of muscular-skeletal diseases", Proc. of ISCS 2001, Napoli, 6-7 december 2001.

[22] DI GIRONIMO G., PATALANO S., LIOTTI F., "A new approach to the evaluation of the risk due to manual material handling through digital human modelling", Proc. of ISCS 2003 - Italian Society for Computer Simulation, Cefalù, 28-29 Novembre 2003.

[23] DI GIRONIMO G., MONACELLI G., PATALANO S., "A Design Methodology for Maintainability of Automotive Components in Virtual Environment", Proc. of International Design Conference - Design 2004, Dubrovnik, May 18 - 21, 2004.

[24] CARRINO A., DI GIRONIMO G., PATALANO S., SPERANZA D., "Una piattaforma ergonomica per lo studio delle vibrazioni", Il Progettista Industriale, I parte giugno 2004, pp. 102-105, II parte luglio 2004, pp. 66-69.

[25] CAPUTO F., DI GIRONIMO G., FIORE G., PATALANO S., "Verifiche di manutenzione e di ergonomia nella progettazione di una locomotiva di manovra mediante l'impiego di modelli virtuali", Atti del Convegno Nazionale XIV ADM e XXXIII AIAS "Innovazione nella Progettazione Industriale", Bari, 31 Agosto - 2 Settembre 2004.

[26] AVALLONE L., DI GIRONIMO G., MONACELLI G., PATALANO S., "Use of Digital Mock Up for Automotive Assembly Design", Proc. of ISCS 2001, Napoli, 6-7 december 2001.

[27] RUBIN J., "Handbook of usability testing: how to plan, design and conduct effective test", John Wiley&Sons, NY, 1994.

CHAPTER 3

CONCEPT DESIGN

3.1 INTRODUCTION

The possibility of applying Virtual Reality (VR) methodologies to make a scene more realistic as possible is a great advantage for the effectiveness of the presentation of a new concept, in order to increase its competitivity. This chapter shows the make up of a virtual showroom and work-through of a train model in order to allow railway companies showing new trains prototypes, in phase of concept, and present their new design in more exhaustive way than simply technical documentation. Shader technology 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 the paper the authors describe the use of shader technology in Virtual Design 2 (VD2) for realistic presentation of train prototypes in VR. The software VD2 is an extensive tool that allows following many phases of product development, from the creation of showroom for realistic presentations supporting shader technology to the assembly simulation or ergonomics analysis. Moreover, the possibility of interfacing with a wide range of input/output devices and the possibility to access to the API made this software to be chosen for Virtual Reality applications in the VR laboratory of the Competence Center for the Qualification of Transportation Systems founded by Campania Region (www.centrodicompetenzatrasporti.unina.it). One of the objectives of the continuous development of Virtual Reality techniques is to improve the photorealism of the scene, in order to give an even more realistic sensation to the operator immersed in the artificial environment.
Researchers worked to assign all the attributes to the objects represented in the scene necessary to appear as in real world [NT05].
A promising way to reach this result is the use of the new *shader technology*, a technique for programming the appearance of the objects in a virtual scene, including lighting and reflections of surfaces.
The great advantage of this technology in terms of improvement of the realism is already known in the automotive field (Figure 1), in which the employment of Virtual Reality techniques for the phase of Concept Design is widespread by now: such advanced design systems allow a remarkable saving of costs and time for the evaluation of several design solutions, which, until few years ago were possible only through the production of many physical prototypes.

Figure 3.1: Shader technology applied to realistic representation in automotive field [VWS]

Not so diffuse is the application of these techniques in the railway industry, which is still characterized by traditional design methodologies.
In the last years railway transport industry has undergone a strong development, pushed by the process of liberalization and globalization of the market. The partecipation of international competitors to the contract contests caused the design standards to be adapted to infrastructures also different from those of the country of origin [CC*05]. In particular, the entry of Asiatic competitors in European contests forces the companies to answer their favourable offers with innovative and technologically advanced projects: if the point in favour of Asiatic competitors consists in the competitive prices, the added value, European companies must take advantage of, is the fund of technological knowledge and innovative methodological approaches [AV03].
Unlike the automotive industry, train design is not bound only by designrequirements, but it must respect also the directives, present in contracts, imposed by the transport company who calls for tenders.
Virtual Reality techniques allow the designer to simulate their complete concept, in terms of design, ergonomics and safety, and then to present a realistic project that respects such requirements for the evaluation during the contest.
Using an innovative methodology for the concept evaluation in virtual environment [DLV06] it is possible to utilize virtual prototyping to screen, by means of virtual experimentation, the design solutions maximizing the customer satisfaction in terms of quality, comfort and safety.
In this work an innovative approach for train industry is developed for presenting in realistic way, using shader technology, the design solutions to the examiners in an interactive immersive environment.

3.2 SHADER TECHNOLOGY

During the last few years the possibility for programmers to control the real-time rendering increased remarkably. The execution of rendering algorithms passed from being controlled in the CPU by assembly language to be written in high-level language and processed by graphic processors. This process followed the considerable improvement of GPU during the years and saw the employment of standard 3D programming interfaces, such as OpenGL and Direct3D.
The control of the effects with this interfaces were still limited to fixed features. The new programmable GPUs have been improved into powerful and flexible streaming processors able to operate with floating-point precision [GWH05].

The request of more programmability brought to the creation of a dedicated high-level language, known as shading language, which gave the programmers some of the advantages, in term of programmability, of traditional high-level languages. Shader technology allows the programmers to have control over shape, appearance (such as color, lighting, reflection) and animation of objects to make very realistic real-time rendering.
By means of a language, such as Cg (NVIDIA Corporation), based on a general-purpose language for programming, like C language, 3D application programmers can write simple code to obtain special effects managing vertex and fragment transformations, which will execute within the GPU [FK03].
Since GPUs are dedicated to image processing, they can reproduce real-time rendering with tens of millions vertex transformations per second: 3D geometries are made of many vertices that will be transformed in the correspondent pixel to be rasterized and this task has to be performed tens of frames per second to give real-time impression.
The shader code written in this language will be called by the application, typically written in C or C++ [Sch96], by means of the shading language runtime, a set of subroutines able to compile shader program in a form acceptable by the 3D programming interface, either OpenGL or Direct3D, which translate and execute it into the GPU [FK03].
Vertices and fragments are processed by the relative vertex shader and fragment shader programs in GPU following the well-known graphics hardware pipeline (Figure 2).

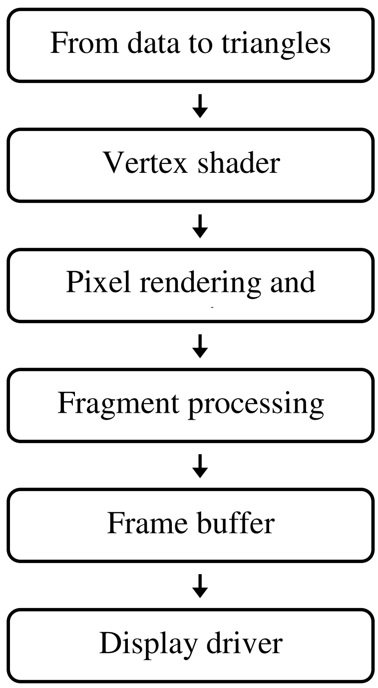

Figure 3.2: Graphics hardware pipeline

The pipeline starts when the 3D application sends objects data to the GPU; then, all data are broken down into triangles. In this way, data are ready to be processed by the vertex shader by means a set of operations, such as calculating the correct position of triangles for rendering and color and depth of each vertex. In the next step triangles are broken down further, calculating the corresponding representation for each pixel on the screen and determining the textures associated. Mathematical data now start to be processed by the pixel shader, setting color, special lighting and textures to each pixel. Finally, pixel data move to the frame buffer memory and GPU moves data from the frame buffer to the display driver, in which scene is displayed [AV05].

3.3 SHADER TECHNOLOGY IN VD2 (VRCOM GMBH)

The Virtual Design 2 software is an extensive tool that allows following many phases of product development, from the creation of showroom for realistic presentations to the assembly simulation or ergonomics analysis. Moreover, the possibility of interfacing with a wide range of input/output devices made this software to be chosen for Virtual Reality applications in the laboratory described in the following.

The two environments of VD2 software consist in a scene editor (VDSE), where there are all necessary tools to prepare the scene, comprehending geometries files, materials, lights, animations and other effects, and the “manager” of the simulation (VD2), in which the parameters to launch the simulation in one’s own laboratory, such as with allowable input/output devices, are set.

The scene, prepared in VDSE, will be loaded in VD2 and then real-time rendering and user interaction can start.

The other way to work, typically during a concept presentation, is to use the two tools in coupling mode: this means that, while the scene is visualized in VD2 on the output system, such as a powerwall, it is still possible to control it by means of the functions of VDSE, for instance from a workstation.

Setting one’s own scene in order to prepare the application, such the train presentation in a showroom, is made easy in VD2 by meaning of several wizards, which accompany the user to each step of parameters setting for the interested module. At the end of the wizard a code is generated, which will be passed through at the launch of simulation; this config-code can be also written manually without utilizing wizards [VPG05].

The material editor module, in VDSE, allows adding a shader to a material definition and treating it like a texture, storing shader parameters into the extensions of the material [VUG05].

3.4 LABORATORY OF VIRTUAL REALITY

The evaluation in virtual environment of concept of industrial products that present large dimensions, such as trains, needs the use of a virtual reality laboratory able to visualize such products in 1:1 scale.

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 [CDP04], named “VR Test”, realized for the Competence Regional Center for the qualification of the transportation systems (CRdC “Trasporti” - www.centrodicompetenzatrasporti.unina.it). The “VR Test” 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 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 visualization of railway carriages, in real dimensions (figure 3), and for their evaluations by the examiners. Characteristics are described in table 1.

Figure 3.3: The “VR Test” laboratory

Table 3.1: VR TEST

Workstation	SGI Onyx4 with O. S. Irix 6,5 (10 CPU, 10 GB Ram, 6 graphical pipes, 1500 GB Hard Disks); Cluster of 3 PC with O.S. Windows/Linux.
Visualization System	Powerwall (7.5m x 2.4m) BARCO ACTCAD 3 DLP Projectors for active stereo BARCO Galaxy 6000 AL
Tracking system	Optical ART Track 1 (3 cameras).
3D Input Systems	Cyberglove with 22 sensors, 5DT with 14 sensors, spaceball, flystick e joystick
Software	Virtual Design 2 by VRCOM (with modules: Showroom, Assembly/Disassembly simulation, Interior design, Lightsimulation, Developer Toolkit); CATIA V5 R16 P3 by Dassault Systems (completed with all the modules); Alias StudioTools R12; Classic Jack (with Occupant Packaging Toolkit, Task Analysis Toolkit modules), TeamCenterVisualization 2005 and Unigraphics NX by UGS.

3.5 APPLICATION TO A NEW REGIONAL TRAIN CONCEPT

The case study deals with the concept of a new regional train and its presentation in virtual environment. Railway field is still characterized by traditional design methodologies, such as two-dimensional technical sheets and huge use of paper documentation.

So, the target was to realize a virtual presentation of the new product, taking care to most important aspects of the real world in order to give a very realistic impression to observers and potential customers.

To do that, the VD2 software described above was used, in both components VDSE and VD2.

Virtual Design Scene Editor (VDSE) was used to prepare all the components of the scene, such as geometries, textures, lights, animations [VSE05]. Therefore, VD2 was used to load the prepared scene and to show it in the virtual environment of the Laboratory of University of Naples Federico II. VD2 is the tool used to set the interface with all allowable devices and, then, to launch final simulation to the output system, in this case a powerwall.

Since VDSE has no CAD functionality, except for simple transforming objects or creating primitives, the complete model of the train and of some additional furniture was imported in VDSE using wrml format.

The model was created in Pro Engineering Wildfire 2 CAD system, and then exported in wrml format without using the capability of exporting texture of this format, as they were applied later in the material editor of VDSE.

Once loaded the train geometry, it was positioned in a three-dimensional environment reproducing an outdoor train-stop with several lamps to illuminate it.

The first aspect it has been implemented is the position of the lights, on which also material effects depend. A light was set to simulate sun effect: VDSE allow reproducing directional light with parallel rays independent by light position.

A different kind of lights, “spot” type, was used to simulate lamps in the scene: setting the spot angle it is possible to simulate rays coming out in conic shape, like lamp lights behaviour.

The characteristics of the lights affect the resulting appearance of the material assigned to the geometries. The material editor module is used to define the material of each geometry by the combination of the four terms of surface colour (emissive, ambient, diffuse and specular), the material properties (shininess and transparency) and applied texture and shaders.

Shaders in VD2 and VDSE work as a material extension, defining material and light parameters by variables in a special syntax. In VDSE it’s possible to load a shader simply accessing to FHS, FHB and FX-shader files in the load dialog. However, in advanced mode, it’s also possible to choose among the three possible shader API’s, loading one or more shader files depending on it.

API’s for CG and the GLSL (OpenGL) [Ros04] need separate shader files for vertex and fragment programs to be loaded, whereas only one file includes all information in CgFX .fx format [VSE05].

A CgFX file includes any individual vertex and fragment programs needed to define a complete rendering appearance or effect, allowing encoding complex shading algorithms requiring multiple rendering passes [FK03].

The possibility to programme some sliders to control shader parameters allows, for example, setting a different level of reflections (Figure 4).

Figure 3.4: Shader applied to the train prototype with different levels of reflection (0, 0.5, 1)

Shaders were applied just only to the outside of the train, presuming a metallic nature of the material, otherwise the inside object were imagined in plastic or textile nature, with no reflection, such as seats or floor. The textures used for textile simulating were captured as shots from real world to increase realistic effect.
The reflection of materials is controlled by means the call to the cube map texture, featuring the environment mapping for the relative geometries.
Looking to a highly reflective object the appearance of the surface is the result of the reflection of the view ray into the surface itself, depending on the normal in that point, and reflecting to the object's surroundings, assumed infinitely distant from the object.
The cube map texture is a cube made of six texture images forming an omni-directional image: the color of the point in which the view ray reflects into the surface is the one reflected from cube map [FK03].

A characteristic of train simulation is the large presence of transparent parts (e.g. the number of windows is quite bigger than in automotive field), so the characteristic of transparency was applied to the material representing the glass and it is calculated many times during simulation, being one of the causes of a large use of resources and reduction of performance.

Figure 3.5: Train rendering with applied shader

In order to simulate the real functioning of the train, in VDSE was possible to realize a sequence of events to produce an animation: the arrival of the train to the station, the opening of the doors, the closing and the departure of the train were "recorded". The possibility of changing camera views in a predefined sequence during animation or just in real time really increases the realistic and immersive effect.
After prepared the scene it can be loaded in VD2, in order to show it in the virtual laboratory by setting its characteristics, such as input/output devices [VUG05].
The figure 5 shows the realistic train rendering with applied shader.

3.6 CONCLUSIONS

The paper offers to rail companies a really more realistic way, than technical bi-dimensional documentation, to present train prototypes in phase of concept and call for tenders.
Improving the realistic effect in the train concept presentation is the future aim of the work. In particular, the possibility of using collision detection between objects will be used. VD2 allows setting some events to trigger some action within the scene. Next phase will be to set realistic actions to give the observer the

possibility of interacting with the scene and feeling a bigger sensation of immersivity. For instance, the event of opening the door will be caused by the pressing of a button added to the train geometry [VUG05].
Moreover, the characteristic of the software to be customized in the developing module will be enjoyed to create special features for railway field, such as the simulation of a digital factory to show innovative systems to produce the train.

3.7 ACKNOWLEDGEMENTS

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3.8 REFERENCES

[AV03] AA. VV.: Il materiale rotabile e il trasporto regionale: nuovi bisogni ed esigenze innovative. *Cesit*, (October 2003).
[AV05] AA. VV.: http://developer.nvidia.com
[CDC*05] CAPUTO F., DI GIRONIMO G., CREA V., ROMANO V.: Progettazione concettuale in ambiente virtuale del comparto passeggeri di un innovativo veicolo ferroviario ad alti contenuti di comfort e di sicurezza. *Convegno CIFI "Evoluzione del materiale rotabile – Tecniche di progettazione ed attività di testing"*, (October 2005).
[CDP04] CAPUTO F., DI GIRONIMO G., PATALANO S.: Specifiche di un centro di realtà virtuale per la progettazione nel campo dei trasporti. *Proc. Convegno Nazionale XIV ADM e XXXIII AIAS "Innovazione nella Progettazione Industriale"*, (August 2004).
[DLV06] DI GIRONIMO G., LANZOTTI A., VANACORE A.: Concept Design for Quality in Virtual Environment. Accepted for publication in *Computers & Graphics.*
[FK03] Fernando R., Kilgard M.: *The Cg Tutorial – The definitive guide to programmable Real-Time Graphics*. Addison Wesley and NVIDIA, 2003.
[GWH05] GOODNIGHT N., WANG R., HUMPHREYS, G.: Computation on programmable graphics hardware. *Computer Graphics and Applications, IEEE, 25,* 5 (September 2005), 12-15.
[NT05] NAKAMAE E., TADAMURA K.: Photorealism in computer graphics - past and present. *Computers & Graphics 19*, 1 (January 1995), 119-130.
[Ros04] Rost R.: *Open GL Shading Language*. Addison Wesley, 2004.
[Sch96] Schildt H.: *Guida al linguaggio C++*. McGraw Hill, 1996.
[VPG05] vrcom GmbH: VD2 – Package Guide 4.5 Feature, 2005.
[VSE05] vrcom GmbH: VD2 – Scene Editor 4.5 Feature, 2005.
[VUG05] vrcom GmbH: VD2 – User Guide 4.5 Feature, 2005.
[VWS] vrcom GmbH: web site - http://www.vrcom.de

CHAPTER 4

MAINTAINABILITY TESTS

4.1 INTRODUCTION

The following chapter describes a complete Virtual Reality environment realized by the author in which to simulate maintainability tests and manufacturing systems. An original VR architecture (MATEMASYS) has been conceived in order to create a unique environment whose features are able to satisfy requirements both for Virtual Maintenance and Virtual Manufacturing tasks. The architecture is based on complex hardware and software technologies available at the VR Laboratory, named '*VRTest*', of the Competence Regional Center for the qualification of transportation systems founded by Campania Region. Two case studies realized in MATEMASYS, regarding the maintainability of a railway boogie and the simulation of a welding work cell, are finally presented.

Virtual Reality (VR) can be defined the technology improving the interaction between human and product models, adding perception with visual, tactile, sound realistic sensations in a real-time simulated environment [1]. User can experience the design phase of a new concept looking it in three-dimensional aspect, moving around or inside it, grasping parts, increasing his analysis, comprehension, design and communication. The advantage of using VR in industrial application is to reduce time and costs for developing a new product, thanks to the new way of design process: from the trial and error method, involving the production of many physical prototypes, to the continuous improvement approach, typical of simulation tasks [2]. The process of Virtual Prototyping uses digital models and VR techniques to simulate a product and its behaviour in a realistic way and to allow designers testing and evaluating their concepts. By now industries use VR techniques in a widespread way in the phase of Concept Design for styling decisions [3]: really less diffuse is the application of VR for the simulation of maintenance tasks and maintainability tests, even if, for example, assembly-disassembly processes affect remarkably in the product cost. Who manages the maintenance is interested to contain the costs due to the frequency of the maintenance operations and the necessary time and work for the execution of the corrective and preventive activities. So it is necessary to optimize these operations reducing the time and improving ergonomics, in order to limit the costs of the staff training and to postpone the operations not immediately necessary. A valid contribution for achieving these objectives can be obtained simulating the maintenance activities in virtual environment [4].

New approaches go towards the integration of the simulation of maintenance operations in the virtual design process in order to optimize the product in all the phases of its life [5]. Unlike traditional design processes, Virtual Assembly systems allow engineers choosing appropriate solutions, depending on assembly sequences of digital models, that provide virtually tangible data even though

without a real physical prototype [6]. Sequences and trajectories of assembly can be calculated, by means of the collision detection in real time, in order to define the optimal path that guarantees the absence of interferences or penetrations among parts [7].
The same approach has been used for simulating the manufacturing systems in order to create a digital copy of the work cells present in all production lines. The evolution of this research activity is the implementation of such simulations in a virtual environment allowing to evaluate in real size active areas and safety margins along the production line. For example, the study of workspaces, the adherence of minimum and maximum distances between machines within the work cells have to be taken into account.
Virtual Reality is the indispensable instrument to make these analyses and simulations, visualizing results in an immersive environment, interacting with the models by means the help of special devices for the virtual navigation and handling, such as gloves, stereoscopic viewing and tracking systems. The direct manual interaction approach provides the transfer of the movements of the user body to the virtual scene in which the activity is simulated; in particular, a digital model of the hand reflects the position and the orientation of the real hand in order to experience and test the task in the virtual environment. Different algorithms for virtual grasping have been studied to realize an even more realistic and comfortable simulation of the grabbing gesture [8]. To increase the realism of the operation the attention has been paid to many aspects of the real world. Real time shadows and models of the physical behaviours have been implemented to improve perception of the scene simulated in the virtual environment [9]. Moreover, Virtual Training is a natural application of the such simulations, allowing the operator to previously acquiring experience with the operations he will execute on the real products.
This paper describes a complete virtual environment realized by the authors in which to simulate maintainability tests and manufacturing systems.

