A Web-Based Platform for Collaborative Product Design, Review and Evaluation

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Chapter 3
A Web-Based Platform for Collaborative Product Design, Review and Evaluation

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Abstract This paper presents a web-based integrated platform, called collaborative prototype designer (CPD), which has been developed to support the collaborative product design activities. The CPD is part of an integrated collaborative manufacturing environment (CME) supporting team work in product development, factory design, and worker training within a Digital Factory framework. The CPD addresses the needs for collaboration, during the product development process, by providing functionality for collaborative product design, review, evaluation, and demonstration. The CPD consists of a web-based platform for content management and users' interaction, a tool for real-time collaborative geometry modeling, virtual and augmented reality platforms, and a tool for collaborative decision making. The use of the CPD is demonstrated by a real life design case, related to the development of a new laser machine. The CPD has a flexible architecture that takes into consideration the design needs of both mechanical and non-mechanical products and it is therefore considered being applicable to a wide range of products. It also integrates design activities, processes, methods, and tools into a modular feature easy to be used and further extended.

3.1 Introduction

Nowadays, product development is the result of a network-based collaborative process, because most of the projects require co-operation among geographically distributed expert groups with diverse competence (Chryssolouris 2006).

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A collaborative product design project should take into consideration issues related to the users' integration, organization, and communication, as well as product data sharing, management, and visualization. New and efficient paradigms of a web-based collaborative product design, in a global economy, will be driven by increased outsourcing, competition, and pressure to reduce product development time (Draghici et al. 2007).

3.1.1 Background

Computer-supported collaborative design has been a widely used term, describing the process of designing a product through collaboration among multidisciplinary product developers associated with the entire product life cycle. Several research activities related with the development of web-based methodologies and prototype systems for computer-supported collaborative design have been reported in the scientific literature (Shen et al. 2008). The collaborative conceptual design has been a major area of research work, mainly addressing several web- and agent-based approaches to support collaboration during the early stages of product development, conceptual design tools and frameworks, conflict resolution, and team/project management for conceptual design (Wang et al. 2002). Extensive research work on collaborative computer-aided design (CAD) has also been reported, addressing issues, such as co-design systems and feature/assembly based representations, web-based visualization, 3D representations for web-based applications, and 3D streaming over networks (Fuh and Li 2005). Several synchronous and asynchronous co-design systems, providing collaborative modeling functionality, have been developed. Most of them are based on the client–server model, while recently, some systems providing real-time online collaboration, based on a peer-to-peer network, have also been presented (Chen and Tien 2007). The integration of different commercial client CAD systems into a co-design platform has been demonstrated in some cases (Li et al. 2007). Virtual reality (VR) based systems for collaborative product modeling were also suggested in the past (Arangarasan and Gadh 2000; Shyamsundar and Gadh 2002). Shared product visualization and collaborative design review has been another major area of research and development work. Methods of sharing virtual product representations over the web and a number of CAD-integrated shared workspaces have been presented in the scientific literature for distributed design review (Sharma et al. 2006; Hren and Jezernik 2008). Shared VR-based environments have also been used to support interactive collaboration in product design review (Kan et al. 2001; Pappas et al. 2006; Chryssolouris et al. 2008). Most of the reported research activities focus on providing collaboration tools for specific phases of the product development process. Only few activities have demonstrated integrated solutions, capable of addressing interrelated phases of this process, such as modeling, review, and analysis (Li et al. 2004). Research works on Internet-based product information sharing and product data management (PDM) related applications have also been widely documented (Xu and Liu 2003; Zhang et al. 2004). Apart from product design issues, several researchers have also worked on the development of methods and tools to support real-time collaboration for distributed activities related to manufacturing and product assembly (Mahesh et al. 2007; Meng et al. 2006). The development of web-based manufacturing systems has also been extensively investigated (Yang and Xue 2003).

Moreover, several software vendors have launched in the market to support collaborative design activities (CoCreate OneSpace.net web pages http://www.ptc.com/products/cocreate/onespace-net, ENOVIA web pages http://www.3ds.com/products/enovia, IBM PLM Express Portfolio web pages http://www-01.ibm.com/software/plm/, Siemens Teamcenter web pages http://www.plm.automation.siemens.com/en_us/products/teamcenter/index.shtml).

