A Web and Virtual Reality Based Paradigm for Collaborative Management and Verification of Design Knowledge

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Abstract This chapter presents a paradigm for collaborative management and verification of design knowledge through a platform that is based on the seamless integration of Web services and Virtual Reality technology. The DiCoDEv (Distributed Collaborative Design Evaluation) platform enables online collaboration among distributed design expert groups or individuals, through a shared virtual environment. The developed platform supports efficient knowledge management and facilitates synchronous and asynchronous communication during the whole design phase of a new product. The use of Virtual Reality enables the advanced multi-user visualization and interaction with the virtual prototype. The aim of this work is to present a robust Web-based collaboration tool for the efficient use of designer's knowledge for improving the group decision making capabilities during the product development.

Keywords: Design knowledge; Web-based collaboration; Shared virtual environment; Ergonomic evaluation

1 Introduction

Manufacturing companies need to innovate themselves frequently, both by designing new products and by enhancing the quality of the existing ones [2]. Usually, during product design, all the persons involved share a great amount of drawings and assembly models. Often, different components or sub-assemblies of the product are designed by different groups of designers at geographically different locations. Companies are frequently out-sourcing engineering activities, performed internally, in order to accelerate the design and the product development process [8]. Nowadays, almost 50–80 % of all the components manufactured by original equipment manufacturers are out-sourced to external suppliers [9].

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However, this policy often creates many comprehension problems due to the lack of an internet based collaborative product design tool, which would effectively disseminate and manage product design knowledge. These problems are typically resolved through meetings or via e-mails and phone discussions. Colleagues are not easily capable of collaborating and exchanging their ideas if they work in different places or even worst, in different countries. A web-based collaborative environment could solve this problem by eliminating unnecessary meetings, repetitive emails and costly product mistakes and delays. The use of such a system aims at identifying, quickly and efficiently, the feasible and the optimal designs through collaboration among product development partners at different locations.

The main goal of the present work is the conceptualization, design and development of a web-based platform for supporting both product data and knowledge management and real-time collaboration through a shared Virtual Environment. The DiCoDEv (Distributed Collaborative Design Evaluation) platform provides both Web-based collaboration capabilities among distributed design groups and individuals, and multi-user navigation and interaction capabilities through a shared virtual environment. Collaboration features related to users, roles, events, projects and files management together with simulation features, related to product design verification using VR, have been developed and incorporated into the integrated Web-based platform.

2 Background Work

Various web-based manufacturing systems have been developed in the past decade for supporting collaborative activities and knowledge management in different life-cycle phases of product development, including marketing, design, process planning, production, distribution, service, etc., and associating these distributed product development life-cycle activities into a globally integrated environment using internet as well as web technologies [3, 4]. Many product development software systems, such as CAD, CAM, database management, intelligent knowledge-based, etc., have also been integrated, through web technologies, into these web-based collaboration systems [13].

An asynchronous collaborative system has been presented [5], called Immersive Discussion Tool (IDT), which emphasizes on the elaboration and transformations of a problem space and underlines the role that unstructured verbal communication and graphic communication can play in design processes. A prototypical system called cPAD has been developed [10, 11] that enables designers to visualize product assembly models and perform real time geometric modifications, based on polygonized representations of assembly models. The Detailed Virtual Design System (DVDS) for shape modelling in a multi-modal, multi-sensory Virtual Environment (VE) has been presented [1], enabling collaborative design and interactions among multiple designers both at the same site and at remote site virtual environments. An Internet-based virtual reality collaborative environment called Virtual-based Collaborative Environment (VRCE) developed with the use of Vnet, Java and VRML [6], demonstrates the feasibility of collaborative design for small to medium size companies that focus on a narrow range of low cost products. A web-enabled PDM system which facilitates various collaborative design activities [12] has been developed providing also 3D visualization capabilities. Another tool for dynamic data sharing in collaborative design has been developed [7], ensuring that experts may use it as a common space to define and share design entities. A web-based collaborative product design platform for dispersed network manufacturing has been proposed [14]. This platform enables authorized users in geographically different locations to have access to the company's product data, such as product drawing files stored at designated servers and to carry out product design work simultaneously and collaboratively on any operating systems.