4.2 MAINTAINABILITY TESTS

4.2.1 Maintainability

Maintainability can be defined the synthesis of different product characteristics: detachability, accessibility, diagnostics, manipulability, facility of cleaning. It can be defined as the probability of a maintenance action to be executed during an assigned time, in assigned conditions of use and maintenance and by means the use of prescribed procedures [4].
The main requirements to satisfy in maintenance verifications are:

1. accessibility of tools, hands and arms for local inspections and repairs;
2. visibility;
3. easy replacement of components;
4. computation of minimal distances among parts to avoid collision detection;
5. computation of assembly/disassembly paths to implement on robot systems.

The maintainability of a system has to be designed in phase of concept in order to identify critical areas for operations of maintenance, provide tools for the immediate check of failures and develop equipment dedicated to the maintenance.
A maintainability analysis can include the following phases: disassembly analysis, accessibility analysis, manipulability analysis. A component can be disassembled if it can be moved from the assembly without detecting collisions along a path. The accessibility is verified when the system allows the introduction of the hands of the operator and tools for small operations or control. Moreover, a part is manipulable when it can be handled quickly, moved without excessive effort or simply utilized. At present, inspections are carried out by means the use of 3D CAD systems allowing the movement of assembly components along any direction and the computation of collision-free assembly paths. Taking advantage from VR, such analyses can be improved executing them in an immersive environment, modelling also hands and tools, simulating their movement and accessibility to validate completely maintenance operations during design phase. In this way the human factor is taken into account.

4.2.2 Simulation of maintenance tasks in VR

In order to integrate 'the man inside the design' by means the use of VR techniques, the approach can be chosen between the employment of virtual manikins or the direct manual interaction. The direct manual interaction is proposed to allow the user to interact directly in a intuitive way with the parts of the product, in order to carry out interactively, through the movement of the hands and the arms, the above mentioned verifications relative to the maintainability aspects. The typical input devices for interaction in VR, such as data gloves ant tracking systems, capture position and movements of the hand of the user and determine the action of a correspondent virtual model of the hand, which can move in the virtual environment and interact with the 3D models. The designer can become the protagonist of disassembly, accessibility and manipulability analyses (Figure 1), unlike the use of a virtual manikins, in which they are demanded to reach a position or grasp an object.

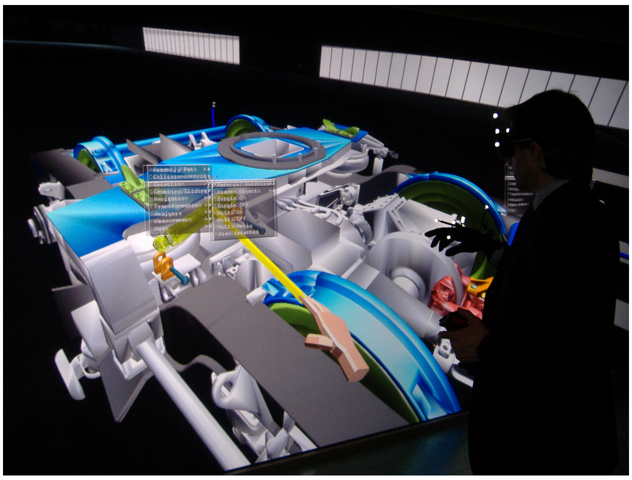


Figure 4.1: Direct manual interaction

It is fundamental to have a strong realism of the scene, guaranteeing to the operator a sense of immersion. The obvious advantage of the direct manual interaction is constituted by the immediate correspondence between the desired verification and the relative action, that makes natural, intuitive and, consequently, fast the analyses.
The maintenance chart is a document containing all the necessary indications and information for a correct execution of the maintenance operations. Data contained in the maintenance chart must answer to all questions that can occur during the preparation and the execution of an operation. Maintenance tests will have positive result if the operator collects all the necessary information to fill in the maintenance chart. Otherwise, the operator has sufficient information in order to identify the problem and review the design.

4.3 MANUFACTURING SYSTEMS SIMULATIONS

Industrial productivity must be improved and maintained to meet the challenges of an increasingly competitive world market. This is possible through technological change or progress. However, the relatively high cost, the lack of integration with existing processes, motivate many Original Equipment Manufactures (OEMs) to pay attention to VR. As a result, the past ten years have seen a strength consolidation in the commercial VR technology industry. In fact 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, machining, inspection, factory simulation, and production management [10].
Human interaction with current and advanced manufacturing technology is essential to achieve the expected levels of system efficiency, productivity, and safety. The benefits of applying VR in manufacturing applications are to improve the visualization of the product and to allow the worker to co-exist in the same environment with the product model. The reproduction of an entire manufacturing process in a virtual environment gives to workers the possibility to learn in their own factory. Moreover it provides users with an environment to explore the outcomes of their decisions without assuming risks for themselves or for equipment [11].
Nowadays many manufacturing industries use Virtual Factory (Figure 2); it 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 [12].

Figure 4.2: Virtual work cell

In general Computer Aided Robotics Systems (CAR-Systems) are used to design robotic cells and to create the offline programs. The realization of a virtual environment to simulate a robotic cell allows to reproduce the assembly line constituted by anthropomorphic robots.

The following activities have to be performed:

1. positioning the robot in the 3d environment;
2. definition of the number of the axes;
3. definition of the maximum stroke, rate, acceleration;
4. setting of the tools;
5. cycle-time programming;
6. collisions analysis.

The exponential increase of the automation level into the factories did not replace completely the manual work cell: that's why ergonomics is concerned with the assurance of safety and well-being of the operator at the workplace while maintaining an optimum level of productivity. It deals with methods of machines design, operations, workstations, and work environments, so that they match human capabilities and limitations. Considerable knowledge has been gained on the principles, methods, and applications of human performance and workplace characteristics. By applying effectively ergonomics principles and data, it is possible to optimize the design of product, job, workstation, training method, and system safety [13].

4.4 VR ARCHITECTURE: MATEMASYS

The realization, in an immersive virtual environment, of maintainability tests and manufacturing systems simulations, above introduced, 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;

- 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 for collision detection, motion programming, kinematics simulation, 3D distance measurements, virtual markup, path recording;
- 3D audio output device increasing the immersion in the virtual environment.

In order to satisfy these requirements an original VR architecture, named '*MATEMASYS*' (acronymous for MAintainability TEsts and MAnufacturing SYstems Simulations) has been conceived (Figure 3).

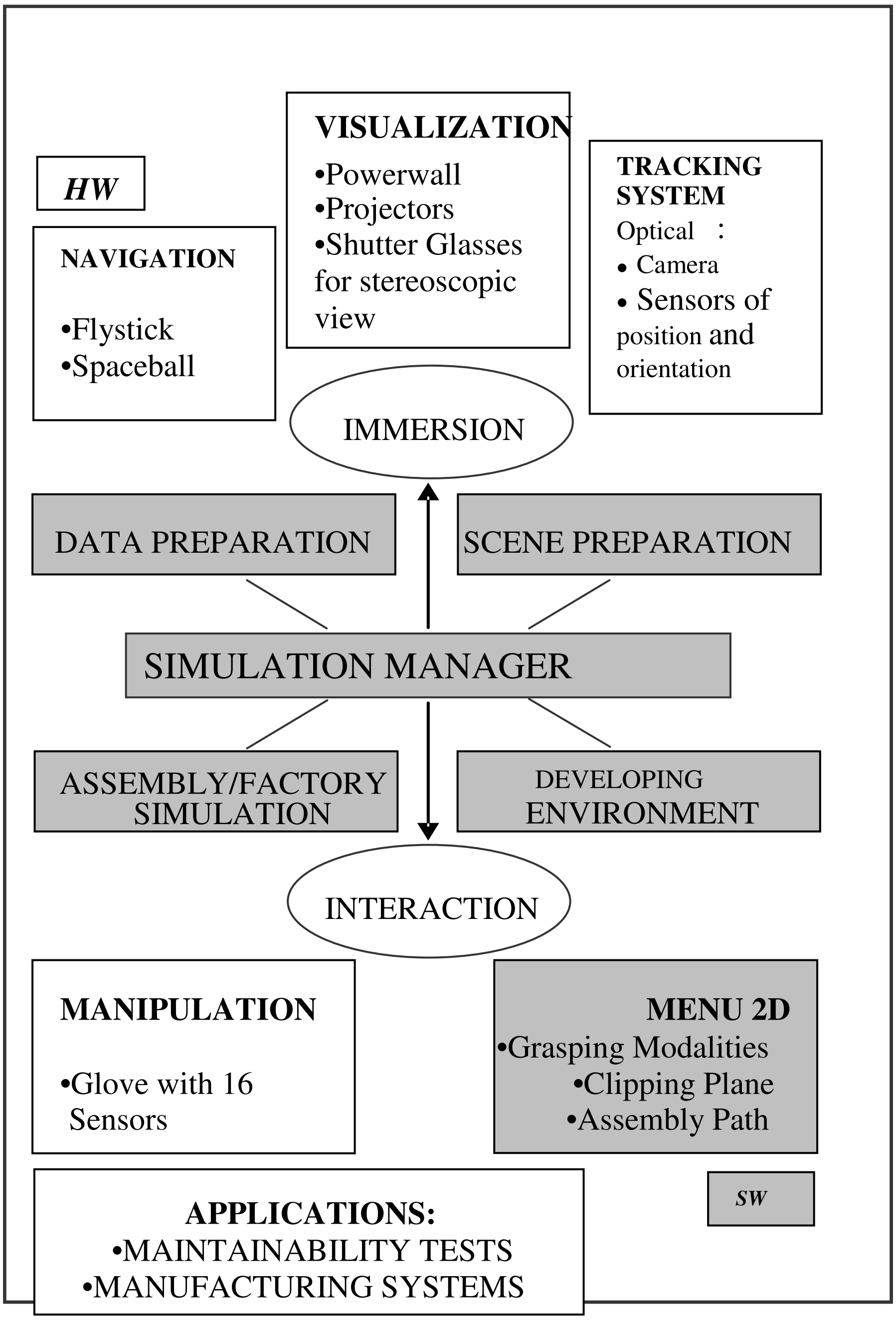


Figure 4.3: VR architecture: *MATEMASYS*.

The architecture is based on complex hardware and software technologies available at the VR Laboratory, named '*VRTest*', of the Competence Regional Center for the qualification of transportation systems (TEST - www.centrodicompetenzatrasporti.unina.it) designed and realized by the researchers of the Department of 'Progettazione e Gestione Industriale' of the University of Naples Federico II in 2005, [1]. The 'TEST' has been founded by Campania Region with the objective of delivering advanced services and introducing new technologies into local companies operating in the field of transport. Table 1 describes the main characteristics of the *VRTest*.
As described in Table 1 the first requirement is widely satisfied by means of a graphic and calculus system characterized by high performance and flexibility.
The visualization of the scene has been obtained by means of a semi-immersive system composed by a powerwall, three DLP projectors and shutter glasses for active stereoscopic view. The advantage of having a VR laboratory able to visualize industrial products and work cell that present large dimensions is to carry out the analyses in virtual environment in full scale.

Workstation	**SGI Onyx4** with O. S. Irix 6,5 (10 CPU, 10 GB Ram, 6 graphical pipes, 1500 GB Hard Disks); **Cluster of 3 PC** with O.S. Windows/Linux.
Visualization System	**Powerwall** (7.5m x 2.4m) BARCO ACTCAD
	3 DLP **Projectors** for active stereo BARCO Galaxy 6000 AL
Tracking system	**Optical** ART Track 1 (3 cameras).
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.

Table 4.1: *VRTest* characteristics

The platform used as *Simulation Manager* is Virtual Design 2 (by vrcom): it is an extensive tool containing many functions for product development, from the creation of virtual environment to the assembly simulation or ergonomics analysis. Since VR software do not offer, to date, standard characteristics to perform engineering applications, in particular maintainability tests and manufacturing systems simulation, VD2 was chosen as it provides Application Programming Interfaces used to customize the *MATEMASYS* Simulation Manager.

This platform gives the possibility of interfacing with a wide range of input/output devices, such as those available in the *VRTest*. The software allows to manage all the input and output devices employed for the visualization, navigation and interaction with the scene. Due to the chosen approach, based on the direct manual interaction, the devices implemented in VD2, in particular for navigation and manipulation, have been:

- a flystick for the activation of actions by means the events associated to the eight keys;
- a system of three cameras for tracking position and orientation of the sensors attached to head, hand and other characteristic human body points, in order to transfer the real movements to the virtual scene;
- a 5DT glove with 16 sensors for the realistic movement of the fingers of the hand to interact with the geometries of the scene.

The navigation in the scene has been simulated by means of a sensor of the tracking system attached to the glove controlled with one button of the flystick: user protagonist of the virtual experience can move the point of view in the scene, clicking the assigned button of the flystick in the left hand and simultaneously dragging the scene with the movement of the hand. This user-friendly modality of navigation allows the operator to decide easily when to use his hand to change the position in the scene, for example for better positioning the geometries during the maintenance operation, rather than to execute the task. This modality of navigation allows also the other members of the design team to participate the virtual immersive experience in a comfortable way since they are not obliged to hold continuously the point of view of the protagonist of the virtual experience. Moreover, a sensor can be attached to the glasses of the protagonist and assigned to the camera control of the software in order to generate relative variations of the point of view by head rotations. In this way, for example, the immediate inspection of the analyzed system is possible for the user just moving his head in a natural gesture.

The virtual manipulation of the objects has been implemented through a glove provided with sensors able to detect position and movement of the real fingers sending data to the corresponding hand in the virtual scene. Three grasping modalities have been implemented in *MATEMASYS*: index-thumbs grasp, palm grasp and gesture recognition grasp. The system allows to choose among the palm, the simultaneous collision with index and thumb fingers, and the recognition of a specific gesture (this last modality can be opportunely programmed).

The first operation for creating the virtual environment is to import all geometries necessary to carry out the simulation: the formats used for data exchange have been VRML and 3ds and then imported files have been optimized for being treated with the VR software.

Once imported the geometries it is possible to set the objects that will act as tools in the maintenance tasks, in order to define automatically the collisions with the virtual hand and with all the other "interactive" geometries. There are three mode to set the interaction of the geometries in the virtual environment: *static*, *grabbable* and *glideable*.

A component defined *static* cannot be grasped and moved with the hand, but subject to the collision detection with the other parts defined interactive. The alternatives *grabbable* and *glideable* concur to make an object possible to be grasped, but in different modalities. A component defined *grabbable* can be attached and moved by the hand. With *glideable* it is possible to define a realistic behaviour of such parts that can slide along the generatrixes of coincident surfaces between two parts, remaining loyal to the hand. Moreover, it is also possible to introduce some cinematic restrictions in order to respect the real constraints of some components, in order to facilitate the simulation, removing the not important movement. The simplest example is the sliding of a screw along its axis. It is also possible to assign a common axis to objects and tools so that, in correspondence of a predefined distance, the instrument snaps to the correct position and the operator is guided in the task; otherwise it would be impossible in simulation to realize the correct relative positioning of the axes with the actual VR devices. Once the coincidence between the axes of tool and part happened, it is possible to visualize the value of the rotation angle of the tool, in order to study for example the accessibility without collision during the task.
Different models of the virtual hand can be chosen in order to simulate the verification activities with hands characterized by different anthropometric dimensions relative to several percentiles of population. Moreover, another function can be activate: a '*ghost*' mode can be set to correctly visualize a component fixed in the last position free from interferences, while the ghost object follows the hand until the successive collision free position. An interactive 2D menu containing many functions that the customer can recall directly during the simulation by means of predefined events has been implemented in *MATEMASYS* (Figure 4). It is possible to select in the menu those objects that have to become *grabbable* to execute the current task.
Moreover, it is possible to record, load, save or modify the path of a virtual component while an assembly operation or a manufacturing process is performed.

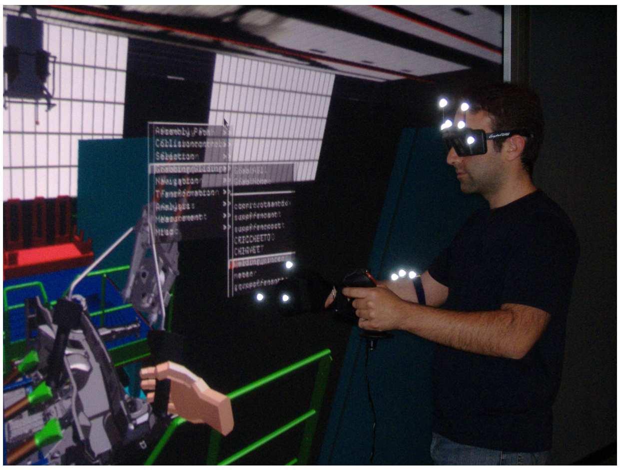


Figure 4.4: Interactive 2D menu

The path is represented by means of the polyline interpolating the positions occupied by the barycentre of the selected object. A clipping plane can be set from the 2D menu in order to visualize the inside of the assembly by means of sections at a predefined distances.

4.5 CASE STUDIES

4.5.1 Maintainability of a railway boogie

MATEMASYS architecture has been used to simulate maintainability tests of a railway bogie designed by Firema Trasporti SpA (www.firema.it), one of the most important train industries in Italy. The study has been directed to the disassembly analysis of some components, chosen from the list of the maintenance activities in collaboration with Firema technicians. In particular, in the following is described one of this simulation, regarding the disassembly of the front transversal suspension (Figure 5).

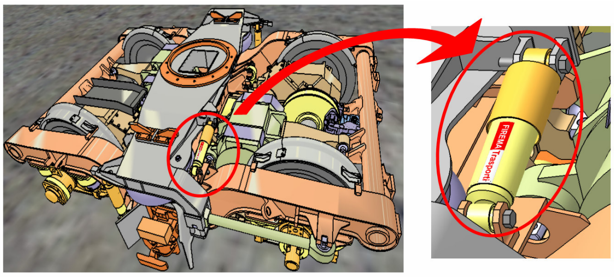


Figure 4.5: Disassembly of the front transversal suspension of a railway bogie

The 3D model of the boogie has been designed with ProEngineer (PTC) and imported in Virtual Design 2 (VD2), after prepared the scene and the geometries with VDSE, the tool of VD2 for preparing data. Then, light sources were introduced and different materials were associated to each parts, by means of colors and textures, in order to improve the realistic effect of the scene. A small table were positioned near the bogie where the tools used in the simulation have been placed.
For the disassembly of the suspension it is necessary to remove the two bolts that fix it to the chassis of the bogie. The digital model of the tool used for this maintenance task was introduced in the virtual environment. The preliminary phase of the study has been focused on the accessibility of the tools. In particular, the presence of the prescribed volume of access has been verified to allow the operator unscrewing the bolts (Figure 6).
Once activated the snapping function, the rotation angle of the tool has been visualized to estimate quantitatively the space available for the operation.

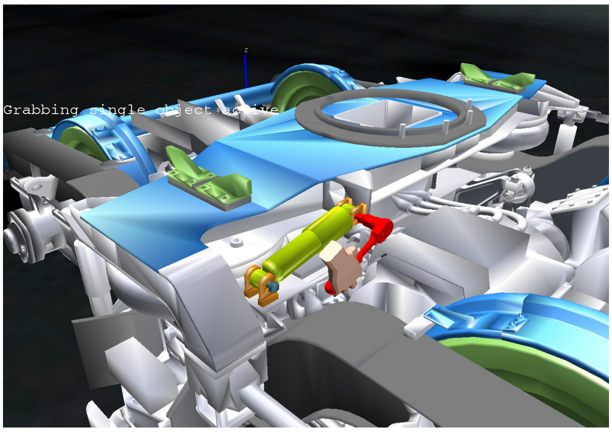


Figure 4.6: Rotation Snapping for removing the bolts of the suspension

The simulation in VR allows the operator to collect all the necessary information for the compilation of the maintenance chart, providing a positive outcome for the feasibility of the whole operation. In particular, detachability, accessibility, and manipulability were verified (Figure 7).

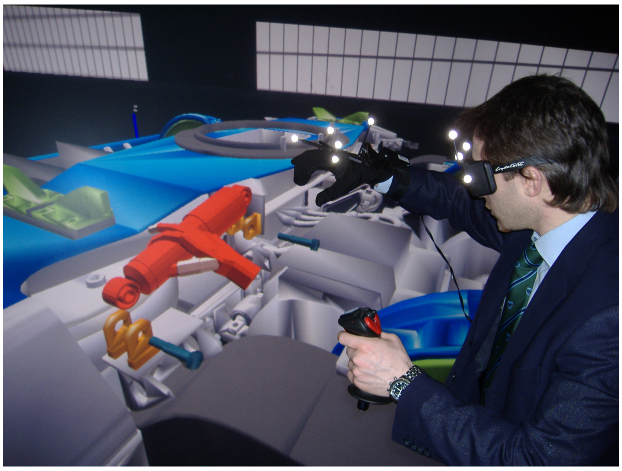


Figure 4.7: Virtual maintenance task

The simulation can be conducted by an unskilled operator and the employment of only one operator is sufficient for the whole task. The mean total time for the execution was about four minutes.