3.1.2 Motivation

Despite the investment made in the recent years, both in research and in industrial applications, the global market still lacks integrated, flexible, and cost-effective solutions to support the collaborative product design. Most of the research-based solutions available focus only on individual aspects of the design collaboration process, e.g., by providing either web-based environment for collaborative PDM/product life cycle management or shared CAD/VR-based environments for collaborative product modeling or review. No research work has provided so far an integrated environment for collaborative data management, product modeling, review, and decision making. On the other hand, most of the commercial solutions on hand are sophisticated, large-scale, and off-the-shelf tools, which are typically very expensive and not easily customized. In this way, small and medium enterprises (SMEs) cannot usually afford to integrate them into their product development process.

Thus, the research work described in this chapter has been focused on the development of a web-based platform for collaborative design, including real-time collaborative geometry modeling, interactive and immersive product visualization along with a smart decision support mechanism for collaborative design evaluation also enabling SMEs to benefit from these tools so as to improve the collaboration in the product development process, specially with original equipment manufacturers.

The collaborative prototype designer (CPD) system serves as a multiuser real-time collaboration tool for supporting product development activities and it could be used, as an efficient tool, by designers, engineers, managers, suppliers, and customers. It enables single users and/or user groups to work in a collaborative way, even if they are dispersed over different sites, without changing the existing design environment. It provides the necessary infrastructure to make engineering teams efficient, by improving their productivity, which results in decreasing considerably the time required for the designing phase to be completed. The key contribution of this system is its architecture that integrates the computer-aided design, VR/augmented reality (AR), and decision-making work space into a modular feature, easy to use and manage. Among the benefits that could be acquired by using the system are:

- Quick and easy product data storage and sharing through an easy to use web-based content management platform
- Synchronous and asynchronous communication among distributed individuals or user groups
- Real-time co-operation for the geometrical design of the product models
- Multiuser visualization and interaction with shared virtual product prototypes
- Decision support for the evaluation of the alternative product designs/variants
- Online demonstration and customization of products into a 3D interactive environment.

3.2 Digital Factory Framework

A *Digital Factory* is a rich virtualized environment that allows to:

- Represent a variety of product life cycle activities
- Share product development resources, manufacturing information, and knowledge
- Simulate the product, the production processes, and the factory operations
- Plan, produce, and manage among different participants and departments.

Both research and industrial communities have contributed to the definition of the Digital Factory vision and suggested how this vision could be implemented in the future (Bracht and Masurat 2005; Ad-Hoc Industrial Advisory Group 2009). In the respective works, collaborative design environments are typically considered as an inherent part of the future Digital Factory framework, integrating new tools to manage both the product and the process architecture, as well as to manage the interaction between the different teams involved in the design process.

The research work presented in this chapter aims to contribute to the implementation of the future *Digital Factory* vision. By providing web-based tools for collaborative product design, review, evaluation, and demonstration, it aims at supporting the evolution of the current design practices into a fully digital co-operative development engineering activity.

This work is part of the development of a collaborative manufacturing environment (CME) for the next generation of Digital Factories (DiFac 2009). The CME consists of an integrated framework for supporting team work in product development, factory design, and evaluation, as well as in worker training (Fig. 3.1). This framework is based on key aspects of the human factors of a Digital Factory, i.e., presence,[1] collaboration, and ergonomics. The CPD, being the

[1] *Presence* is a defining characteristic of a good VR system, a feeling of being there, immersed in the environment, able to interact with other objects there with a perceptual illusion of non-mediation.

Fig. 3.1 The collaborative manufacturing environment framework (IMS DIFAC EU Project)

output of the work presented in this chapter, is one of the major components implementing this framework for collaborative digital manufacturing activities.

3.3 Collaborative Prototype Designer Functional Architecture

The CPD functional architecture specifies the way the system addresses the collaboration needs of the product development process, within a Digital Factory framework (Fig. 3.2). This functional architecture is generic, taking into consideration the design needs of both mechanical and non-mechanical products and it is