Further to the research activities at the field of web-based collaborative product design, a few commercial tools are available to support such functionalities. OneSpace.net [15] is a lightweight web collaboration tool that supports online team collaboration for project development. It combines architecture for web services with familiar concepts, such as organized projects, secure messaging, presence awareness and real time online meetings. IBM's Product Lifecycle Management Express Portfolio is designed specifically for medium-sized companies that design or manufacture products. This system mainly focuses on business processes but also allows design engineers to share 3D data, created with diverse authoring tools and thus, product development can be managed. It includes CATIA V5 Instant Collaborative Design software and ENOVIA SmarTeam [16] for product data and release management. ENOVIA MatrixOne [17] is designed to support deployments of all sizes. It includes PLM business process applications that cover a wide range of processes including product planning, development and sourcing and program management. The tool furthermore, allows diverse design disciplines to be synchronized around design activities and changes, by reducing the critical errors and cost associated with poor collaboration. SolidWorks eDrawings [18] is an email-enabled communication tool that eases the review of 2D and 3D product design data across extended product development teams. UGS TeamCenter [19] powers innovation and productivity by connecting people and processes with knowledge. Teamcenter's portfolio of digital lifecycle management solutions is built on an open PLM foundation. Teamcenter solutions link users with secure, global access to a single source of product knowledge.

Despite the investment made in the last years, both in research and in industrial fields, the global market still lacks in collaboration tools, capable of providing Virtual Reality techniques as well for product and process design evaluation. Most collaborative tools are more related to Product Lifecycle Management and less to a purely web-based collaborative platform. Thus, the development of a lightweight web platform that supports the collaborative knowledge management, validation and dissemination of product designs/projects as well as the immersive interaction of multiple users with the virtual prototypes, comprise the goals of this chapter. The proposed shared VE provides collaboration capabilities among multiple users, as well as multi-user immersion and interaction on virtual product prototypes under evaluation. Collaboration features related to users, roles, events, projects and files management have also been developed into a web-based platform in order to support the simulation features, which are provided by the shared environment and which are related to product design verification.

3 Platform Implementation

The DiCoDEv platform was designed based on an open architecture and Browser/Server technology. The development of the DiCoDEv platform was driven by standard technologies applied to the J2EE language. Such technologies include Java Server Pages (JSP) for visualizing data by creation of HTML pages and Servlets for data manipulation and user interaction. For the Web Server and Servlets container 'Apache Jakarta Tomcat 4.0.4' was used. The development was assisted by 'Borland JBuilder X' as the Integrated Development Environment (IDE) and InterDev together with Oracle 9i development and administration tools for the database design and creation. The development as well as the installation took place on Windows XP Professional Edition operating systems but the same tools, technologies and development processes could be applied to other operating systems, such as Unix.

3.1 Architecture

The web platform architecture is following the 3-tier example and includes three layers (Fig. 1):

- The Data Layer
- The Business Layer, and
- The Presentation Layer

These layers communicate through Internet or Intranet, depending on the type of communication.

Data layer (1st tier): includes the application's database and the connections with all the other external systems as for example an external database for the recovery and storing of data. Some characteristics, such as data locking, consistency and replication ensure the integrity of data. Oracle 9i was used for the platform's database implementation.

Business layer (2nd tier): consists of the business logic. The architecture of this level can be divided and analyzed furthermore into: the connection mechanism between the mainframe PC and the application (JavaServer), the Java Bean Architecture, which contains the work-division planning algorithm and the database