4.5.2 Body welding work cell simulation

MATEMASYS architecture has been applied also for the simulation of a manufacturing system: in particular a body welding work cell in an automotive assembly line has been analyzed.
The operation performed in this manual work cell consists in a manual braze welding renewal (Figure 8) of the spot welding realized in a previous automatized work cell by anthropomorphic robots. The position of a body welding pincer has been evaluated through the manual direct interaction in order to guarantee the

maximum postural benefit of the worker. The creation of the virtual environment has been realized importing the geometries, the tools, and the equipment in VD2 using the VRLM format.
The VR simulation has allowed to evaluate in real time several layout configurations of the equipment in order to realize the grasping in ergonomic way and to define the best solution.

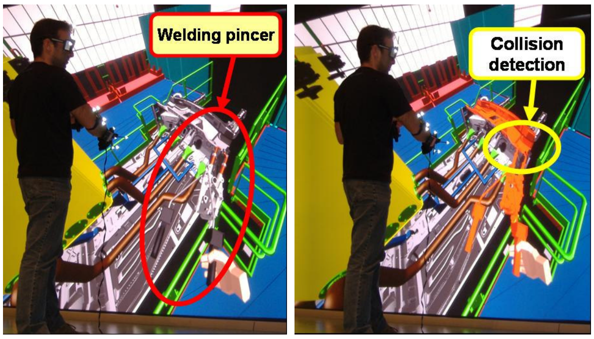


Figure 4.8: Collision detection during the welding operation.

4.6 CONCLUSIONS

The present chapter wants to demonstrate the important potentialities offered from VR techniques in industrial applications, in particular, for maintainability tests on complex assemblies and for the simulation of manufacturing systems.
Obtained results not only provide a valid answer to the design questions in the field of maintenance and manufacturing systems simulation, but they make objective the effective applicability of the proposed methodology: in spite of the subjective character of the approach to the simulation, based on the direct manual interaction, the information collected in the case studies, allow to grant the feasibility of tasks and to individualize the design parameters on which operating to better answer the functional requirements and, finally, to improve the design.
After each design modification, a new phase of simulation follows in order to verify the effective satisfaction of the requirements. In particular, the virtual simulation is important also for the training of the staff assigned to the maintenance and manufacturing activities.
The analyzed case studies have highlighted that the proposed *MATEMASYS* architecture satisfies all the requirements needed to perform maintainability tests and manufacturing systems simulations. Nevertheless future works have to be focused on the implementation of more grasping conditions of the virtual objects, in order to increase the realism of the simulation, reproducing the natural posture of the hand assumed in the manipulation of the objects. Also the possibility to introduce a virtual reproduction of the wrist, the forearm and the arm of the operator, represents an interesting objective, in order to increase the sense of immersion into the scene and to make more precise and concrete the results of the simulation.
Moreover, a future interesting task will be to implement algorithms for the automatic calculation of assembly/disassembly paths, starting from the initial and

final position of the components: obtaining the theoretical collision free path, the simulation can allow the operator to reproduce the previously calculated trajectory. Finally the introduction of shadow effects on the examined system would increase the realism of the scene, in order to improve the perception of distances and volumes between virtual hand, tools and components.

4.7 REFERENCES

[1] Caputo, F., Di Gironimo, G., Patalano, S., 2004, Specifications of a Virtual Reality centre for design in transports field (in Italian), Proceedings Of The XXXIII National Conference Adm – Aias Innovation In Industrial Design, Bari, 31 August – 2 September.

[2] Bonini, F., 2001, Numerical simulation and Virtual Reality Applied to the Real Word, Bollettino Del Cilea, 80: 34-35.

[3] Di Gironimo, G., Papa, S., 2006, Use Of Shader Technology For Realistic Presentation of Train Prototypes in Virtual Reality, Proceedings of the Fourth Conference of Eurographics Italian Chapter, Catania, 22 – 24 February: 105-109.

[4] Di Gironimo, G., Caputo F., Fiore, G., Patalano, S., 2004, Maintainability and Ergonomics Tests for the design of a Shunting Engine Through Virtual Manikins (in Italian), proceedings of the XXXIII National Conference Adm – Aias Innovation In Industrial Design, Bari, 31 August – 2 September.

[5] Gomes De Sá, A., Zachmann, G., 1999, Virtual Reality As A Tool For Verification Of Assembly And Maintenance Processes, Computers And Graphics, 23/3: 389-403,

[6] Li, J.R., Khoo, L.P., Tor, S.B., 2003, Desktop Virtual Reality For Maintenance Training: An Object Oriented Prototype System (V-Realism), Computers In Industry, 52: 109-125.

[7] Jayaram, S., Connacher, H., Lyons, K., 1997, Virtual Assembly Using Virtual Reality Techniques. In: Computer-Aided Design, 29/8: 575-584.

[8] Bruno, F., Luchi, M. L., Milite, A., Monacelli, G., Pina M., 2005, An Efficient Grasping Technique for Virtual Assembly Applications, Proceedings of XVII Ingegraf – XV Adm, Sevilla, 31 May – 2 June.

[9] Di Gironimo,G., Leoncini, P., 2005, Realistic Interaction for Maintainability Tests in Virtual Reality, Proceedings of Virtual Concept. Biarritz, 8-10 November.

[10] Schaefer, D., Borgmann, C., Sheffter, D., 2001, Factory Planning and the Potential of Virtual Reality, Proceedings of AVRII & CONVR, Gothenburg, Sweden, 4 – 5 October.

[11] Mujber, T. S., Szecsi, T., Hashmi, M.S.J., 2004, Virtual Reality Application in Manufacturing Process Simulation, Journal of Materials Processing Technology, 155-156: 1834-1838.

[12] Choi, H., 2003, Integration of Multiple Human Models into a Virtual Reality Environment. Ph.D. Thesis, Washington State University.

[13] Saadoun, M., Sandoval, V., 1999, Virtual Manufacturing and its Implication, Virtual Reality And Prototyping, 1, Laval, France.

CHAPTER 5

COMPLEX ASSEMBLIES

5.1 INTRODUCTION

In the present Chapter a methodology developed to execute maintainability tests of complex assemblies in Virtual Reality is presented. Different approaches have been analyzed, described and compared in the paper. The main goal of the work was to draw up a methodical approach in order to perform disassembly, accessibility and manipulability analyses in semi-immersive virtual environment of complex mechanical systems. The method is based on a direct manual interaction: user in charge of the maintenance task can interact directly with the virtual model of the product by means of special devices. The tests were carried out in a complete Virtual Reality environment, realized by the authors, characterized by an original VR architecture.
The characteristic of maintainability of an industrial product is included in the definition of the functional design parameters. Maintenance activities, in fact, often affect for 30÷40% the entire cost of the life cycle: as it is possible, since the first phases of design activity [H1], [IT1], [B1], [BF1], to reduce such incidence, analyzing the characteristics of detachability, accessibility and manipulability, the employment of suitable methodologies is fundamental; moreover, it constitutes a competitive advantage more and more interesting due to the tendential increase of the hour cost of skilled manpower. In the case of complex assemblies, such as air, naval, railway and automotive transportation systems, for which safety and reliability requirements are essential during the exercise [S1], the analyses of maintainability results fundamental, even if particularly onerous, due to the great number of components [AF1], [MD1], [ED1].

5.2 MAINTAINABILITY TESTS OF COMPLEX ASSEMBLIES

Approaches and methodologies proposed in previous works have remarked the potentialities of simulation software to analyze, in virtual environment, the operations of assembly/disassembly and, therefore, of maintenance of industrial products [CG1], [DM1], [LP1], [CD2]. EDIVE methodology, present in literature, allows, using digital human models for simulating maintenance activities, to answer in precise and objective way to the problems relative either to maintainability tests of existing systems and parts or to new design activities; moreover, it provides precise information about ergonomics of the posture assumed from the operators, taking in account the human factor as fundamental requirement to respect [AB1], [DP1], [CD1], [DP2], [D1], [CA1], [CO1]. However, such methodology results quite onerous due to the time needed for the

set up of the simulations; therefore, 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. The employment of Virtual Reality allows to "filter" a great number of operations in order to limit more as possible the use of digital manikins and offers moreover the possibility to simulate quickly several activitie. It represents also a useful instrument for the training of the staff assigned to the maintenance. Moreover, the proposed methodology allows to evidence possible errors in virtual environment, on the Digital Mock-up (DMU) of the product, before the realization of the physical prototype: in such a way the opportune design modifications can happen at very reduced costs [DM2].
In particular, the detachability could be verified by means of opportune modules, already present in commercial and customized CAD systems, dedicated to the collision free trajectories calculation [BM1], [OH1], [AD2] and, then, accessibility and manipulability could be estimated by sight, simply observing on a screen the digital model of the complex system (visual approach). However, some experiments, carried out at the VRoom and VR Test laboratories of University of Naples Federico II, have demonstrated, even relatively to, in appearance, extremely simple operations, how the customer can make a mistake when he tries to estimate accessibility and manipulability of a component just by means of a simple visual approach.

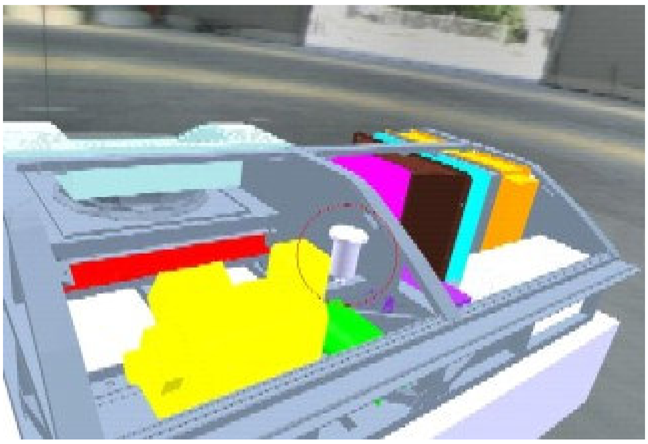


Figure 5.1: Removal of a component by Visual approach.

A sample of ten persons has been asked to judge accessibility and manipulability, of a dehydrator filter present on the air conditioning system of a railway vehicle, whose detachability previously had been already verified (figure 1). Users had only the possibility to navigate in the digital environment, changing the position of the point of view by means of a spaceball. The questionnaire was submitted in the following way:

- **is the component accessible?**

[ ] YES [ ] NO [ ] I CAN'T ANSWER

- **is the component manipulable?**

[ ] YES [ ] NO [ ] I CAN'T ANSWER

The experiment has been lead placing users at first in front of a 19"LCD screen, obviously in monoscopic modality, therefore in front of the VRoom screen, 2,4m x 1,8m large, both in monoscopic and stereoscopic modalities, and, then, in front of the VR Test screen, 7,5m x 2,2m large, also in this case both in monoscopic and stereoscopic views. In the first case the great part of the sample declared not to be able to judge, in such conditions of visualization, neither the accessibility neither the manipulability of the analyzed component. Even if the percentage of doubtful decreased progressively by improving the visualization conditions (dimension of the screen and stereoscopic effect), a strong dispersion in the answers has been recorded during all the experiments. Therefore, the study, even demonstrating that the perception of the reality improves with the stereoscopic view and, above all, with the dimensions of the screen, has carried to the conclusion that it is impossible to judge, with absolute certainty, accessibility and manipulability of a component by means of a simply visual approach, even if lead in stereoscopic modality in front of a large screen and, therefore, observing the assembly in real dimensions. During the experiment, users revealed that the uncertainty in their answers was mainly due to the impossibility, typical of the visual approach, to visualize the own hands in the virtual environment, and to the consequent impossibility to judge the sufficiency of the areas of access and the volumes of handling. The natural solution of such problem is to estimate accessibility and manipulability by means of a direct manual approach in a virtual reality environment. Thanks to dedicated devices for the virtual reality, such as digital gloves, tracking systems, virtual menu, user can interact whit the virtual scene in really immersive way, feeling to be in contact whit the object, grasping and moving it as well as in real world: a virtual hand moves in the scene following the movements of real hand and fingers of the protagonist of the virtual experience [WR1], [RH1], [P1]. Due to the considerations here exposed, the authors have completed a methodology for the analysis of maintainability of complex assemblies, whose first results on a railway case study are described. Figure 2 shows all steps to follow in order to analyze the maintenance operations on a complex assembly in virtual environment.

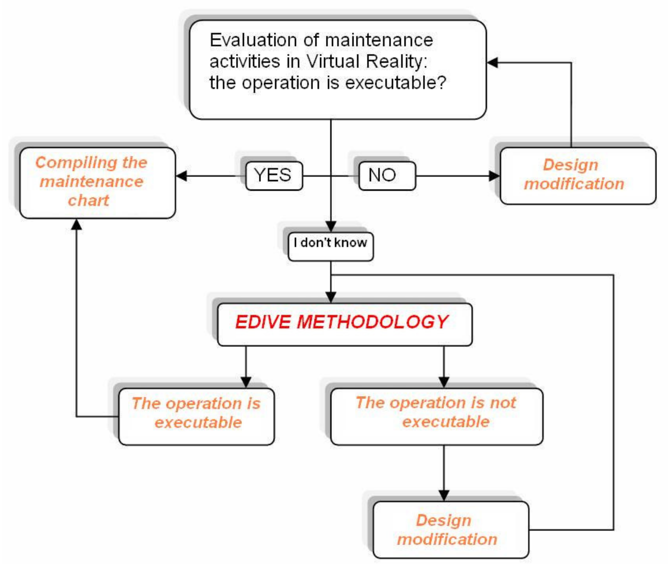


Figure 5.2: Methodology of maintainability analysis of complex assemblies in virtual environment.

In the first instance the operator analyzes the maintenance operations previewed on the assembly, object of the simulation. The DMU has got, in fact, all the characteristics of the physical product, either for the geometries or for the operations of assembly/disassembly. The simulation of the maintenance operations is carried out in the first instance in immersive environment, with a direct manual interaction approach. By the analysis of the results the operator will be able or not to compile the maintenance chart, in particular he will stay in front of three possibilities:

- information deriving from the simulation in virtual environment are sufficient to establish the feasibility of the analyzed operation;

- information deriving from the simulation in virtual environment are sufficient to establish the not feasibility of the analyzed operation;

- information deriving from the simulation in virtual environment are not sufficient to make the operator able to express about the possibility to execute the maintenance operation.

In the first case the expert, possessing all the necessary information, can compile the maintenance chart. In the second case, according to achieved results, the expert can express about the impossibility to execute the particular operation and orient to a design modification. It is important to emphasize that, in this case, the eventual modifications to take to the model can be implemented directly on the digital mock up, with obvious saving of resources, time and costs. In the event the expert is not able to express a precise judgment, it is possible to recur to EDIVE methodology by means the digital manikins. Also in this case the analysis of the maintenance activity will result positive if the operator owns all the necessary information for the filling of the maintenance chart. Otherwise the operator will dispose of sufficient means in order to identify the problem and demand a modification to the project, to submit to further analyses by the design team.

5.2.1 The maintenance chart

The maintenance chart is a document containing all necessary information for a correct execution of the maintenance operations. The maintenance chart collects the information answering to the questions directed to assigned operators, during the preparation and the execution of an operation. Besides the information regarding the assembly and the relative object to maintain, the operations and the type of maintenance to carry out appear in the chart, as well as data relative to the necessary tools, the employed staff and the mean time of execution (table 1).

MAINTENANCE CHART		
INTERESTING INFORMATION	***TO COMPILE BY THE OPERATOR***	***TECHNICAL NOTES***
Examined assembly:		
Examined operation:		
Type of maintenance operation:	• **Corrective maintenance** • **Preventive maintenance**	
Outcome of the operation:	• **Feasible** • **Not feasible**	
Disassembly sequence:		
Used equipment:		
Required staff:	• **Specialized** • **Not specialized**	
Number of required operators:		
Total time of operation:		

Table 5.1: Example of maintenance chart.

5.2.2 Advantages of the methodology

The employment of Virtual Reality allows to "filter" a great number of operations in order to limit more as possible the use of EDIVE methodology and offers moreover the possibility to simulate several activities, representing a useful instrument for the training of the staff assigned to the maintenance. Even if EDIVE methodology assures more complete and objective results, as well as precise information about ergonomics of the posture assumed by the operators, the exposed methodology presents the advantage to evidence quickly possible errors in virtual environment, on the DMU of the product, before the realization of the physical prototype, allowing the opportune design modifications to be provided at very reduced costs.

5.3 CASE STUDY: ANALYSIS OF MAINTENANCE OPERATIONS OF A RAILWAY BOGIE

The exposed 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 new railway vehicle (figure 3). In particular, the company demanded to analyze the feasibility of every single operation of maintenance, to verify and to compare, as provided in the preliminary RAMS analyses, the required time and the number of necessary operators for the realization of the operation and to suggest the eventual employment of special and/or standards equipments. The bogie constitute a good example of complex assembly with a great number of required maintenance operations (approximately two hundred). By a first observation of the DMU of the bogie and of the maintenance operations to verify results immediately obvious that it was not opportune to analyze all the operations with EDIVE methodology. That for two reasons: the time necessary to carry out such analyses was bigger than that previewed by the company; many operations, already by a first observation, appeared extremely simple to evaluate. Therefore, all the operations have been "filtered", analyzing them in immersive environment of Virtual Reality by means of direct manual interaction in order to identify, in first request, either those not critical, whose feasibility could already be estimated in subjective way, or those critics, instead, which demanded objective and more in-depth analyses, to execute with EDIVE methodology.

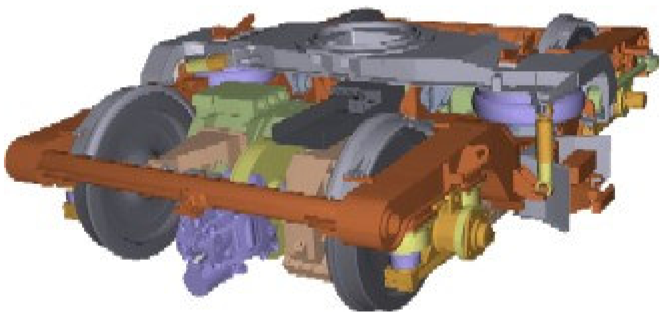


Figure 5.3: The examined railway bogie

Three different strategies of simulation of maintenance activities in VR have been developed, analyzed and compared, based on three software, in order to identify the most usable one by a user not necessarily expert of VR technologies and, at the same time, such one able to provide more reliable and realistic results in the less time possible. The study has been lead on three maintenance operations extracted from the list provided by the company: disassembly of the front cross suspension; disassembly of the brake system; disassembly of a wheel cover.

5.3.1 Disassembly of the front cross suspension

The front cross suspension (figure 4), due to the position where it lies, needs in damage case (breaking or oil leaks), an off-line operation and, therefore, the substitution of the bogie interested by the breakdown. For a preventive maintenance operation (every three months), instead, a simple visual inspection is sufficient in order to control the release of the screws and the presence of eventual leaks of oil.

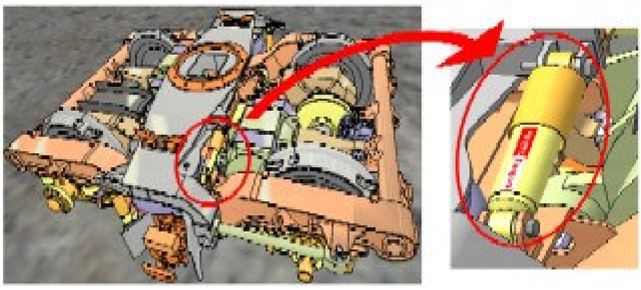


Figure 5.4: Front cross suspension.

For the disassembly of the suspension it is necessary to remove the two bolts that fix it to the chassis of the bogie; to execute such operation the use of a ratchet spanner is provided (figure 5).

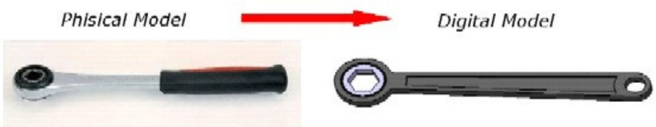


Figure 5.5: Ratchet spanner

5.3.2 Disassembly of the brake system

For the disassembly of the brake system (figure 6) it's necessary to remove the four screws that fix it to the chassis of the bogie.