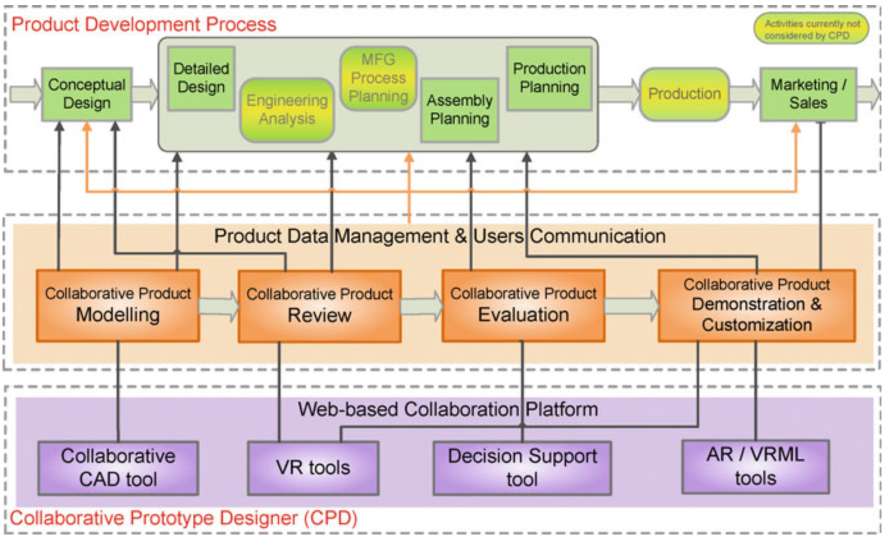

Fig. 3.2 CPD and the product development process (CAD computer-aided design, VR virtual reality, AR augmented reality, VRML virtual reality modeling language)

therefore considered being applicable to a wide range of products. The main functional steps within the CPD integrated system are:

PDM and users communication: The actors involved (designers, engineers, suppliers, etc.) can login into the CPD platform, review the product-related stuff, share files, and communicate in a synchronous or asynchronous way to share ideas, knowledge, opinions, and data. Using the central workspace, the users may access all CPD functionality using the respective interfaces for each module.

Collaborative product modeling: Within this step, the remote actors can have real-time, online, concurrent CAD sessions, using typical CAD functionality (e.g., design curves, surfaces, solids, etc.). The users participating in the collaboration session will have the capability of concurrently viewing and modifying the attributes of the geometry model. They are provided with the ability of real-time collaborative manipulation, creation, and modification of the product/part models and not just collaborative visualization. During a CAD design session, the end user may initiate a collaboration session with a given topic name. Other participants may join the collaboration session and have an online CAD collaboration. Then, all the CAD users, participating in the session, will be able to share and work concurrently on a common CAD model. However, each user has his own desktop and capable of selecting his own view plane, view angle, etc. Additionally, the user may select whether to automatically accept all model changes, submitted by the other collaborative users, or to manually check and verify each change in their model instance.

Collaborative product review: In the next step, users may create together the virtual prototype of the product by importing the geometry models, built during the collaborative CAD session. They are able to navigate, visualize, and interact with the virtual prototype, so as to review the different design solutions. Typical scene-building functions (e.g., lighting, add/remove geometry, coloring, and material selection, etc.) are provided. The product assembly sequence may be further built and simulated in the shared environment, for the impact of the design options on the product assembly process to be reviewed.

Collaborative product evaluation: Following a review session, remotely located actors may be engaged in a collaborative decision-making session, so as to reach a decision on the best of the reviewed alternatives. Multiple evaluation criteria and their respective weights may be defined according to the decision policy. Depending on the actors' role and technical background, different weights may be also assigned to them by the manager of the design project. The actors can then provide values for each criterion of each design alternative. The expert-based evaluation may be complemented by including a set of criteria that get values directly from simulation sessions carried out within the CPD platform or within the CME, e.g., related to the assembly or production planning. The output of the session is a relative ranking of the design alternative solutions, which allows the selection of the comparatively best one.

Collaborative product customization and demonstration: During the last step, the final product designs are ready to be uploaded to the online product catalogue.