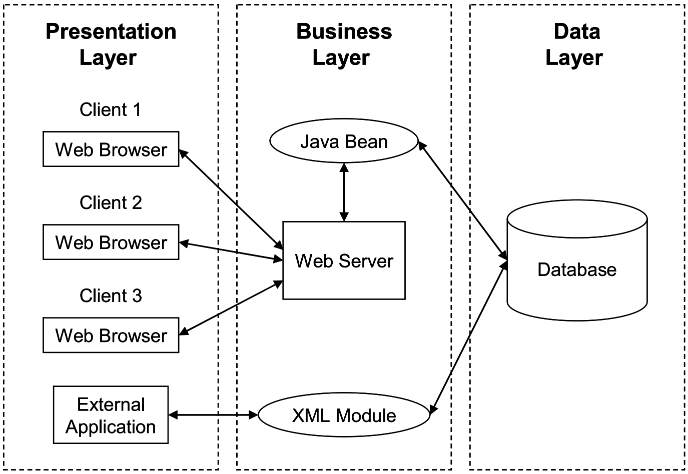

Fig. 1 3-tier system architecture

interactions, and finally an independent XML unit, which is going to manage the connection between the platform database and the external applications.

Presentation layer (3rd tier): concerns the clients and consists of the Netscape and Internet Explorer web browsers for this application.

3.2 User Workflow

The connection among users complies with the browser user interface models, in a user-friendly Windows environment, which allows the exploitation of all net-place capabilities by using any desired web browser. The user workflow is presented in Fig. 2.

User Home Page is the first page and presents information about the number of the new messages in the user's inbox and the number of projects that he/she participates in. Through the Manage Profile page users can change their personal profile. Users can also manage (send/view) all their messages for all the projects they participate in, through the message pages (Manage Messages & Send/View Message). Once a user has been authorized to the platform he/she is able to participate in an on-line communication and cooperation by exchanging thoughts and ideas with other authorized users through the Chat page. A list of the online users also appears in this page. Moreover, users are able to join specific project-related chat channels.

All projects in which a user participates are presented in a list form, in the Manage Workspace page. Information, such as the project's description, the owner and starting date, also appear in this list. If a user is the project owner then he/she has the right to modify the project-related information (name, description, etc.) through the Manage Project page (Fig. 3), otherwise he/she can only view this data.

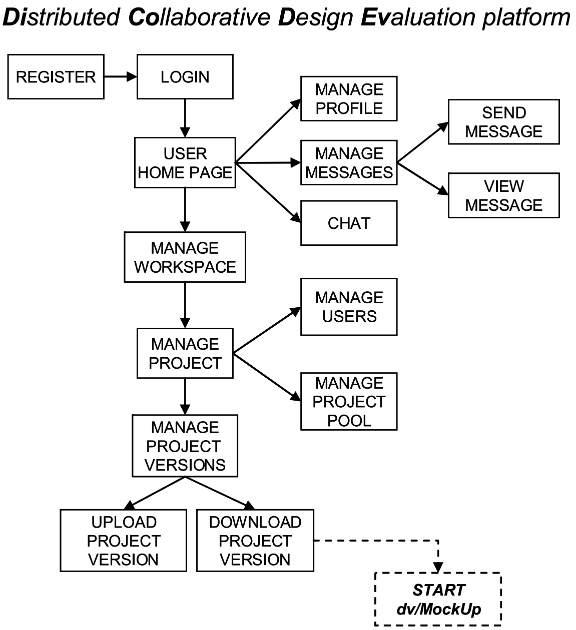

Fig. 2 DiCoDEv platform user workflow

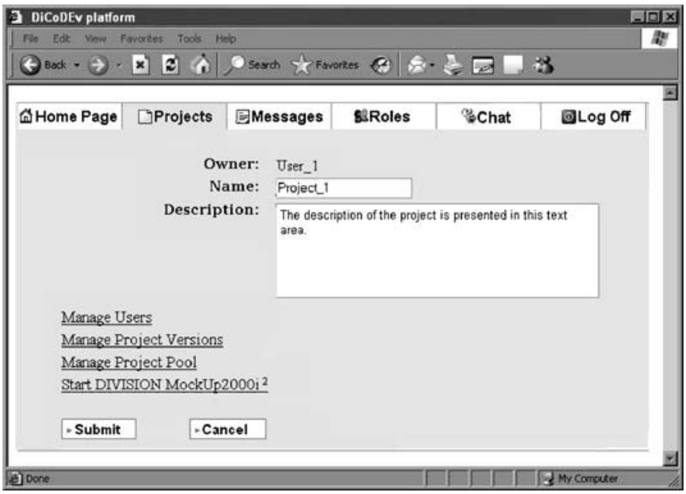

Fig. 3 Project management capabilities of DiCoDEv platform

Through the Manage Users page, the project owners can add/remove active users to their own project, from the list of the authorized users and select their roles for the specific project. Roles are project-related and are specified by the project owners. Through the Manage Project Versions page, the users can manage (view, delete or create) project versions with respect to their authorities in the specific project. The Manage Project Pool page enables users to upload and download files of any type that could be used by all authorized users during a collaborative design session. In most of the pages, search function and filters are available in order to make the search for specific information easier.