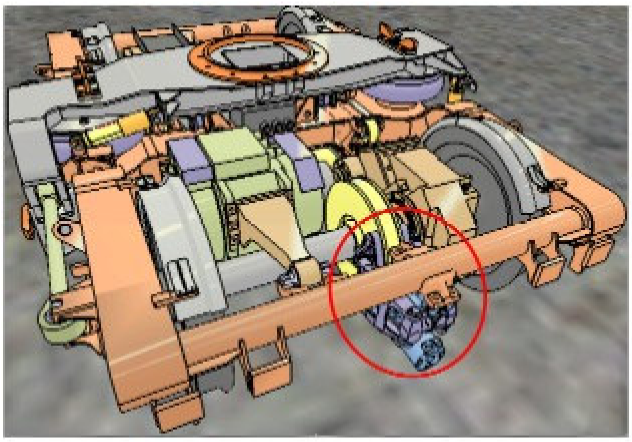


Figure 5.6: Brake system

To carry out such operation the use of a T spanner shown in figure is provided (figure 7).

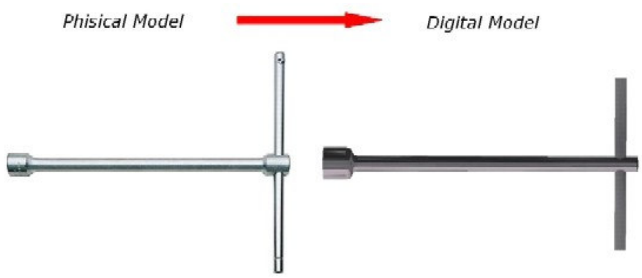


Figure 5.7: T spanner

5.3.3 Disassembly of a wheel cover

The wheel cover (figure 8) is bound to the chassis by means of bolts that must be removed with a T spanner.

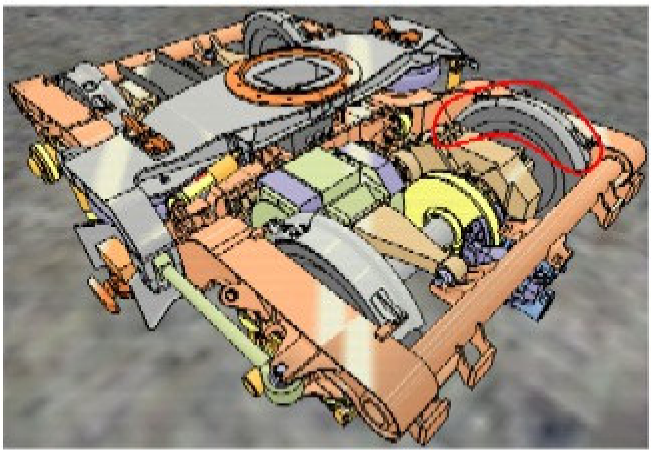


Figure 5.8: Wheel cover

5.4 CATIA V5 – VIRTUAL HAND APPROACH

Virtual Hand, module of Catia V5 [V1], allows to detect the collisions between the virtual hand and the objects present in the scene, but not the collisions among the objects themselves. In order to solve this disadvantage, the authors proposed a methodology that allows to carry out analyses of maintainability in Catia environment. Such methodology provides the integrated employment of both the Virtual Hand and the module DMU Fitting Simulator of Catia. The steps are the following:

- the operator, wearing the glove and the HMD, simulates the operation of disassembly in immersive environment with the Virtual Hand. In this phase the operator verifies accessibility and manipulability of the object to remove since it'is possible, in such environment, to verify the collisions between hand and objects. After the simulation the trace of the barycentre of the object, that has been moved, remains shown.

- Subsequently, in the Fitting Simulator module of Catia the object is bound to move along such trace, verifying contextually that there are not interferences among the object to remove and the other elements composing the assembly.
This methodology allows, therefore, to verify either the detachability or the accessibility, or the manipulability during the simulation of a maintenance operation.

5.4.1 Disassembly of the front cross suspension

First part of the study interested the verification of available spaces. In particular, the presence of areas of access allowing the operator to bring the tool near the head of the screws has been verified. The operation of approach of the tool has been simulated in VirtualHand; in this environment the operator ability has been estimated in completing the necessary movements and the presence of interferences among the virtual hand and the other objects present in the scene (figure 9).

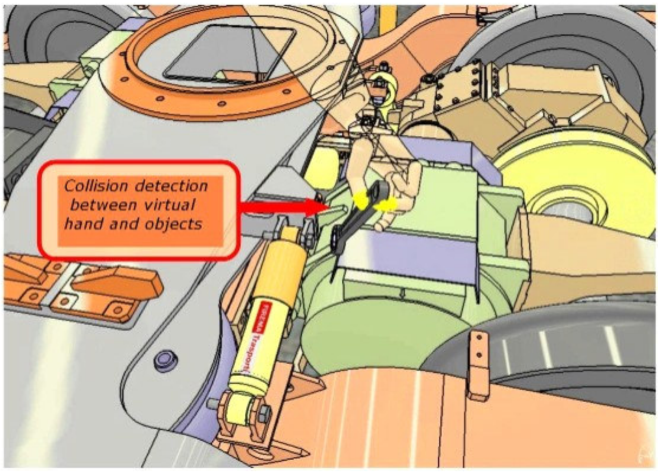


Figure 5.9: Approach of the tool in VirtualHand

To be sure that along the trajectory followed by the operator collisions were not present among the tool and other elements (in VirtualHand, in fact, the collision detection among objects does not exists, but only between hand and objects), the trace left from the barycentre of the tool has been highlighted, as trajectory to follow in the DMU Fitting Simulator module of Catia; in this environment, in fact, it is possible to have a visual and acoustic feedback of the collisions among the objects (figure 10).

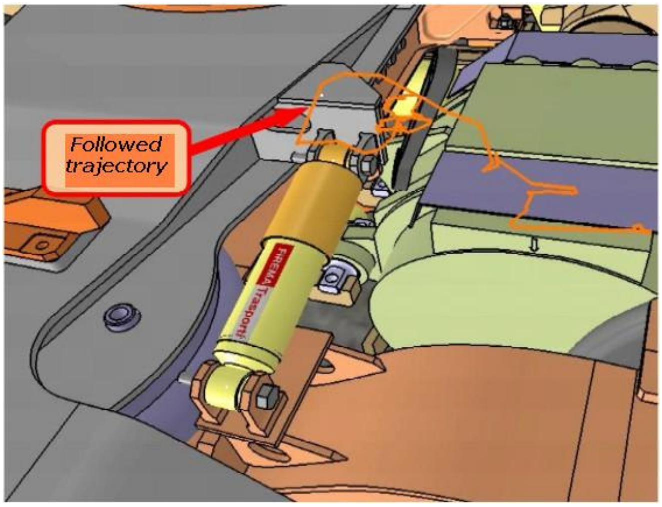


Figure 5.10: Approach of the tool in the DMU Fitting Simulator of Catia

After that the accessibility of the tool had been verified, the operation of release of the screws has been simulated; that in order to verify the presence of a sufficient volume for the handling of the spanner. In order to make this operation simpler, a single degree of freedom was allowed to the spanner: the rotation around the axis of the pin. In figure 11 the constraints imposed among the parts are evidenced: 1) coaxial axes between the pin and the axis of the hexagonal hole of the spanner; 2) coincidence between the face of the tool and the surface of the support indicated in figure.

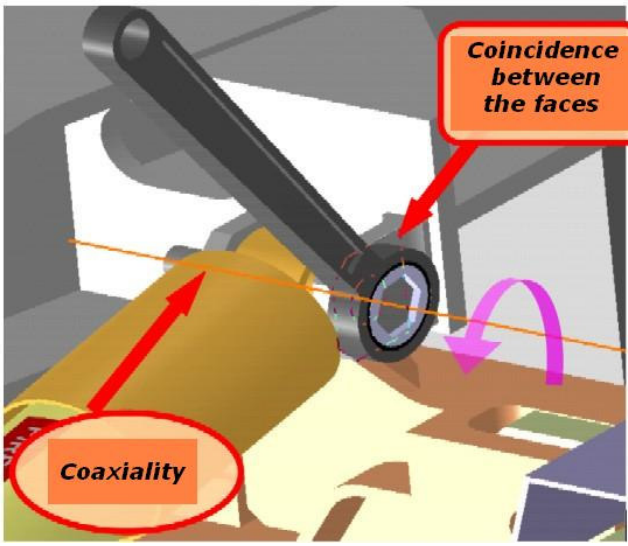


Figure 5.11: Imposed constraints

Figures 12 and 13 show, respectively, the operation conducted in VirtualHand and the trace left by the barycentre of the spanner, followed in the DMU Fitting Simulator module.

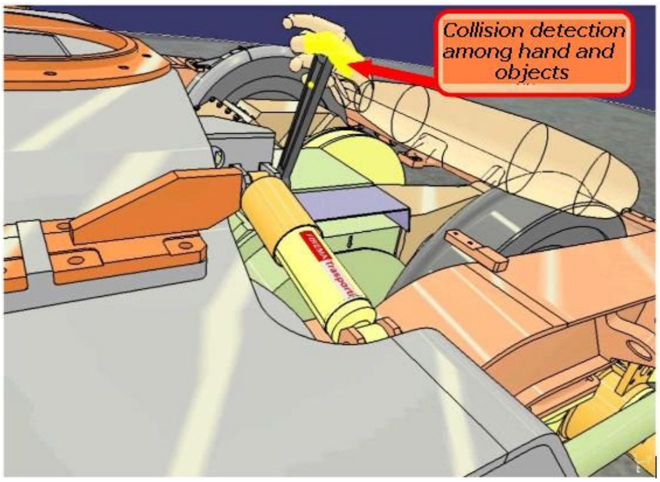


Figure 5.12: Release of the bolts in VirtualHand

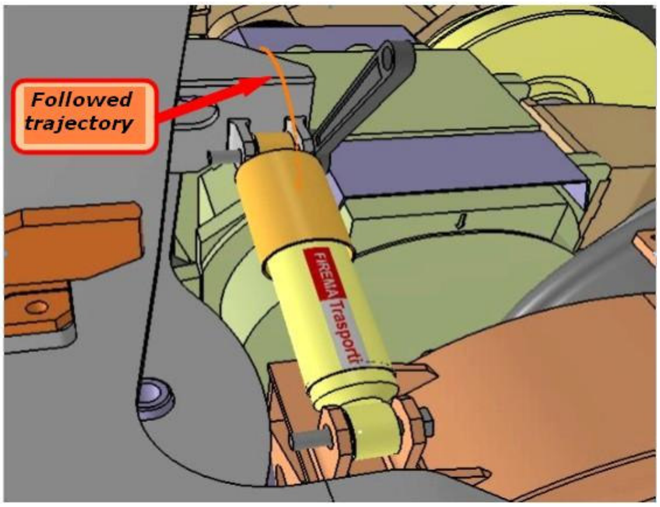


Figure 5.13: Release of the bolts in the DMU Fitting Simulator

In the successive phase the possibility to unthread the screws from their seat and to remove the suspension has been verified, without colliding with the other present objects. To simplify the analysis the screws have been bound to move only along their axis; the suspension, instead, has been imposed to move with the symmetry plan coinciding with the mean plan of the supports (figure 14).
Figures 15 and 16 show, respectively, the simulation of the operations conducted in virtual environment (VirtualHand) and in the DMU Fitting Simulator module of Catia.

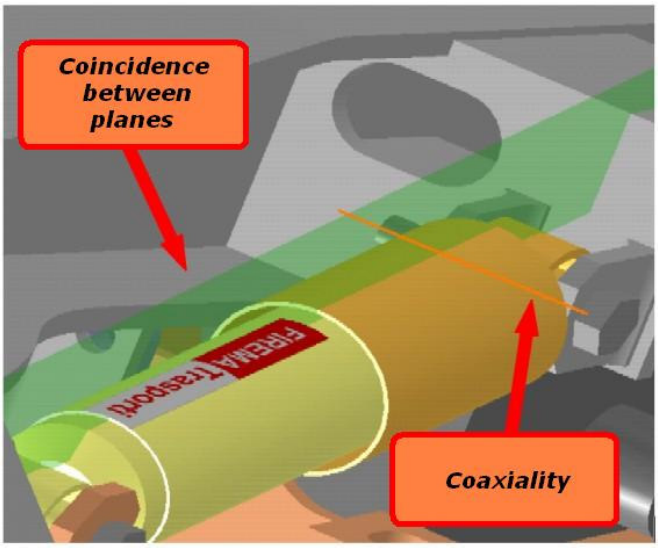
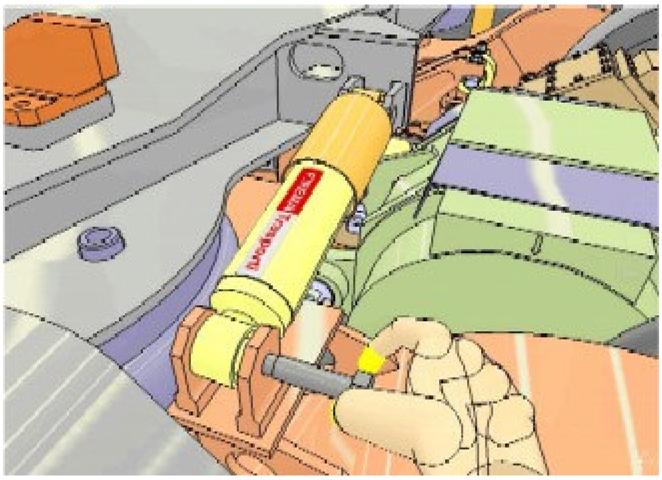


Figure 5.14: Constraints imposed for the removal of the screws and the suspension



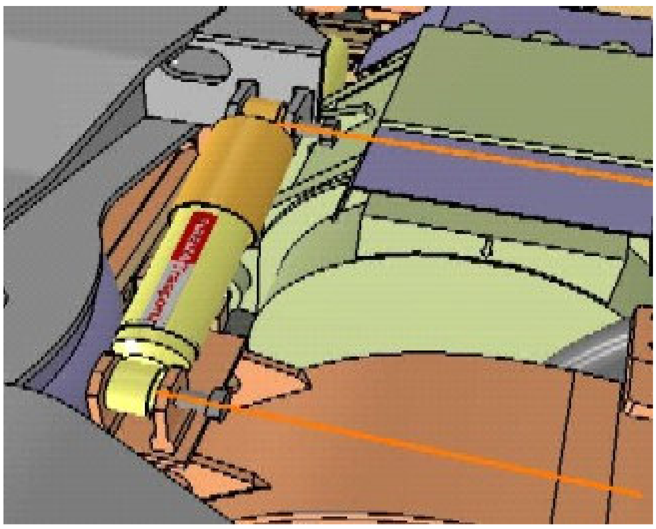
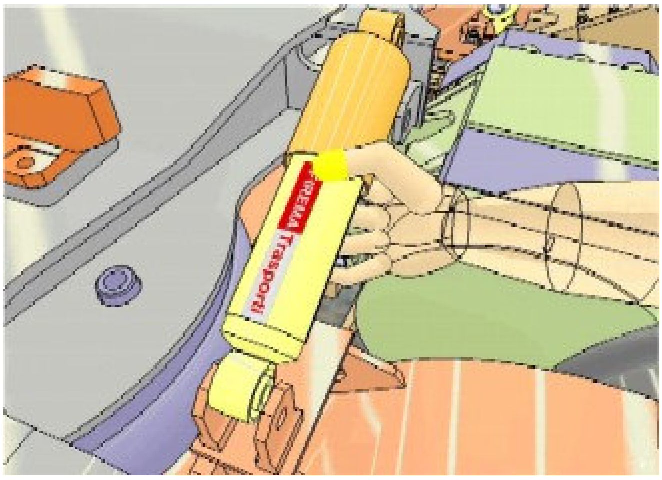


Figure 5.15: Removal of the screws in VirtualHand and in the Fitting Simulator of Catia



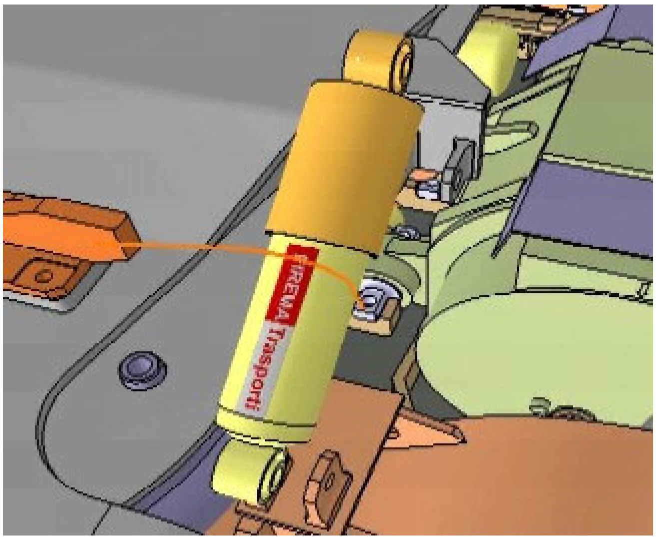


Figure 5.16: Removal of the suspension in VirtualHand and in the Fitting Simulator module of Catia

For the particular analyzed operation, the operator, using the Virtual Reality, is able to express about the possibility to carry out the disassembly and, therefore, to compile the maintenance chart (table 2) .

MAINTENANCE CHART		
INTERESTING INFORMATION	***TO COMPILE BY THE OPERATOR***	***TECHNICAL NOTES***
Examined assembly:	**Railway bogie**	

Examined operation:	Disassembly of the front cross suspension	
Type of maintenance operation:	• Corrective maintenance X • Preventive maintenance	
Outcome of the operation:	Verified Detachability, Manipulability and Accessibility	
Disassembly sequence:	a) Removal of the screws; b) Removal of the suspension	
Used equipment:	Ratchet spanner	
Required staff:	• Specialized X • Not specialized	
Number of required operators:	1	
Total time of operation:	5 min	

Table 5.2: Maintenance chart relative to the disassembly of the suspension

5.4.2 Disassembly of the brake system

Also in this case the study began verifying the availability of sufficient spaces for the access of the tool to the screws to remove. The approach of the spanner has been simulated in VirtualHand; in this environment has been estimated the ability of the operator in completing the operation and the presence of interferences between the virtual hand and the other objects present in the virtual environment (figure 17). To be sure that along the trajectory followed by the operator collisions were not present among the tool and other elements, the trace left from the barycentre of the tool was imposed to leave a trace, to follow in DMU Fitting Simulator module of Catia; in this environment, in fact, it is possible to have a visual and acoustic feedback of the collisions among the objects (figure 18).

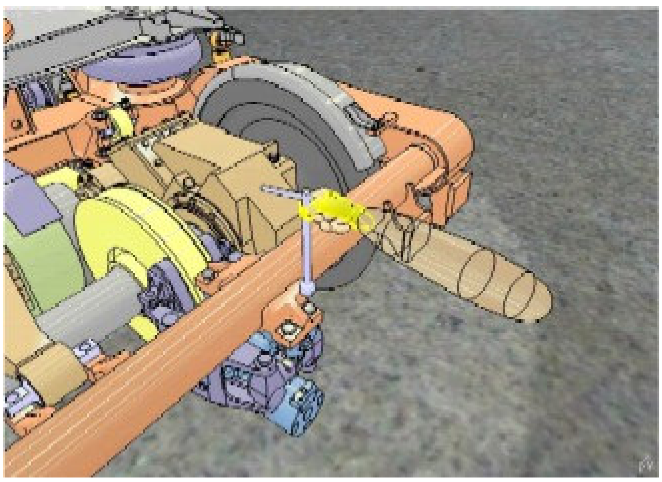


Figure 5.17: Approach of the tool in VirtuaHand

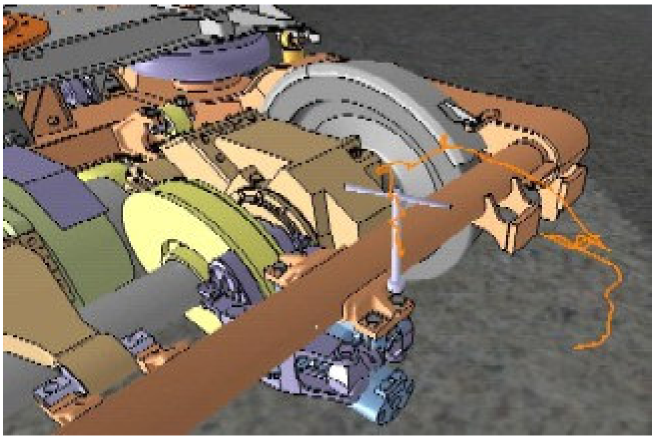


Figure 5.18: Approach of the tool in the DMU Fitting Simulator

Once verified the accessibility of the tool, the release of the screws has been simulated in order to assure the existence of adequate handling spaces. To simplify such operation, only one degree of freedom has been allowed to the spanner: the rotation around its axis. In figure 19 the constraints imposed between the components have been highlighted: 1) coaxial axes of the spanner and of the screw; 2) coincidence between the face of the tool and the surface of the support indicated in figure.