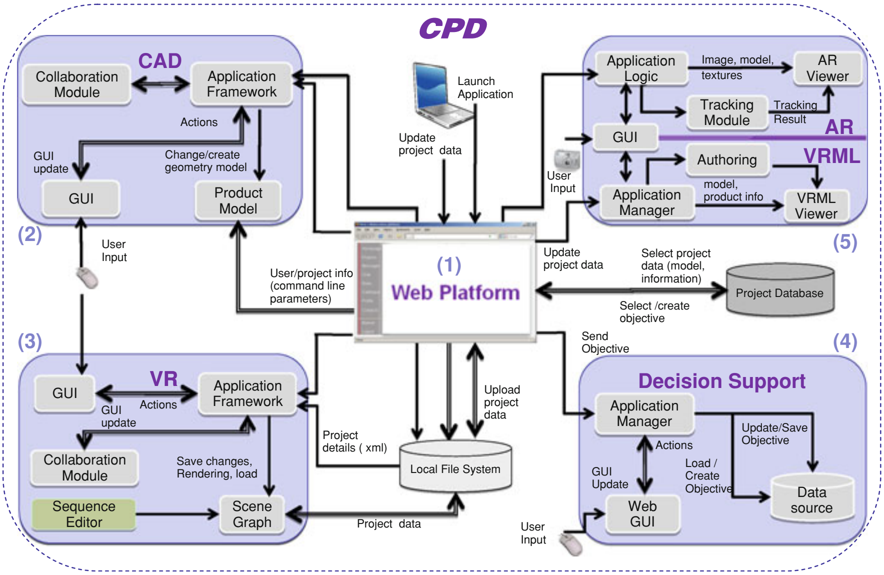

Fig. 3.3 CPD's components and user workflow

> Customers would be able to use this functionality to explore, online, all the products available, in a standalone mode or within a 3D interactive environment.

3.4 CPD Component Architecture

The CPD is designed based on an open architecture and a browser/server technology that follows the three-tier example and includes: the data layer, the business layer, and the presentation layer. These layers communicate through the Internet or an intranet, depending on the type of communication. Oracle is used for the platform's database implementation, and for the connection mechanism among the mainframe PC and the application (JavaServer), the Java Bean Architecture, which contains the work division–planning algorithm and the database interactions. CPD consists of the following components, each one comprising several modules (Fig. 3.3):

1. The web-based collaboration platform that supports communication of the remote actors and PDM
2. The collaborative computer-aided design (CAD) tool that enables distributed real-time co-design of the 3D geometry models of the new product components
3. The VR tools that enable product design and assembly review within a shared VR environment

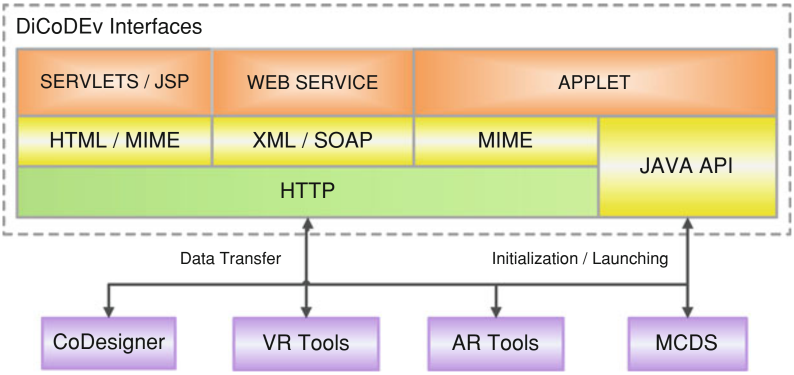

Fig. 3.4 Interface architecture

4. The decision support tool that supports the evaluation of the alternative design solutions, based on a set of criteria, and decision making
5. The AR/VR Modeling Language (VRML) tools that enable the interactive product demonstration and customization.

3.4.1 *Web-Based Collaboration Platform*

An "in-house" web-based platform (Distributed Collaborative Design Evaluation—DiCoDev) has been developed to support user authentication/authorization, data management/synchronization, and synchronous/asynchronous communications in CPD, based on some previous works (Pappas et al. 2006; Chryssolouris et al. 2008). The web platform consists of the following modules:

- *Authentication module*: This module provides security and blocks any unauthorized access into the system. Users should register first before being assigned by the platform administrator the proper rights and privileges of accessing the data and services of the electronic collaborative environment.
- *Communication module*: This module enables remote synchronous and asynchronous communication, such as VoIP (Skype), private/public chat, and e-mail.
- *Data management module*: This module provides a shared working space, user's roles, and access rights management. It also offers a mechanism for the automatic project file versioning; thus, providing the users with an easy way of keeping track of all recent modifications on product designs.
- *Authoring module*: This module enables the users to upload the new product models to the company's online catalogue, so that product information can be made available to customers.

The web-based platform also serves as the integrator of all the CPD components (Fig. 3.4).

```
-<xsd:CADCommand invoker=“Designer2”>
  -<xsd:SolidCreatePrimitiveConeTypical name=“Acone” height=“200” radius1=“100” radius2=“1”>
      <xsd:basePoint x=“0” y=“0” z=“0”/>
      <xsd:direction x=“0” y=“0” z=“1”/>
   <xsd:SolidCreatePrimitiveConeTypical />
</xsd:CADCommand >
-<xsd:CADCommand invoker=“Designer2”>
  -<xsd:ComplexCreateExtrudeTypical name=“extrudedObject”>
      <xsd:geoobject>article</xsd:geoobject>
      <xsd:axisdirection x=“0” y=“1” z=“0”/>
      <xsd:height>150</xsd:height>
   </xsd:ComplexCreateExtrudeTypical>
</xsd:CADCommand>
```