3.3 Virtual Environment

In order for the DiCoDEv platform to provide design collaboration capabilities through a shared virtual environment, a commercial VR software tool (DIVISION MockUp2000i2 or dV/MockUp of PTC – http://www.ptc.com/), is used as a basis for the visualization and development of the virtual prototype and workspace. Thus, in order for a user to have a full functional system (both Web and VR-based collaboration) running in local PC, he/she needs to locally install dV/MockUp. Ergonomic evaluation of product's design can be also performed in the virtual environment by using the appropriate digital human module, called dV/Safework. This system has been integrated into the web platform so as to be directly accessed by users through the platform's GUI. The shared virtual project environment is used for the visualization and simulation of products during a collaborative design evaluation session. The users are able to create, open, view, modify and save the virtual project environment they work on. All collaborative distributed users can work on the same environment in real-time either in desktop (Fig. 4) or immersive

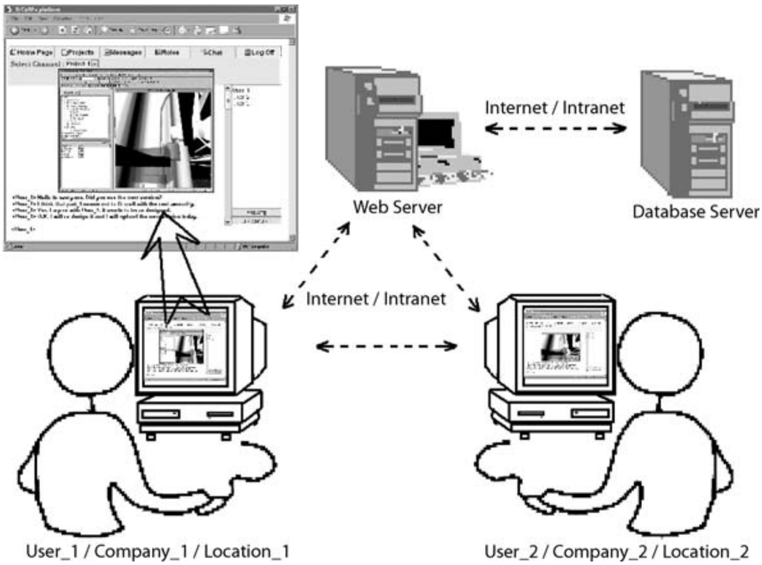

Fig. 4 Collaborative design through the DiCoDEv platform

mode, using VR peripheral devices (i. e. Head Mounted Displays, Motion Tracking Systems, Navigation Devises, Data Gloves). A pilot case demonstrating the virtual collaboration capabilities of the DiCoDEv platform is presented in Sect. 5.

3.4 Communication

The communication between the front-end and the platform's database is achieved by Oracles' drivers. The web interface provides access to the portal and runs on a Windows 2000 or XP Operating System. A 128kbps ISDN (or DSL) line is capable of confronting with the data load during a collaborative session. Through this communication, the authorized users can upload/download the required virtual project environment and information. By the time the project-related files are uploaded, a new version of the selected project is automatically created into the database.

The communication between the front-end and the back-end external application (dV/MockUp) enables authorized users to open and modify a virtual project environment and it is realized through the XML protocol (Fig. 5). Communication between the DiCoDEv platform and other external applications, such as databases, is also possible.