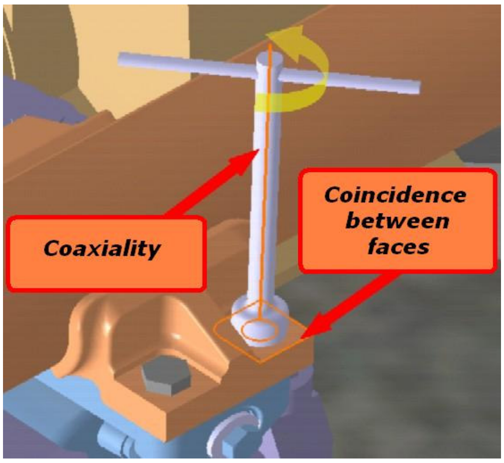
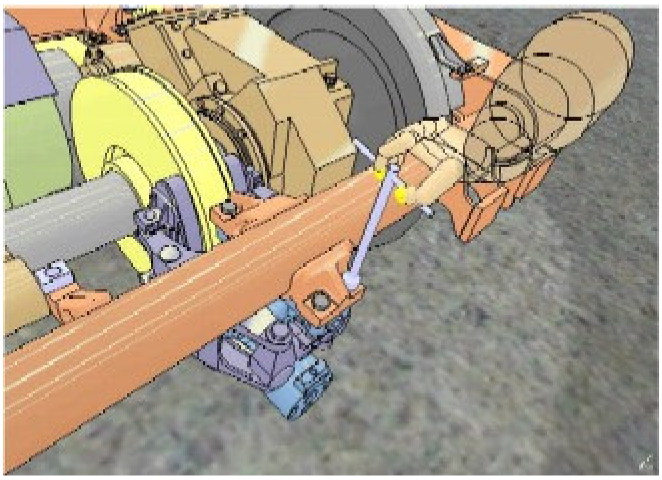


Figure 5.19: Constraints imposed for the release of the bolts

Figure 20 shows, the operation lead in VirtualHand and in the DMU Fitting Simulator (in this case, turning the tool just around its axis, the trace left by the barycentre is one point).



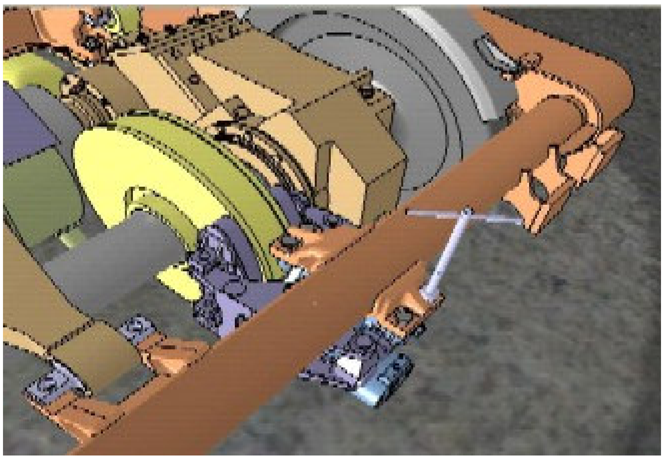


Figure 5.20: Release of the screws in VirtualHand and in the Fitting Simulator Module of Catia

Successively the possibility to extract the screws from their seat and to remove the brake system has been verified, without collision with the other objects. Screws have been bound to only move just along its axis and the brake system to translate in the plan evidenced in figure 21.

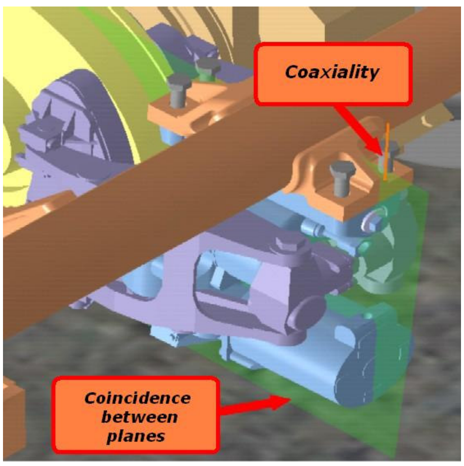


Figure 5.21: Constraints imposed for the removal of the screws and the brake system

Figures 22 and 23 show some phases of the simulations realized in VirtualHand environment and in the DMU Fitting Simulator module of Catia.

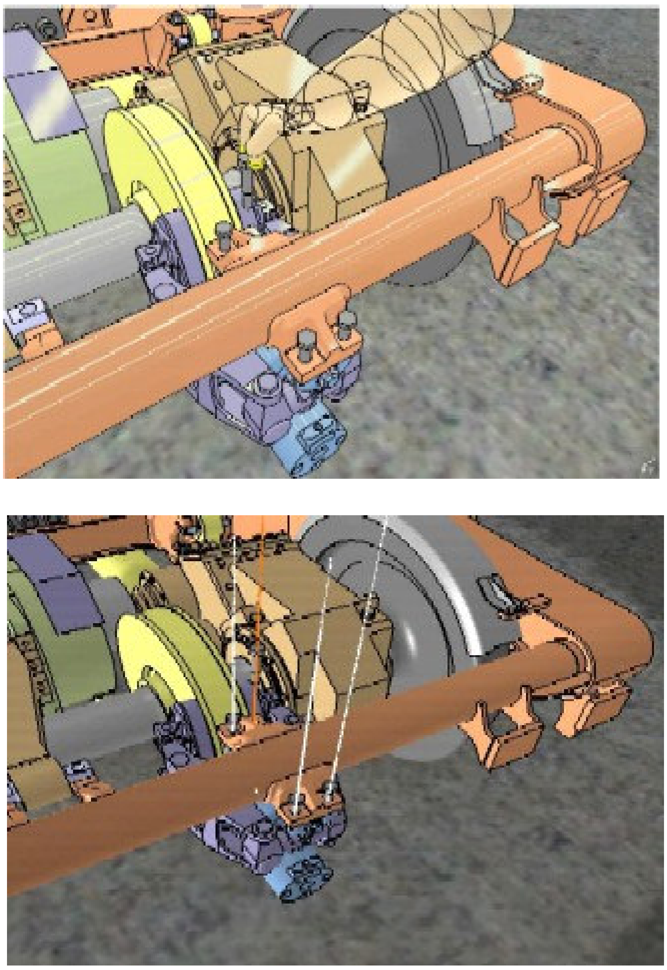


Figure 5.22: Removal of the screws, respectively in VirtualHand and in the Fitting Simulator of Catia

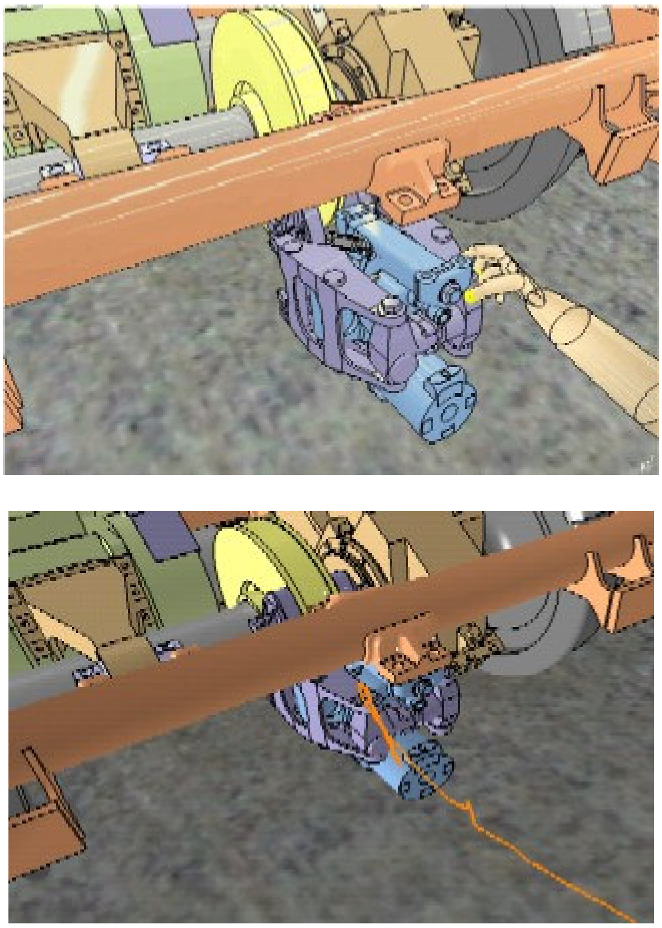


Figure 5.23: Removal of the brake system in VirtualHand and in the DMU Fitting Simulator module

5.4.3 Disassembly of a wheel cover

The wheel cover is easy accessible; for this reason, in maintainability analysis, greater attention has been dedicated to manipulability and detachability verifications. For the disassembly of the wheel cover various tests have been executed in virtual environment, which evidenced the difficulty, for the operator, to remove the component avoiding collisions or penetration with others parts of the assemblies. The various traces, generated by the movements of the object in VirtualHand, have been imported in the DMU Fitting Simulator module; these, activating the algorithm of collision detection, have revealed the presence of interferences and collisions between the objects. Being unable to express about the feasibility of the operation, the Automatic Path Calculation tool has been employed in order to verify the existence at least of one collision free path. Setting some parameters in opportune way, the software generated the trace shown in figure 24.

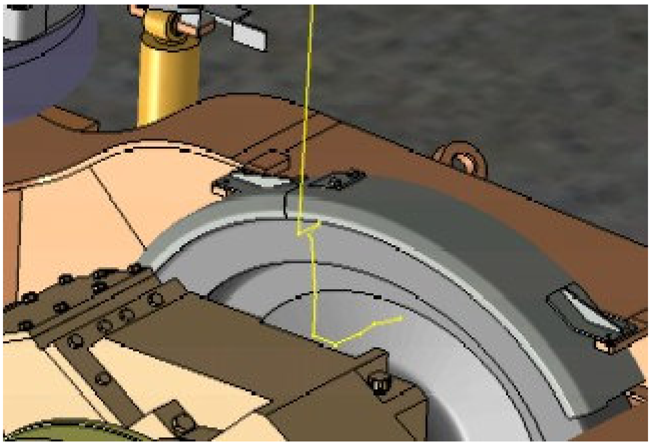


Figure 5.24: Trace obtained with the Automatic Path Calculation of the DMU Fitting Simulator of Catia

Once verified the presence of sufficient spaces for the manipulation of the component by the operator in the Virtual Hand and the existence at least of one collision free path in the DMU Fitting Simulator, it'is possible to conclude that the analyzed disassembly operation is executable and that it is possible to compile the maintenance chart. The proposed applications have demonstrated that the illustrated methodology results effective, even if sometimes complex. For this reason, the possibility to invert the already illustrated procedure has been considered, before calculating a collision free path and, then, verifying the possibility that the operator made the obtained trace visible in order to make the manipulated object to follow it.

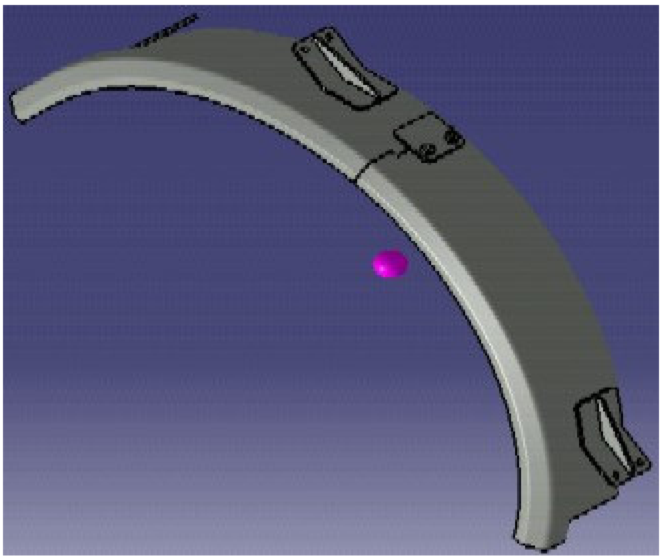


Figure 5.25: Barycentre of the wheel cover

For this purpose, the barycentre of the element to handle (figure 25) has been highlighted so that the operator could make it to slide along the visualized trace.

In figure 26 it is possible to see both the small sphere indicating the barycentre and the trace to follow.

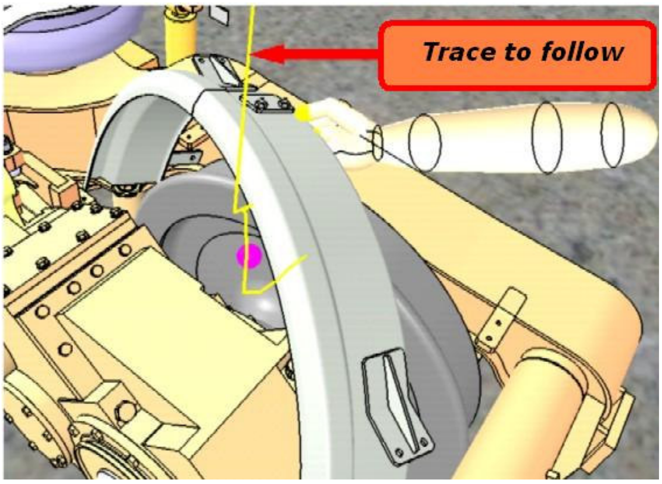


Figure 5.26: The operation executed in VirtualHand

In figure 27 the trace obtained by the operator during the simulation in virtual environment is shown in white color.

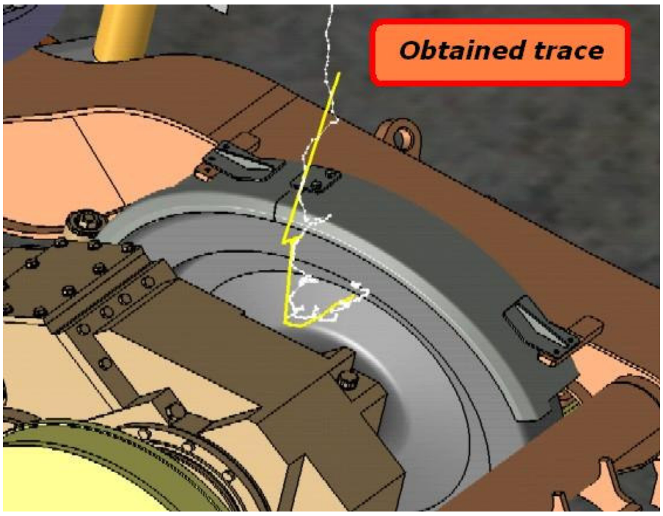


Figure 5.27: The obtained trace

Comparing now the two traces, the error made by the operator following the “guide path” in virtual environment has been evaluated. The comparison has been realized measuring the distance between the points obtained with the intersection of the traces with plans orthogonal (point by point) to the trace obtained by the automatic calculation. The comparison has been executed in the Shape FreeStyle module of Catia V5, using the Distance Analysis tool. This analysis, however, is executable between curves and not between traces, considered as separate entities. In order to solve such problem, interpolating parametric curves (6° degree) have been constructed, passing through some points of each trace (this operation has been lead in the Shape Automotive Class A module); the obtained result is shown in figure 28.

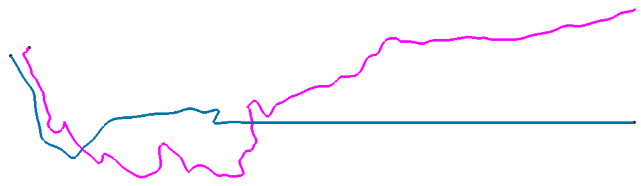


Figure 5.28: The interpolating curves obtained from the traces

Figure 29 shows the result of the distance analysis. On the Y axis it is possible to read the distance between the curves, according to the value of the curvilinear abscissa having origin in the beginning of the “guide trace”.

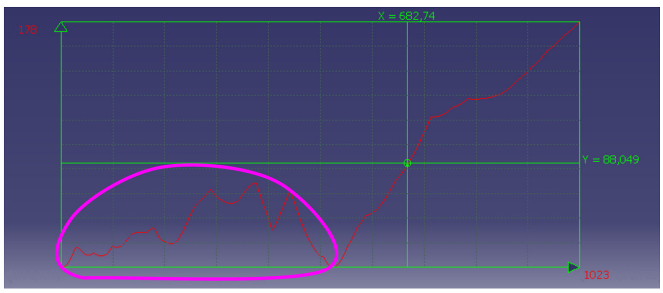


Figure 5.29: Distance analyses results

Figure 30 shows, in detail, the zone of figure 29 where the comparison is more important (in the remaining part, in fact, the operator, once extracted the component, goes away from the “guide trace”). The diagram evidences a maximum deviation between the two traces equal to 75.7 millimetres and a medium deviation equal to 29,3 millimetres.

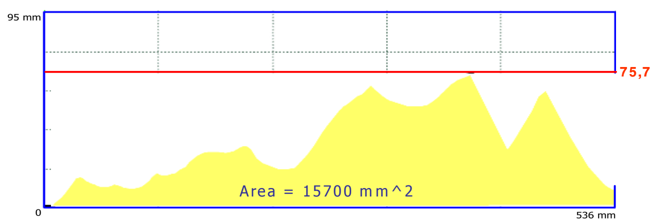


Figure 5.30: Error of the operator: maximum deviation = 75.7 mm; mean deviation = 15700/536 = 29.3 mm

These values result unacceptable when elements must be disassembled that compose an assemnly, in which they are present areas of movimentazione and you play very small. The last approach, therefore, has been thought not valid.

5.5 VR VIEWER APPROACH

5.5.1 Disassembly of the front cross suspension

Also in this case, the study regarded the verification of accessibility of the spanner to the head of the screws. Such operation revealed itself more immediate than the approach Catia - VirtualHand. In fact, the Viewer [DL1] implements a simulator of dynamics, which allows to estimate both the collisions between the hand and the objects and those between objects and objects. The operator, therefore, can estimate accessibility of the tools and the possibility to remove components, already in phase of manipulation, since the penetration among objects are cancelled by the reaction forces that happen in the moment of the contact. Moreover, at the VR Test and the VRLab of the CIRA, the implementation of an algorithm that allows to obtain a directional sound feedback of the collisions, by means of which the operator will be able to notice also eventual contacts that happen out of its field of view (e.g. contacts between elbow and objects). For the verification of removing the screws and the suspension, the creation of some dynamic joints between screws and bogie and between suspension and screws has been necessary. Since, in fact, only the right hand is available in the virtual environment, the disassembly of the screws would have involved, in absence of dynamic joint, the fall of the suspension on the bogie under the effect of the gravity. Figure 31 shows, for example, the axes of the joints constructed between suspension and bogie.
The dynamic joints, created ad hoc, allows the screws to slide along the axis until a distance, beyond which the joint is broken off and the screw is free to move inside the space.

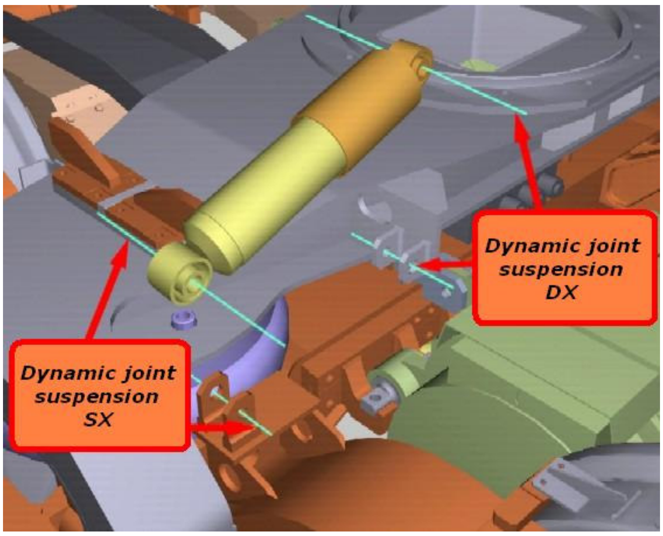
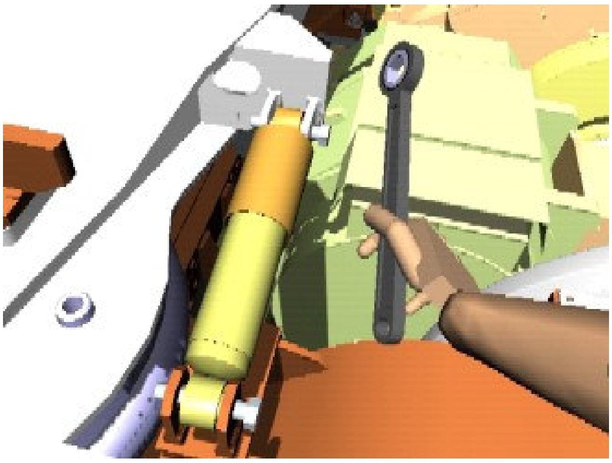


Figure 5.31: Dynamic joints between suspension and bogie

For the suspension, instead, a light forcing by the operator causes the immediate breach of the dynamic joint. Also in this case the suspension, as a result of the breach of the joint, is free to move inside the scene. Figure VI.32 shows a phase of the approach of the tool and a phase of the removal of the suspension.



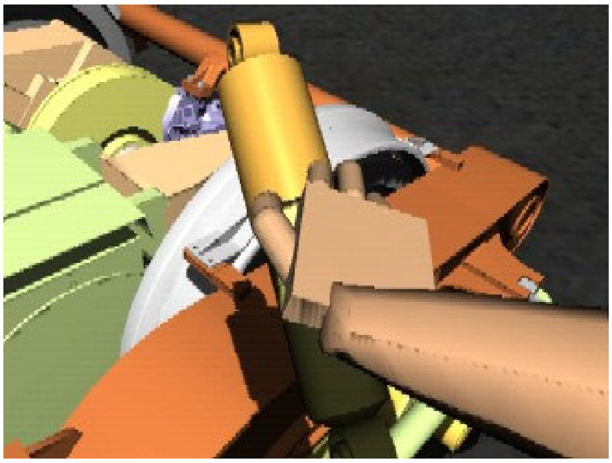


Figure 5.32: Approach of the tool and removal of the suspension in the VR Viewer

For the analyzed operation, the operator, using the instrument of the Virtual Reality, is able to express about the possibility to carry out the disassembly and, therefore, to compile the maintenance chart. In this case, the conclusions of the analysis realized with the Viewer are coincident with those obtained by means of the Catia - Virtual Hand approach.

5.5.2 Disassembly of the brake system

Once again, the study is begun with verifying that the spaces available were really sufficient, so that the operator could bring the T spanner near the screws to remove. Also in such case, the operation has resulted more immediate than the Catia - VirtualHand approach, thanks to the presence of the dynamic behaviour simulator and to the presence of the shadows. Subsequently the possibility to extract the screws and to remove the brake system from their seat has been verified, without collide with the other present objects.

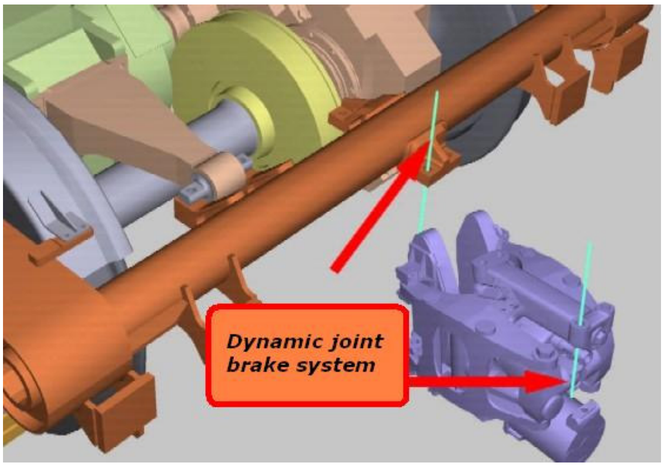


Figure 5.33: Dynamic joints between brake system and bogie

Like for the removal of the suspension, to verify the removal of the screws and the brake the creation of dynamic joints between screws and bogie, and between brake and bogie has been necessary. Since, as said before, in the virtual environment only the right hand is available, the removal of the screws would have cauesd, in absence of dynamic joints, the fall of the brake for effect of the gravity. Regarding to the screws, created dynamic joints allow them to translate along the axis until a determinate distance, beyond which the joint is broken off and the screw is free to move inside the space. Regarding the brake, instead, a light forcing by the operator causes the immediate breach of the dynamic joint (the two components are moved beyond the snap-distance). Also in this case the brake, as a result of the breach of the joint, is free to move inside the scene (figure 33). Figure 34 shows one phase of the removal of the braking system with the VR Viewer.

Figure 5.34: Removal of the brake system in the VR Viewer

For the analyzed operation, the operator is able to express about the feasibility of disassembly operation and, therefore, to compile the maintenance chart (also in this case the conclusions coincide with those obtained by means of the Catia-VirtualHand approach).

5.5.3 Disassembly of a wheel cover

During the disassembly of the wheel cover, because of the several points of collision with the other objects present in the scene, the simulation results strongly compromised. The repulsion forces, that are generated in correspondence of the contact areas and that avoid the penetration of the objects, are responsible of the anomalous behaviour of the component. In fact, during the handling, the wheel cover is submitted to the action of several forces agent in various directions that prevent the operator from controlling with precision the movements and the spins of the component. In this case the operator, with the VR Viewer is not able to compile the maintenance chart.

5.6 VIRTUAL DESIGN 2 APPROACH

5.6.1 Disassembly of the front cross suspension

The preliminary phase of the study has been focused on the analysis of accessibility of the suspension. In particular, it has been verified the presence of areas of access sufficient to allow the operator to bring the ratchet spanner near the the head of the screws. In the first instance the user activate in the 2D interactive menu the event of grasping of the tool, carrying it in correspondence of the parts to disassembly. The operation of approach of the tool has been simulated in VD2 [V2] and the ability of the operator has been estimated in completing the necessary movements to the disassembly, as well as the presence of interferences between the virtual hand and the other objects present in the scene. Thanks to the algorithm of collision detection implemented in VD2 and to the characteristics of visual feedback for the collisions defined in the Assembly Simulation, the feasibility of the approach of the virtual hand equipped with the tool for the disassembly of the screws has been demonstrated in simulation (figure 35).

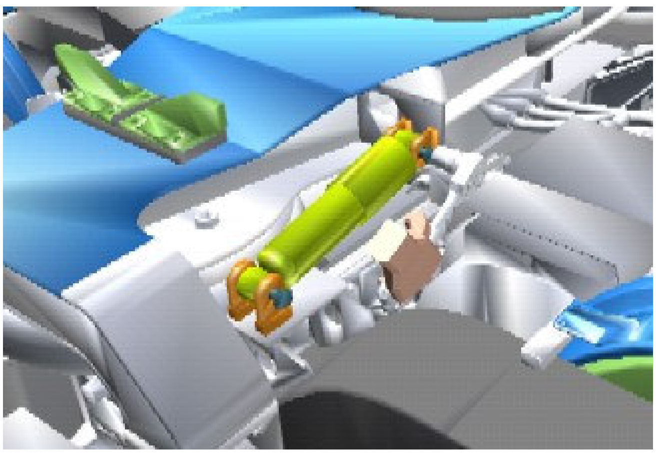


Figure 5.35: Accessibility test of the hand provided with the tool for removing the suspension screws

Once verified the accessibility of the tool, it the operation of release of the screws has been simulated in order to verify the presence of a sufficient space volume for the handling of the ratchet spanner. In order to increase the realism of the simulation and to guarantee a correct alignment of the axis of the hexagonal head of the tool and the axis of the screws, a dynamic joint has been defined in the Rotation Snapping section of VD2 ASM module (figure 36). After activated the snapping, the possibility to visualize the angle of spin of tool and screw, correctly positioned for the release, allows to estimate, also quantitatively, the space available for the operation.

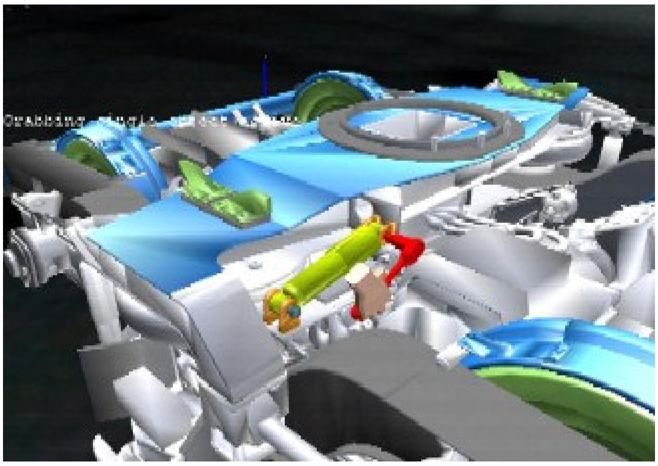


Figure 5.36: Rotation Snapping for the removal of the suspension screws

Subsequently it has been verified the possibility to extract from their seats the screws previously locked and to remove the suspension, taking care to estimate the absence of penetrations or interferences with other present objects. For simplicity the screws have been bound to move just along their axis and the suspension to move only in parallel with the vertical axis. For the definition of constraints it has been necessary to define static the objects interested. In this way the collision activates the possibility to move the parts along the permitted directions in a intuitive and completely natural way. Figures 37 and 38 show, respectively, the removal of the screws and of the suspension, according to the imposed constraints.

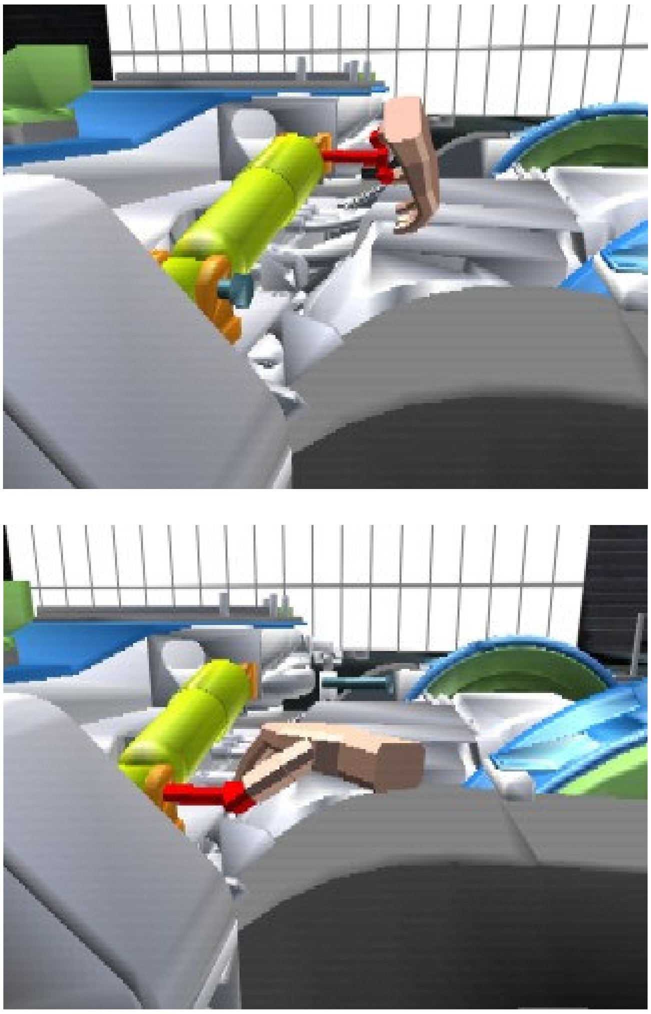


Figure 5.37: Simulation of the removal of suspension screws

Figure 5.38: Simulation of the removal of the suspension

For the corrective maintenance operation of removal of the front cross suspension, simulation in Virtual Reality allows the operator to obtain all the necessary information for the compilation of the maintenance chart, formulating a positive judgment for the feasibility of the entire operation. In particular it has been possible to verify accessibility, detachability (according to the disassembly tree) and manipulability of the analyzed components. The simulation has not been conducted by specialized staff and for the entire maintenance operation on the front cross suspension the employment of only one operator is sufficient, as well as the use of the only ratchet spanner. The mean total time for completing is about four minutes. The conclusions, therefore, are analogous to those obtained with the Catia Virtual Hand approach.

5.6.2 Disassembly of the brake system

Figure 39 shows the brake system of the front axle of the examined railway bogie, during the analyses simulated in VD2.

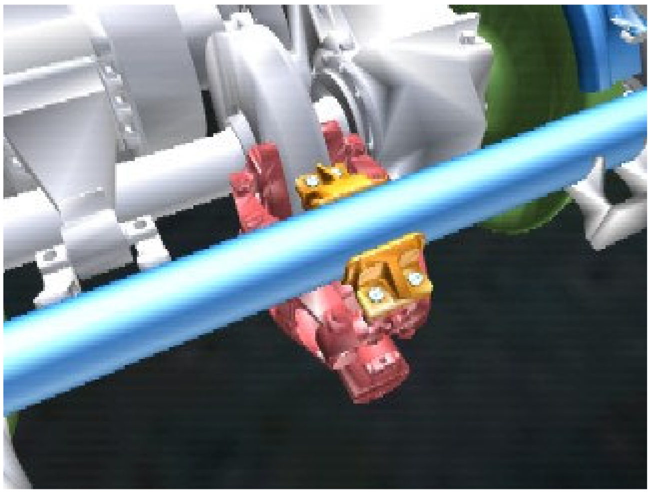


Figure 5.39: Brake system of the bogie front axle

Once again the first verification interested the accessibility of the hand of the operator and the tool to the screws to remove. Once verified the accessibility of the tool, the release of the screws has been simulated in order to verify the existence of adequate working spaces. Figure 40 shows the more critical disassembly condition found during the simulation, relative to the release of the screws of the posterior part. As in the previous case, a Rotation Snapping has been imposed between spanner and screws in order to place correctly tool and component along a common axis and, therefore, to visualize the angle of spin useful for the unscrewing.

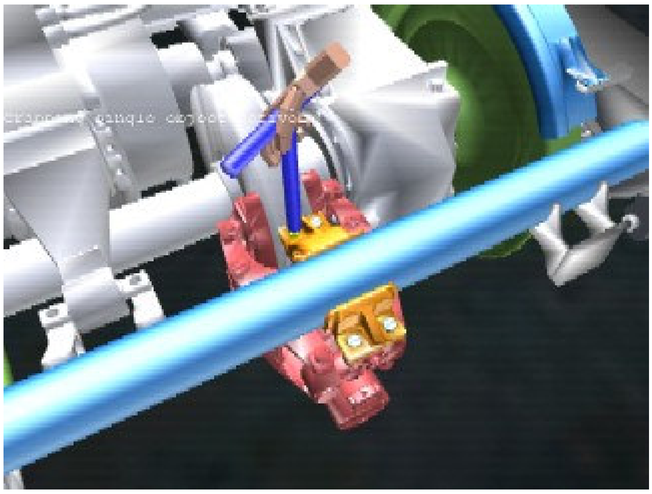


Figure 5.40: Accessibility test and release of the brake system screws

Moreover, the possibility to extract the screws from their seat has been verified and to remove the brake system estimating the absence of collisions with other objects (figure 41). Once again the screws have been bound to move only along their axis.

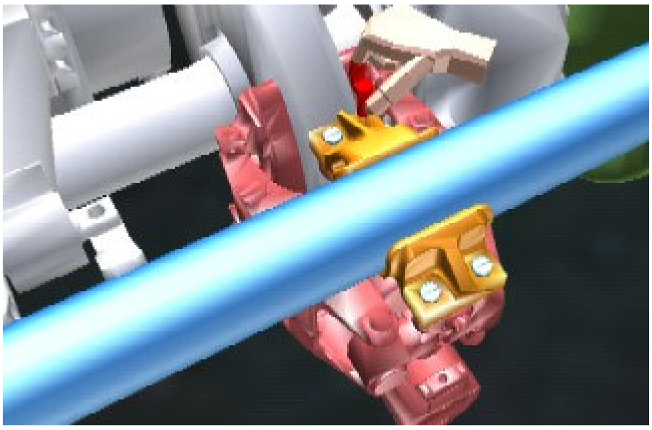


Figure 5.41: Simulation of the removal of the suspension screws according to imposed constraints

The procedure has been reiterated for all the four screws, according to the program of the maintenance activities. Subsequently figure 42 the removing of the two brake system supports has been completed, defined as grabbable for being free handled, loyally to the virtual hand, once happened the collision with the palm. The grasping event can be activated directly from the 2D interactive menu of VD2 by means of the flystick. During the simulation it has been possible to execute the removal of the supports without penetration or interferences with other objects. The operation finished with the removal of the braking system of the bogie, defined glideable in the ASM module (figure 43).

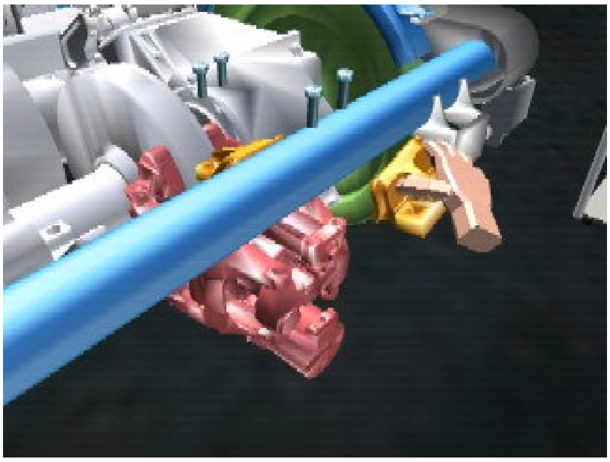


Figure 5.42: Removal of one support of the brake system

In spite of the calculation heaviness for the elaboration of the data, that allowed to increase the realism of the simulation, guaranteeing to the component to not penetrate the brake pulley, but to slide on it.

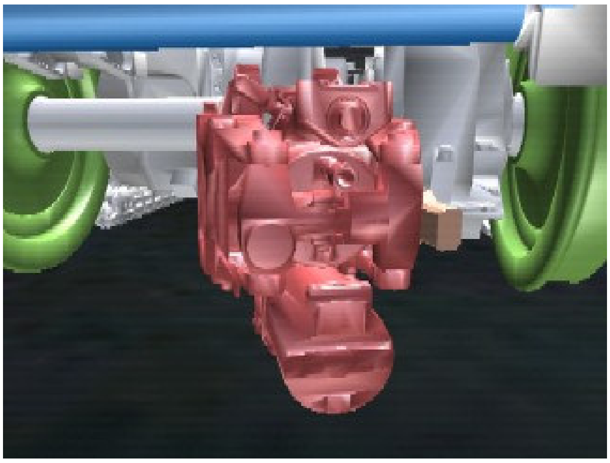


Figure 5.43: Simulation of the removal of the brake system

The pavement of the workshop has been previously made interactive, in order to estimate, during the simulation, the possibility to extract the brake system directly with the bogie on the railroad, in absence of collisions with the ground. Also this verification had positive result. For the corrective maintenance operation of removal of the brake system of the bogie front axle, the simulation in Virtual Reality allows the operator to collect all the necessary information for the compilation of the maintenance chart, formulating a positive judgment about the feasibility of the entire maintenance activity. In particular, it has been possible to verify accessibility, detachability according to the disassembly tree and the manipulability of the analyzed components. The simulation has not been conducted by specialized staff and for the entire operation of maintenance on the front cross suspension the employment of two operators is sufficient, according to actual norms, because of the weight and the dimensions of the brake system, as well as the use of the only T spanner. The total time of activity is about eight minutes. Also in this case the conclusions have been analogous to those obtained with the Catia - Virtual Hand approach.

5.6.3 Disassembly of a wheel cover

Analyzing the component the facility of access appears evident, so the maintainability analysis has been focused on the verifications of manipulability and detachability. About the disassembly of the wheel cover, it is bound to the chassis by means of bolts: therefore, it is necessary the use of an appropriate spanner. However, as previously said, the available volumes of access are sufficiently wide, then an analysis of the spaces necessary to the removal of the connection organs results less meaningful. Instead, once executed various tests in virtual environment, the difficulty emerged, by the operator, to carry out of the removal avoiding collisions or penetrations with others parts of the component. Two different modalities of approach have been used in this case: in the first instance the component has been made grabbable and the disassembly has been simulated tracing an assembly path, estimating subsequently the depth of penetration (figure 44); alternatively, the object has been made static and the constraints for its movement have been defined, allowing the only degree of freedom of translation along the horizontal axis (figure 45).