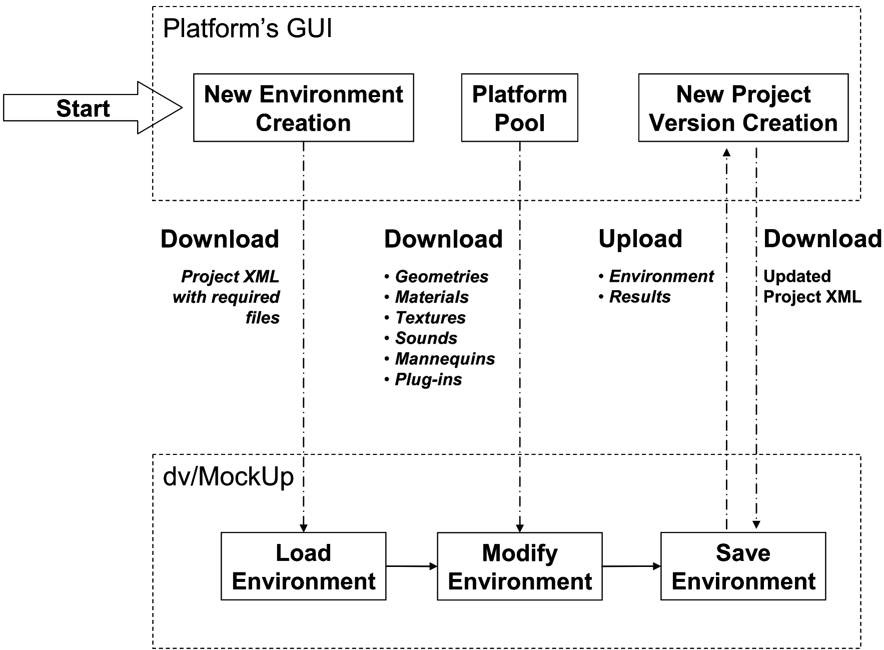

Fig. 5 Interface between web-platform's GUI and dv/MockUp

4 Platform Functionality

The key features of the DiCoDEv platform have been implemented so as to cover both the development standards of the web-based applications and the requirements of a typical industrial virtual collaborative scenario.

4.1 Collaborative Functions

The developed collaborative functions enable the management of users and data as well as real-time collaboration. The supported collaboration functions are:
Security: The Platform Administrator manages the overall security of the system and provides the users with passwords. Every user has to give a login and password in order to have access to the platform's data. Moreover, in order to eliminate spamming phenomena, filters and disk-storage limitations are provided.

Users/roles management: This function enables the management of the security and the rights on every file within a project depending on the predefined role of each user. Based on the user's role, the system provides him/her with specific access rights to the various platform's features, information and capabilities.

Messages/chat: E-mails and chat (Fig. 6) are supported to enable authorized users to communicate with each other. This function allows participants to exchange easily and quickly ideas about a new product and improves decision making in product design review, allowing issues that could hinder a project's progress to be quickly removed by team members.

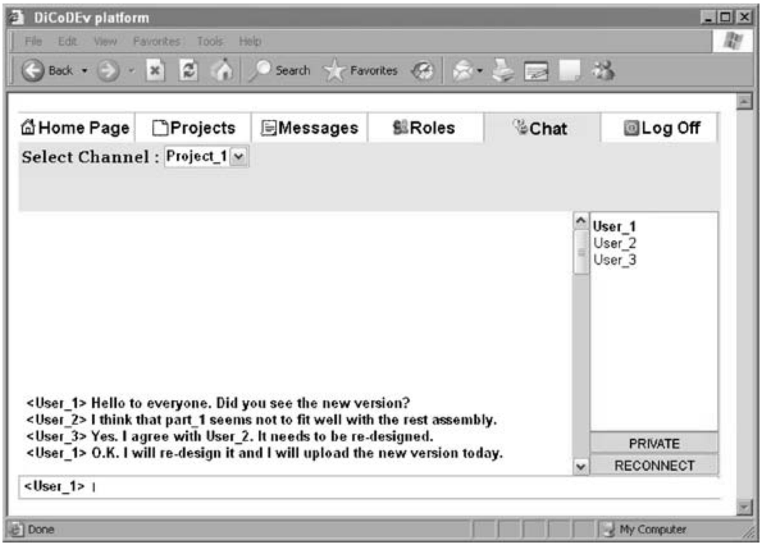

Fig. 6 Synchronous multi-user communication capabilities (chat) of DiCoDEv platform

File sharing: This function enables authorized users to easily send and receive large files via internet without the hassle of FTP or the limitations of the e-mails' providers.