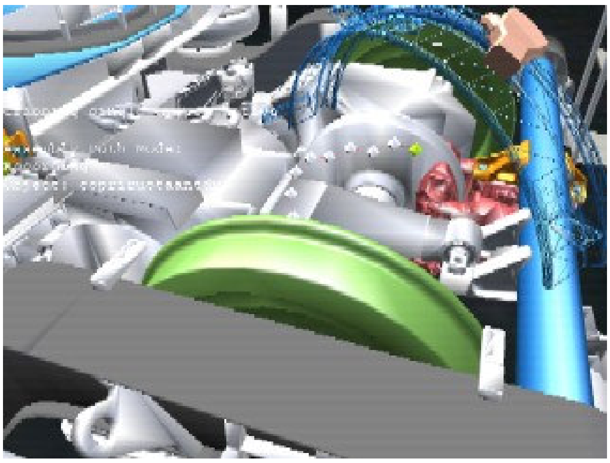


Figure 5.44: Registered disassembly trajectory of the wheel cover

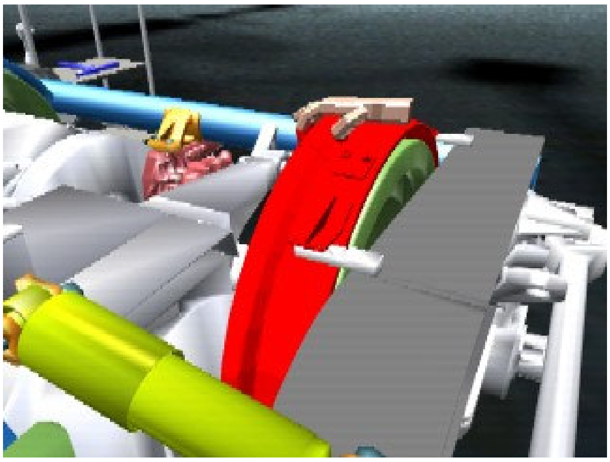


Figure 5.45: Removal of the wheel cover according to imposed constraints

In both cases the verification of accessibility had positive result, thanks to the presence of sufficient spaces for the manipulation of the component by the operator. About the identifying of an operative disassembly trajectory, without penetration or interferences with the other objects, the information obtained in both cases of simulation have not been sufficient to establish the feasibility of the operation. According the first approach, in fact, the depth of penetration exceeds the allowed tolerances. In the second case, instead, the component has been constrained, allowing only simple degrees of freedom of translation, but the executed tests have involved many collisions with adjacent objects. That demonstrates that the possibility to verify the detachability of a part from a complex assembly, in presence of minimums clearance with the adjacent ones, is still difficult to carry out in simulation and constitutes undoubtedly objective of future development. VD2, in fact, still does not provide the possibility to identify automatically a collision free trajectory, as instead other software do, such as DMU Fitting Simulator of the Dassaults Systems. Moreover, it is not possible to insert boundary conditions that allow the movement of the disassembled part along an arbitrary trajectory.

After all, the analysis conducted in VD2, for the removal of the front wheel cover of the bogie, had negative outcome about the verification of detachability of the component. However, the information obtained with the simulation constitute an optimal starting point in order to implement design modifications apt to guarantee the maintainability of the component, in particular acting on the support and blocking devices of the wheel cover on the chassis.

5.7 COMPARISON

A comparison between the various approaches can be realized according to two fundamental aspects: facility of realization of the simulation; use of the software by experts of maintenance but not of VR technologies.

Regarding the first point it is necessary to notice that Catia and VD2, since have an intuitive graphical interface, simplify remarkably the phase of simulation preparation. The Viewer, instead, does not present a graphical interface, therefore the realization of the simulation needs, by the user, the knowledge of the programming language of the software. This substantial difference has an important weight on the execution of all the operations to execute in order to realize the simulation; an example is the positioning of the element to examine respect to the assembly and to the commands necessary to the corrected handling of the same in virtual environment. That demands the imposition of opportune constraints among the parts. Such operation results simple and immediate either in Catia or in VD2, while in the VR Viewer the creation of dynamic joints between the components needs the knowledge of specific commands. An other difference among the software regards the possibility to execute the virtual simulation in the same environment in which the design of the assembly takes place. Catia allows to manage all the devices necessary to the creation of a virtual environment. For using both VD2 or the VR Viewer is necessary, instead, to use opportune protocols of data exchange. Catia, therefore, allows to bring modifications to the design in the same environment in which the maintenance operations are executed and to estimate in immediate way the effects of such modifications.

Regarding the second point previously listed, a series of factors that influence the facility of use of the software by the operator must be considered. Particular importance has the factor “realism”, since it influences remarkably the number and the quality of the information that are possible to obtain by the simulated environment. The determinant aspects of a simulation in virtual environment are essentially the visual realism and the interaction realism. In order to increase the visual realism, shadows play certainly a decisive role. In particular, the shadows have a fundamental importance since they favour the perception of the spatial relations among the objects of the scene, such as, for example, the position of the virtual model of the hand, controlled by means of a glove provided with sensors, respect to the objects of the environment.

In order to achieve a greater realism in the interaction, instead, it is necessary to model correctly physics behaviour, making the objects of the virtual environment to react in a way completely similar to one in real world, either in the direct interaction, or in that deriving from the transmission of the forces through hits and fixed cinematic chains. About such aspects, the VR Viewer allows sure to obtain more realistic simulations; it is in fact possible to add shadows to the visualized scene, to simulate the behaviour of virtual objects according to the laws of classic physics and to determine the collisions among the objects thanks to a dynamics simulation motor of and a collision detection system. Moreover, the grasp and the manipulation of the objects happen thanks to the presence of an algorithm for the simulation of friction forces between virtual hand and grabbed objects.

In VD2 and Catia, instead, the lack of the shadows obstructs the perception, by the operator, of the spatial relations among the objects of the scene and the virtual hand. Moreover, such software does not provide an algorithm for the simulation of dynamics of rigid bodies and, therefore, for the realistic manipulation of the objects present in the scene. These differences allow the simulation of an operation in the VR Viewer to be realized in shorter times and to allow the operator to give answers characterized by greater objectivity, about the characteristics of accessibility, manipulability and detachability of a component.

Unlike the VR Viewer and Catia, VD2 is a specific software for the VR, and owns a module dedicated to the assembly/disassembly analyses. The functionalities of such module have been revealed remarkably useful during the simulations and have allowed to estimate the various aspects of the maintenance activities. Moreover, VD2 is an open source and developable software. Such considerations bring to consider the approach based on VD2 that probably more promising, among the three, for the analyses of maintainability in VR, even if ulterior developments and improvements are needed. In fact, the conducted preliminary study allowed to highlight new research topics regarding the possibility to implement ulterior grabbing conditions of the virtual objects, in order to increase the realism of the simulation, being reproduced the assumed natural posture from the falangi of the virtual hand in the manipulation of the objects. Evidently also the possibility to introduce a virtual reproduction of the wrist, the forearm and the arm of the operator, represents an important objective, in order to increase the sense of presence inside the scene and to provide more precise and concrete answers to the verifications of maintainability in Virtual Reality. Moreover, the results obtained by the simulation of the disassembly of the front wheel cover of the railway bogie evidenced the concrete difficulty to validate with Virtual Design 2, inside a complex assembly, the detachability of components in presence of small clearance respect of the adjacent parts. It would result interesting to provide the software with added algorithms for the automatic calculation of operating collision free trajectories of disassembly of a component, to use in the case of evident impossibility to obtain, with the simulation, an assembly path free from collisions with other virtual objects. That would allow to establish the feasibility of the maintenance activity on the analyzed component, at least from a theoretical point of view, while the simulation could be oriented to the attempt of the operator to reproduce the previously calculated trajectory. The limit is due to the input 3D devices for the navigation and the manipulation: for this reason the possibility to impose cinematic constraints, allowing the operator to follow precisely the operating collision free trajectory, would represent an important potentiality for Virtual Design 2, also in the optical of automating the maintenance process, giving to a robotic mechanism the motion for each component. At last, the introduction of effects of shadow on the cases of virtual maintainability, would increase not only the realism of the scene, but it would make simpler and more intuitive the evaluation of distances and volumes of access among virtual hand, tools and objects.

5.8 CONCLUSIONS

This work has demonstrated the important potentialities offered from the employment of technologies of Virtual Reality for verifications of maintainability, in industrial field, on any type of assembly. The obtained results not only provide a valid answer and concrete to the design problems regarding assembly-disassembly and maintenance activities, but they make objective the effective applicability of the proposed methodologies. In spite of the subjective character of the approach to the simulation, based on the direct manual interaction, the

information collected in the case study allow therefore to establish the feasibility of a maintenance or to indicate, in an intuitive and direct way, the design parameters on which to work in order to make possible an activity. To every design digital modification, a new phase of simulation follows, in order to verify the effective correspondence of maintainability requirements.
Moreover, the employment of not specialized staff increases the complexity of the simulation, since the ability and the baggage of competences of the expert operator, executing the maintenance activity, are ignored. However, the simulation environment, constructed in the design phase, results of particular importance also for the successive phases of virtual training for the training of the staff assigned to the maintenance.
Differently, the methodological approach based on the employment of digital human models or virtual manikins gives a more objective and general character to the results of the simulation, as it has been demonstrated with the employment of EDIVE methodology. In this case, not only the repeatability of the simulation is taken in account, reproducing the anthropometric characteristics of different percentiles of the sampled population, but it is possible to estimate also the ergonomic aspects of the posture regarding every maintenance operation conducted in virtual. In order to overcome the limits found in the two described approaches (virtual manikin and direct manual interaction) with the aim to value their advantages, several researches are currently active at the University of Naples Federico II, in order to estimate the possibility to handle the virtual manikins directly tracing the movements of a human on which some sensors have been placed in opportune positions.

5.9 REFERENCES

[AB1] Abshire K.J., Barron M.K., “Virtual Mainteinance: Real World Application within Virtual Environments”, Proc. of Realiability and Maintainability Symposium, Ohio, 1998.

[AD1] Avallone L., Di Gironimo G., Monacelli G., Patalano S., “Use of Digital Mock-Up for Automotive Assembly Design”, Proc. of ISCS 2001, Napoli, 6-7 december 2001.

[AD2] Avallone, L., Di Gironimo, G., Monacelli, G., Patalano, S., “Use of digital mock up for automotive assembly design”, Proc. of ISCS 2001, Napoli, 6-7 december 2001.

[AF1] Amendola A.M., Fusaropoli P., “Evoluzione delle specifiche RAM e riflessi sulla gestione del Materiale Rotabile nelle fasi di sviluppo ed esercizio”; Giornate di studio su “Risparmiare sui trasporti: si può?”-Napoli 23-24 febbraio 1995.

[AV1] AA.VV., “Laboratorio di Realtà Virtuale del CIRA”, http://www.cira.it/html/italiano/laboratori/.

[B1] Baldin A., “Gli impianti industriali: la manutenzione e il rinnovo”, Enciclopedia di direzione ed organizzazione aziendale, Franco Angeli Editore, 1983.

[BF1] Baldin A., Furlanetto L., Roversi A., Turco F., “Manuale della manutenzione degli impianti industriali”, a cura di A. Roversi, Franco Angeli Editore, 1988.

[BM1] Beasley D., Martin R.R., “Disassembly Sequences for Objects Built from Unit Cube”, Computer-Aided Design, vol.25, n.12, 1993.

[CA1] Chaffin, D.B., G.B.J. Andersson and B.J. Martin., “Occupational Biomechanics” (3rd Edition), J. Wiley & Sons, New York, NY 1999.

[CD1] Caputo F., Di Gironimo G., Patalano S., Biondi A., Maione R., Liotti F., “Use of Ergonomic Software in Virtual Environment for the Prevention of Muscular-skeletal Diseases”, Proc. of ISCS 2001, Napoli, December 6-7, 2001.

[CD2] Caputo F., Di Gironimo G., Monacelli G., Sessa F.. “The Design of a Virtual Environment for Ergonomics Studies”, Proceedings of XII ADM International Conference, Rimini, Italy, 2001, CD – Proceedings.

[CG1] Cozzolino, G., Gerbino, S., Lanzotti, A., Patalano, S., “Progettazione per la manutenibilità di un carrello di atterraggio mediante sistemi CAD”, Actas de XI Congreso Internacional de Ingeniería Gráfica – Universidad Publica de Navarra – Universidad de la Rioja, España, vol. IV, 2-4 de Junio, 1999.

[CO1] Colombini D., Occhipinti, E., Cairoli, S., Baracco, A. “Proposta e validazione preliminare di una check-list per la stima dell'esposizione lavorativa a movimenti e sforzi ripetuti degli arti superiori”, Med. lav., 2000, 91, 5, 470-485.

[D1] Di Gironimo G., “Studio e sviluppo di metodologie di progettazione ergonomica in ambiente virtuale”, Tesi di Dottorato di Ricerca in Progettazione e Costruzione Meccanica, Università degli Studi di Napoli Federico II, Napoli, Novembre 2002.

[DL1] Di Gironimo G., Leoncini P., Realistic Interaction for Maintainability Tests in Virtual Reality, Proceedings of Virtual Concept 2005, Biarritz, France, November 8th – November 10th, 2005.bshire K.J., Barron M.K.Virtual Mainteinance: Real World Application within Virtual Environments. Proc. of Realiability and Maintainability Symposium, Ohio, 1998.

[DM1] Di Gironimo G., Monacelli G., Patalano S., “A Design Methodology for Maintainability of Automotive Components in Virtual Environment”, in Proc. of Design 2004 8th International Design Conference, vol. 2, pp. 723-734, Dubrovnik, Croatia, May 18-21, 2004.

[DM2] Di Gironimo G., Monacelli G., Martorelli M., Vaudo G., “Use of Virtual Mock-Up for Ergonomic Design”, Proc. of 7th International Conference on “The role of experimentation in the automotive product development process” – ATA 2001, Florence IT, 2001, CD - Proceedings.

[DP1] Di Gironimo G., Patalano S., Liotti F., “A New Approach to the Evaluation of the Risk due to Manual Material Handling through Digital Human Modelling”, Proc. of ISCS 2003, Cefalù , November 29-30, 2003.

[DP2] Di Gironimo G., Patalano S., Liotti F., Conserva U., Paruccini E., “Valutazione comparativa del rischio da movimentazione manuale dei carichi mediante protocolli di analisi e l’impiego di modelli umani digitali”, Giornale

Italiano di Medicina del Lavoro ed Ergonomia, Volume XXVII, N. 1, Gennaio-Marzo 2005, Issn 0391-9889, pagg. 124-128.

[ED1] Engineering Design Handbook, "Maintainability guide for Design", 1967.

[MD1] Monti A., Diversi D., Fusaropoli P., Palazzini C., "Presente e futuro della manutenzione del Materiale Rotabile delle ferrovie dello stato", Giornata A.I.MAN. "Manutenzione e Trasporti"-Facoltà di ingegneria-università di Bologna, 28 febbraio 1996. Sito web http://www.areatrasporti.it

[H1] Hubka, V., "Scienza della progettazione", Masson Editoriale ESA, 1994, pp.23-56.

[IT1] Ivory, C.J., Thwaites, A., Vaughan, R., "Design for Maintainability: the Innovation Process in Long Term Engineering Projects", Proc. of the Conference "The Future of Innovation Studies", Eindhoven, Netherlands, September 2001.

[LP1] Lanzotti A., Patalano S., "Generazione e gestione di famiglie di componenti su sistema CAD parametrico", Pixel, n. 9, pp. 5-9, 1996.

[LS1] Liang J., Shaw C. and Green M. On temporal-spatial realism in the virtual reality environment. In proceedings of the ACM Symposium on User Interface Software and Technology, pp. 19-25, 1991.

[OH1] Oliver H.J., Huang H.T., "Automated Path Planning for Integrated Assembly Design", Computer-Aided Design, vol.26, n.6, 1994.

[P1] Poupyrev I., et al, "Go-Go Interaction Technique: Non - Linear Mapping for Direct Manipulation in VR". In ACM UIST'96, pp. 79-80, 1996.

[RH1] Rezzonico S., Huang Z., Boulic R., Magnenat Thalmann N. and Thalmann D. Consistent Grasping Interactions with Virtual Actors Based on the Multi-sensor Hand Model. In Virtual Environments '95, Springer, Wien, 107-118, 1995.

[S1] Serger, J. K., "Reliability Investment and Life-Cicle Cost", IEEE Transaction on Reliability, 32, 1983, pp 259-263.

[V1] VirtualHand® for CATIA V5, Immersion Corp. (www.immersion.com/3d/products/virtualhand_for_v5.php).

[V2] vrcom GmbH: web site - http://www.vrcom.de

[WR1] Ware, C. and Rose, J. Rotating virtual objects with real handles. In ACM Transactions on CHI, 6(2): 162-180,1999

CHAPTER 6

DESIGN REVIEW

6.1 INTRODUCTION

As said before, Virtual Reality is knowing at present a large diffusion in any field of product design. Whilst it has viewed its wider development in automotive and aeronautic industries thanks to the considerable investment available for research, now other companies involved in transportation sector and characterized by a traditional methodology of design are approaching to the use of such new techniques and technologies. Design in Railway industries is mostly carried on with CAD systems in the typical desktop configuration. If this approach already represents a good step forward respect to the traditional way of representing the project by means of bi-dimensional tables, it does not offer yet the possibility to view in exhaustive and complete shape all phases of design.
In particular, this chapter will describe a methodology developed for supporting the design phase of a new train concept systems and its effective application to design review sessions of an important Italian railway company.
The well-known advantages of VR include the possibility to substitute the physical mock-up of a product concept with the models obtained by means of virtual prototyping; thanks to the progress of technologies it's also possible to have the model in 1:1 scale of a large dimensions product such as a transport vehicle. Moreover, simulation is not limited to the simple visualization, but gives the designer the possibility to have an immersive experience, "living" the product before it's really realized. Virtual prototyping allows to validate not only much more alternatives of a product but also of processes.
The research activity follows the results already reached in the same field with the approach of Virtual Reality in the styling decisions [1] and in the virtual simulation of maintainability activities for maintenance operations verifications [2]. The evolution of a complete VR architecture developed for carrying on maintainability tests and manufacturing systems simulations [3] brought to the introduction of new tools and features for the set-up and the execution of session dedicated to the evaluation end the correction of service installations, provided on the current release of a train project.
Respect to other not immersive systems, VR allows to analyze maintenance operations in faster and more reliable way carrying on them directly in the simulated environment: therefore, it's possible to highlight immediately design lacks due, for example, to visibility problems or disassembly difficulties, allowing to concentrate successively the study on the critical operations by means more complex instruments such as Human Modelling tools.
The new instrument offered in this activity is dedicated to the "Design Review" of a project: one of the tool, for example, allows to point out the critical points with opportune virtual markers, which can be saved and loaded successively,

overlapping to a new release of the system. Moreover, the possibility to involve a great number of persons, not only designer but also personnel assigned to the real maintenance, makes them to share the experience with staff of other company sectors according to the Concurrent Engineering.

6.2 THE VIRTUAL ENVIRONMENT

The described activity has been lead in the complete virtual environment [3] created at the VR laboratory of the Competence Center for the Qualification of Transportation Systems founded by Campania Region, named VR Test. The simulation manager is represented by the Virtual Design 2 software, by vrcom, able to manage all hardware and software advanced devices present in the laboratory. The availability of the API offers an open system environment for customizing the functionalities and increment the features of the software with applications which integrate themselves perfectly with the base framework.
The kernel of VD2 consists of three modules: the Rendering kernel, based on the OpenGL graphic libraries, explores the current scene-graph and present the virtual scene according to the point of view of the observer. The Interaction Manager manages the behaviour of the virtual environment according to the interaction of the user with some elements of the scene: a VE, in fact, is composed by a static part, which is not possible to interact with, and a dynamic part, able to react to events generated by the user or other virtual object; the behaviour of this part can be programmed by means of a configuration script according to the input-event-action paradigm. The Device Manager controls the different input and output devices, such as virtual glove, tracking system, HMD visors.
To be usable by the final user (designer, experts of ergonomics, staff assigned to the maintenance), the VE must be opportunely programmed: such activity consists in previously defining the behaviour of each element of the scene in reply to the interaction with the user. Programming phase of the VE (authoring) is, therefore, fundamental: the more accurate such phase is, the more realistic the behaviour of the environment will result and consequently the reliability of the outcomes reached with the virtual simulation.
The advantage of the chosen platform is that the authoring activity can easy developed not only by expert programmer, but also by CAD operator or simple user: such activity in VD2 is possible by means the writing of scripts, in the shape event trigger action, enough simple to assimilate [4].

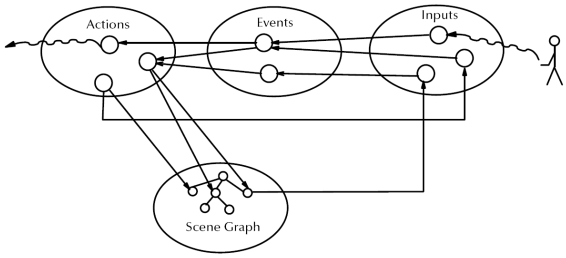


Figure 6.1: Input Event trigger Action approach

Moreover, as said before, the software offer the possibility, thanks to the open developing environment, to write any plug in, in a common language, such as C or C++, which, once compiled in a shared library (DSO), can be called at the happen of defined events (e.g. a collision, the pressure of a key, a particular gesture of the virtual hand) as well as any other base command. Such possibility gives practically infinite possibilities to programme the Virtual Environment. It is possible, for example, to programme the reproduction of a sound (action) at the happen of a defined condition of collision between two elements of the virtual scene (input). In general, inputs are produced by physical devices, such as gloves or tracking systems, but they can be generated by he same software too, such as in the case of the collision detection. The actions on the objects of the scene can be represented by both base or external libraries.

6.3 OBJECTIVES

The present study deals with the development of an interactive environment designed to take advantage from the VR instrument in the Design Review phase of a project. The case study was offered by the demand of an important railway company to verify, in the preliminary design phase, the maintainability of components of service systems of a regional train. The work has been carried out at the VR Test laboratory of the Competence Center for the Qualification of Transportation Systems founded by Campania Region, situated at Firema S.p.A. (Caserta, Italy). In particular, 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 the user, not necessarily expert of VR technologies;
• hiding the chassis and the furniture to show the only analyzed service system;
• highlighting, showing in wire-frame mode or hiding every single element of the scene;
• affixing markers in the virtual scene to note the critical points where to return successively;
• recording annotations;
• taking high resolution snapshots of the scene by the user in real time;
• storing the whole virtual scene.

6.4 AUTHORING OF THE VIRTUAL ENVIRONMENT

As said before, VD2 kernel gives the possibility to call in run time functions contained in external libraries. Every libraries generally exports a set of function destined to a defined application; therefore, each one represents a plug-in. Plug-in appear in the shape of dynamic shared libraries (DSO), that is object files,

characterized by the .so extension, which export a certain number of functions. These are shared, in the meaning of they can be called by several applications and other DSO's at the same time and are linkable dynamically, that is their linking to the main module of the simulator can happen at run to time. The advantage of using dynamic libraries is double: on one hand, in fact, memory is saved, as the code is loaded only one time and reused by different processes thanks to the management of the virtual memory, on the other hand an useless burdening of the simulation is avoided, since, when the characteristics implemented by such plug-in are not necessary, the library functions are not connected.
All commands implemented in the virtual environment have been assigned to the buttons of a fly-stick 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.

6.4.1 Navigation

Navigation in the virtual environment can be performed in two modalities: mainly user can move the scene in a certain direction proportionally to the distance covered with his hand while he is pressing the key 1 of the flystick. In this way he has the feeling to pull or to push the scene in the desired direction. In the second modality a second operator controls the movement by means of the spacemouse. Then, the first modality will be used for small movements where a greater precision is required, while the second modality will be chosen for great movements.

Figure 6.2: Navigating with the flystick

6.4.2 Selection

It is possible to select elements of the scene simply pressing the key 4 of the flystick. A light beam will be associated to the forefinger of the virtual hand, so it is possible to select an object simply indicating it. The further pressure of the key allows confirming the selection and exiting from such modality. Successively, thanks to the options of the 2D menu, some operations can be done on the selected object.

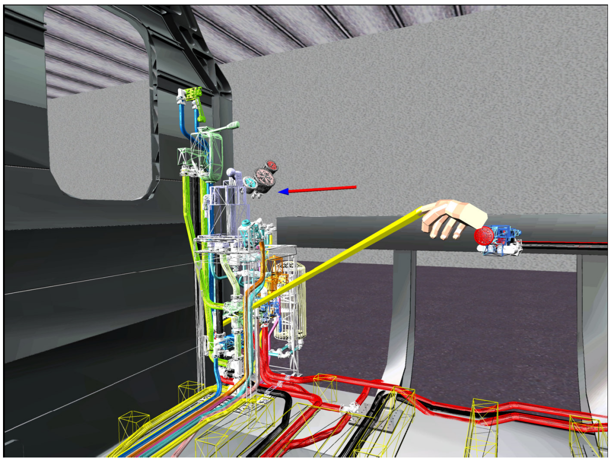


Figure 6.3: Selection

6.4.3 2D Menu

Pressing the central key of the flystick it is possible to open the 2D menu. The menu offers a series of functions: choosing the action on the selected objects (hiding, showing in wire-frame mode, deselecting); changing the parameters relative to the stereoscopic vision, such as the distance between eyes; activating the introduction of markers; activating the function of image capturing.

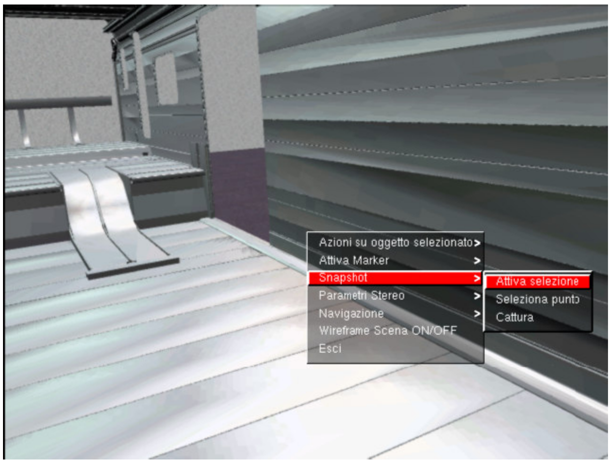


Figure 6.4: 2D Menu

6.4.4 Snapshot

In the 2D menu it is possible to activate the modality of images capturing: once selected the first point of the capture window, user can drag the second diagonal point by means his tracked virtual hand until to fix the whole area of the snapshot; then he can move the scene in order to adjust the desired image in the created frame. The image will be numbered and saved in the specified path.

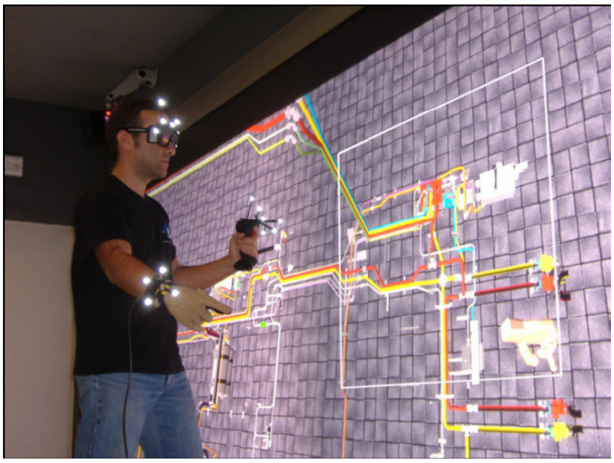


Figure 6.5: Selecting area of snapshot

6.4.5 Markers

With markers user has the possibility to 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 study.
Two types of markers are provided and, then, the correspondent two voices in the 2D menu: *numbered marker* allows to leave in the VE a marker provided with a progressive number. The release of the marker happens pointing the wished point of an object by means of a virtual laser: pressing the 2 key of the flystick the marker is bound to the point and oriented with the movement of the hand, successively releasing the button the marker will be fixed. It's necessary to note that this type of marker must necessarily be bound to an object.

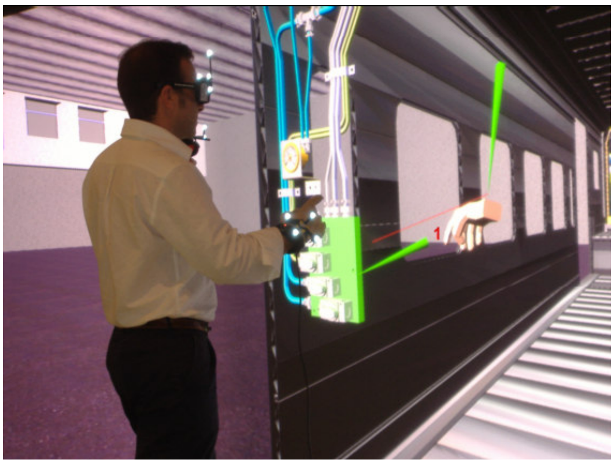


Figure 6.6: Numbered marker

Marker with annotations allows to leave markers in any point of the VE, not necessarily bound to a specific object. The release of the marker happens simply pressing the 2 key of the flystick. The marker will appear in correspondence of the forefinger of the virtual hand in the shape of an arrow.

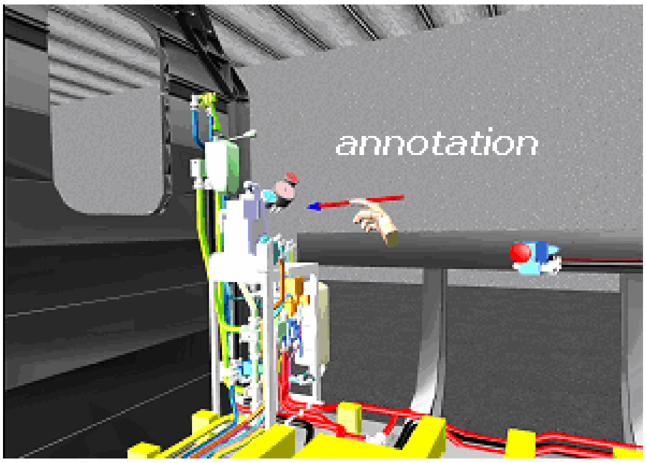


Figure 6.7: Marker with annotation

In this case the possibility has been provided to the operator to write and leave an annotation in correspondence of the marker, which will appear when the marker stays in the centre of the scene according to the point of view of the user. These annotations can be saved and loaded successively, for example for comparing different configurations of the analyzed assembly. Definitely, the first type of markers can be managed completely by the only protagonist of the virtual experience by means of the buttons of the flystick, in absence of a second operator at the console, when leaving particular annotations is not required. The second type, instead, has the advantage of not being bound to a specific object, but it needs of the participation of another operator to write annotations. The system allows user to choose one of the types in real time.

6.4.6 Virtual Sketching

Another feature has been implemented in the programmed environment, that is the possibility for the user to draw in real time directly in the virtual scene. This feature gives the user the tool for sketching any graphical note in immediate way in a sort of three-dimensional digitizer, increasing the utility and the usability of the environment.
This function has been implemented providing a real pen with a target of the tracking system, associating this target to the virtual reproduction of the pen and activating the *sweeping* of its end: such geometry keeps rendered in every position during the movement, leaving a track, which can be saved.

6.5 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.
Some examples of analyzed critical points are reported.

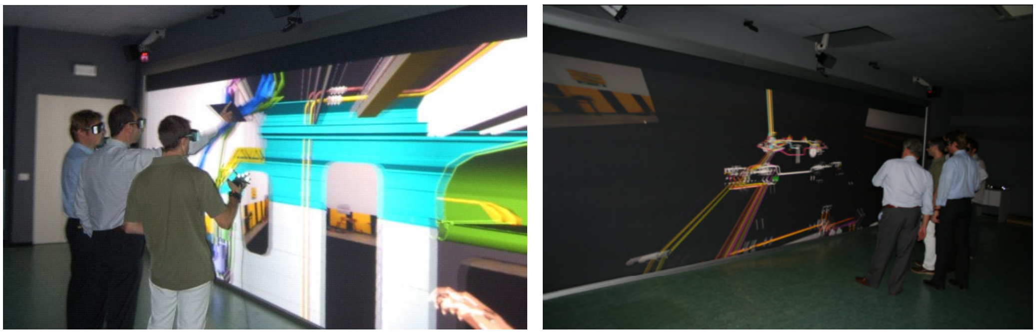


Figure 6.8: Design Review Session

In the plane head zone some connectors of the pneumatic system are present, situated between the electric deck and the partition wall of the rear hall. Therefore, the possibility to access to such zone from the inside of the deck has been studied.

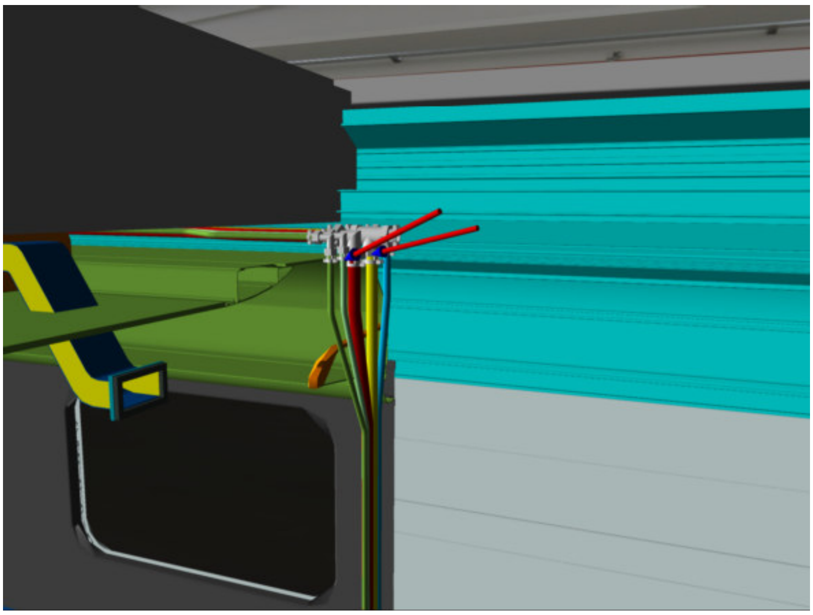


Figure 6.9: Plane head zone connectors

Position and accessibility to the hatches of the system cabinets have been studied to allow more operator handling the contained equipment.

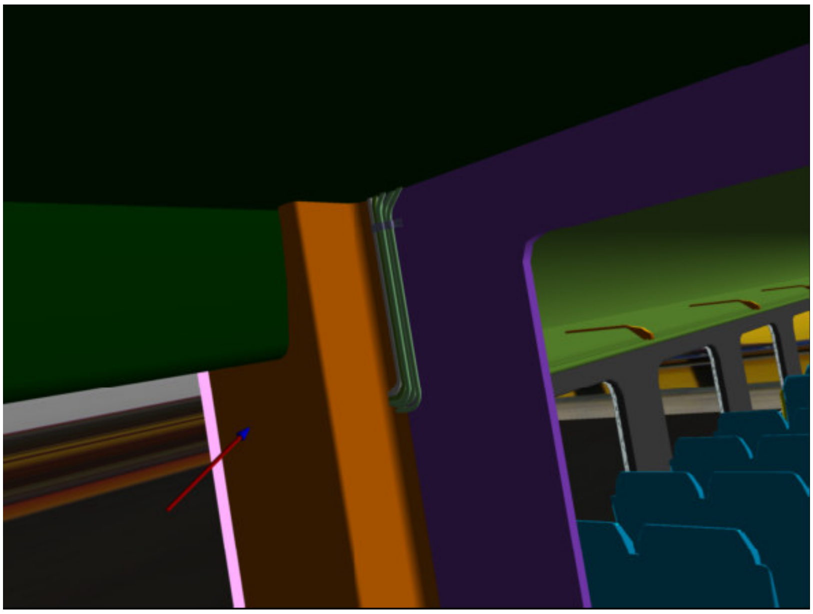


Figure 6.10: Systems cabinet

In the engineer's cab a brake drive is situated on the right of the shunting bench: the position of the engine-drivers seats has been studied for a better ergonomics. Moreover, the accessibility to the connectors for maintenance operations has been analyzed.

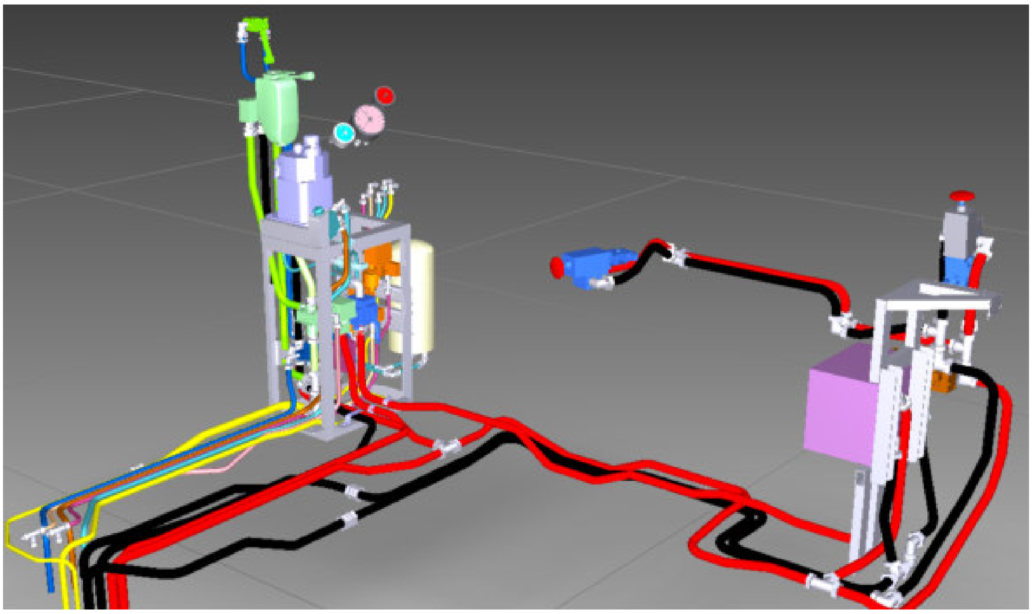


Figure 6.11: Engineer's cab systems

In the front under-carriage the pulling-out of the battery has been simulated, as well as the interference with the bogie and eventual connectors or pipes to be inspected.

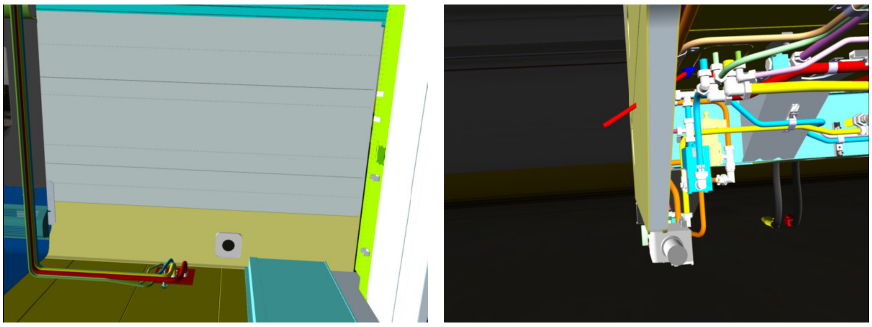


Figure 6.12: Front under-carriage

Analyzing the plenum zone, the 3D model sketch of the blocking hangers has been drawn, compatible with the maintenance operations to carry on the present components.

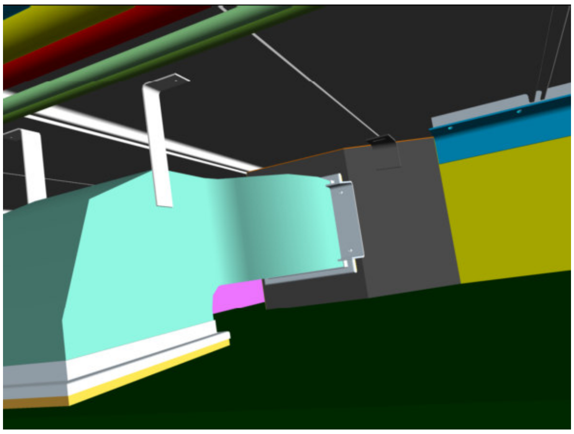


Figure 6.13: Plenum zone

The assembly and the accessibility of the doors opening/closing mechanism and the door frame have been studied.

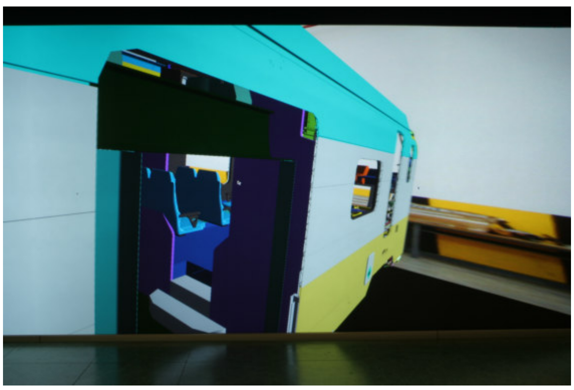


Figure 6.14: Doors frame

6.6 CONCLUSIONS

With the present activity Vritual Reality has been applied as an important instrument of support in the maintainability analyses of whole systems, even quite complex, such as those ones present in a railway carriage. 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 tools of Human Modelling. 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. One of the more significant contributes of the VR is the possibility to involve, directly in the analysis, a variety of figures: designers, technicians, but also the staff assigned to the maintenance. From the interaction among such different company figures, at the base of the Concurrent Engineering, indispensable indications can originate about the improvement of the maintainability and, therefore, to robustness of the definitive design. In the future, the immersive sensation of the environment could be increased, giving the user, for example, the possibility to control, with his movements, a virtual manikin. In this way it would be possible to simulate maintenance operations by the same staff. That would allow to study with more details the spaces and the movements, with the possibility of an immediate digitalization and reproduction for successive analyses.

6.7 REFERENCES

[1] Di Gironimo G., Papa S., “Use of Shader Technology for Realistic Presentation of Train Prototypes in Virtual Reality”, Proceedings of the Fourth Conference of Eurographics Italian Chapter, pp. 105-109, Catania, 2006.
[2] Di Gironimo G., Papa S., “Maintainability Tests Of Complex Assemblies In Virtual Reality”, accettato per la pubblicazione “Research in Interactive Design - Vol. 2", Springer Verlag, Proceedings of Virtual Concept 2006, 26 novembre – 1 dicembre Playa del Carmen Mexico, 2006.
[3] Di Gironimo G., Marzano A., Papa S., “Design of a Virtual Reality Environment for Maintainability Tests and Manufacturing Systems Simulations”, Proceeding of International Conference CIRP-ICME 2006, 26-28 luglio, Ischia Italia, 2006.
[4] vrcom GmbH: VD2 – Programming Guide, 4.5 Feature, 2005.