File storage/versioning: File storage and versioning is provided through the platform's database. Several types of files (drawings, documents, 3D models, textures, etc.) could be stored and retrieved by the users. An automatic and easy-to-use mechanism for file versioning has been developed in order to help involved users to review the history of modifications of every project-related file.

File browser/info: A user friendly web-based interface allows authorized users to create, delete, edit, copy, rename, move, download and upload files and directories. It has been designed for rapid adoption throughout an organization, requiring little or no training to get familiar with it in order to enable the quick search of any required information stored into the database.

4.2 Virtual Reality Functions

These functions have been implemented into the dV/MockUp to allow the visualization and functional simulation of products as well as the users' immersion and interaction within a shared virtual environment. The basic Virtual Reality functions are:

Behavioural simulation: Behavioural simulation controls the functional characteristics of the virtual systems involved in the process performance. Based on the event/action engine of dV/MockUp, developers can model complex behaviours in the virtual environment (assembly joint constraints, part movement restrictions etc.), in order for the virtual objects to 'behave' in a realistic way.

Assembly support mechanism: This mechanism allows the fast and accurate assembly execution within the virtual environment. During an immersive execution of an assembly process, the part to be assembled is automatically released from the user's hand, so as to be assembled in its final position, as soon as a good positional and orientation has been achieved by the user (magnet concept). The final mounting position and orientation of each part should be pre-programmed by the designer of the assembly environment. The user has just to achieve a "good" position and orientation of the part with respect to the exact final mounting position. The field of the 'magnet' can be adjusted to account for various levels of fitting precision (Fig. 7).

Collision detection: Dynamic clash detection is provided within the simulation environment among static parts and either moving parts or the user's hands. In this way, visual and acoustic alerts enable the user to verify the feasibility of a manufacturing process (i. e. assembly), in terms of reachability of picking and mounting locations and manipulation of parts.

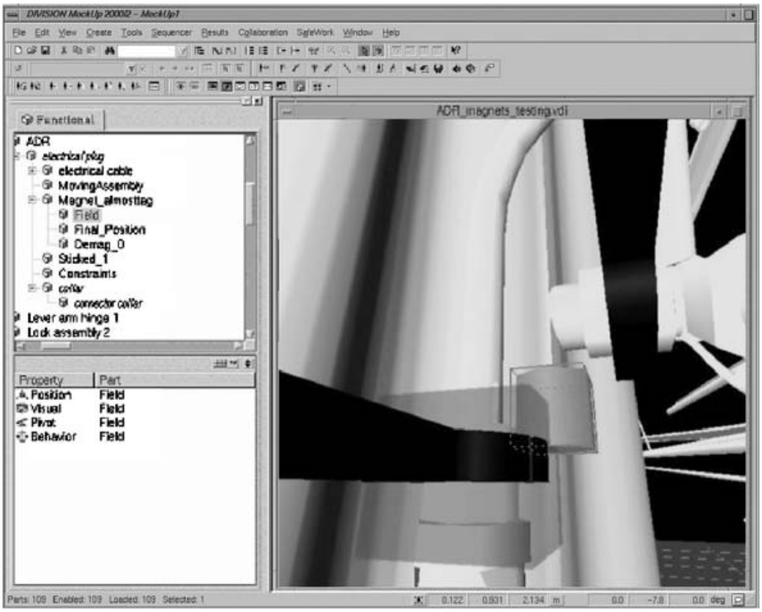

Fig. 7 Visualization of the assembly support mechanism (magnet concept)

5 Pilot Application

Based on the requirements of a commercial refrigerators' company, a virtual reality environment has been developed in order to demonstrate the capabilities of the DiCoDEv platform. The virtual environment represents a typical milk-shop with refrigerators (Fig. 8). The scenario involves the collaboration between different users in order to review these refrigerators in terms of design (i. e. capacity, ergonomics functionality, etc.) and appearance (i. e. colors, textures, logos, etc.) before proceeding in the production phase.

Several collaborative sessions have been performed to assess the knowledge management and the capability of real-time collaboration among different users. They can use all the virtual collaboration functions of the environment (Fig. 9) as well as the ergonomic evaluation tools, using digital humans in the virtual environment (Fig. 10). Immersion capability is also available for realistic human interaction.

Fig. 8 Virtual environment of the pilot application

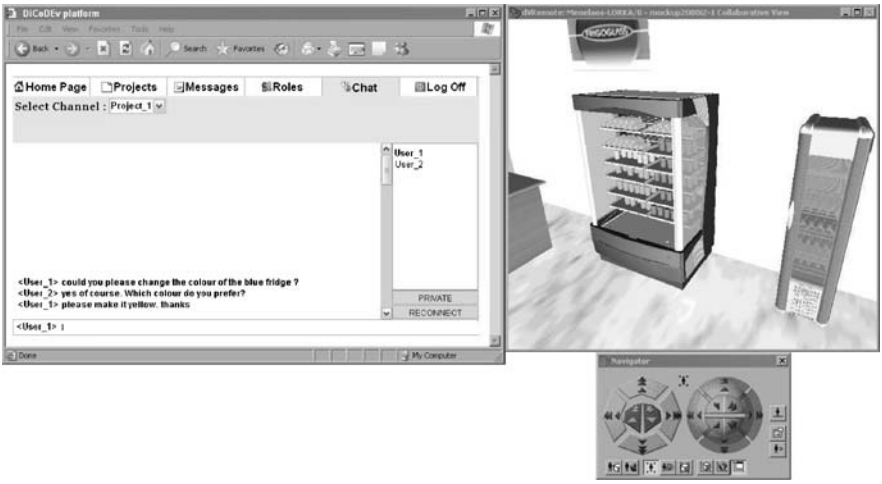

Fig. 9 Real-time collaboration session for product design review

During a multi-user collaborative session, each participant has its own copy of the graphical user interface (GUI), which provides a rendered 3D view of the virtual product. All users can interact with the virtual product at any time, with no restriction on the number of simultaneous interactions. The changes made by a user are immediately visible to the others. Real-time chat capabilities represented enable the continuous communication among the online users. Moreover, a user can be represented by an animated manikin figure called avatar. Any number of users can join a collaborative session using TCP/IP over local or WAN networks. There is no limitation on the use of specific Operational System or VR peripherals.

Fig. 10 Ergonomic evaluation of the virtual prototype

The integration of the DiCoDEv platform with Virtual Reality provides an advanced environment in the network as a common virtual design space in which people can simultaneously work during the product life cycle. The developed pilot environment enables:

- The cooperation among distributed actors during the refrigerator design stage
- The real-time multi-user interaction into the same virtual prototype/design
- The effective and efficient use, sharing, and simulation of design and manufacturing data through the web (e. g. ideas, drawings, 3D-models, analysis results, …)
- The ergonomic evaluation of the products using digital humans (computer manikins) that represent different user populations
- Activities in a many-to-many session within a shared virtual environment (e. g. conceptual design, virtual prototyping, assembly execution, ergonomic evaluation, etc.)
- The knowledge management and the exchange of ideas and comments based on the 3D representation of the product
- The advanced product demonstration through the web (virtual web showroom)

6 Conclusions

The DiCoDEv platform allows multiple users to work in collaborative and distributed way, decreasing considerably the time required for the designing phase to be completed. DiCoDEv improves team productivity and knowledge management, providing the infrastructure necessary to make the engineering teams efficient, even if they are dispersed over different sites, without changing the existing design environment. The platform's integration into the VR environment enables the immersion and interaction of users with the virtual prototypes that lead to the efficient evaluation of product designs where the human intervention is crucial. The benefits of using the virtual capabilities of the DiCoDEv platform include:

- Efficient knowledge management during the product design phase;
- Multi-user visualization, immersion and interaction;
- Real-time collaboration on the same virtual design;
- Simultaneous review of alternative virtual designs;
- Ergonomic evaluation using digital human simulation.

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