Fig. 3.5 Sample XML files

Agents have been used for the integration of the web platform with the collaborative CAD tool (CoDesigner) and the VR/AR tools. There are three types of agents, one for each module. Each agent “knows” how to communicate with the specific module and with the server. The data exchange is performed between the agent and the web-based platform. For each application instance, a user agent is created on the end user’s computer, which handles data exchange as well as application initialization. On starting and closing the application, the agents participating in the same collaborative session make sure that each participant has the same product model with the one found on the web-based platform. In case an agent identifies incompatibilities in a physical file (i.e., a texture), then it requests the “server” version of the file, or it updates the server file to the local version, on closing the application, for future use. The data versioning is performed server side by the web platform.

The interface between the web platform and the multicriteria decision support (MCDS) tool is currently based on a parameter passing (similar to the other interfaces) through the http protocol, because MCDS is itself a web application. This interface is to be extended in the future to support the data exchange too, with the use of web services.

3.4.2 Collaborative CAD Tool

A collaborative CAD tool (CoDesigner) has been developed to allow users (product/part designers) to launch real-time, online, concurrent CAD sessions. The development approach has been based on a mechanism that translates typical CAD commands into XML files, which are transmitted to different CoDesigner application instances, that ‘listen’ to the same topic, and then are translated back into CAD commands. The main benefit of the “commands-based” approach is that the size of the data transmitted is small, because the geometry details (e.g., edges, vertexes, surfaces, etc.) are created locally, at each CoDesigner application and this usually huge amount of data is not transmitted over Internet. An example of the XML representation of CAD commands is given in Fig. 3.5. However, a limitation is that

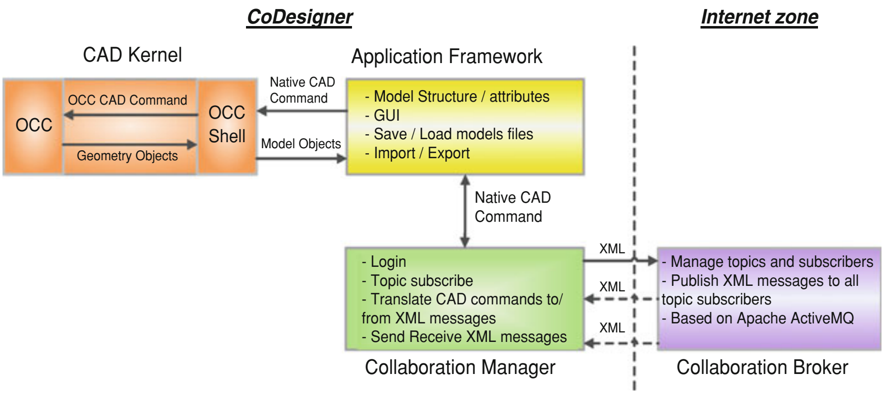

Fig. 3.6 CoDesigner s/w component architecture

for the application to be integrated into a heterogeneous CAD tools environment, a translation from the XML-based commands to a specific CAD tool command is required. Currently, the integration into other CAD systems is achievable "off-line" through the export and import of neutral formats, such as STEP, IGES, BREP, STL, and VRML. However, a real-time integration with other CAD systems using the "command-based" approach is feasible (Li et al. 2007), but would require further development of the CoDesigner, especially in the direction of translating the XML commands into native CAD commands for a specific CAD tool.

The CoDesigner consists of the following modules (Fig. 3.6):

- *CAD kernel*: The CAD kernel is based on the OpenCascade engine (Open CASCADE web pages http://www.opencascade.org/). It provides the required application-programming interface to create, manipulate, and visualize geometry.
- *Application framework*: This module provides access to the CAD kernel functionality, enables the management of the model information (load, save, select objects, etc.), and provides the end user with the necessary graphical user interface (GUI).
- *Collaboration manager*: This module handles the collaboration among different CoDesigner applications. It is responsible for translating native CAD commands into XML messages and sends those messages to the *collaboration broker* that is responsible for dispatching the messages to all the subscribed clients.
- *Collaboration broker*: This module is based on the Apache ActiveMQ message broker. Different CoDesigner application instances may communicate by subscribing and publishing topics in the server.

3.4.3 Virtual Reality Tools

The integration of a VR tool into the CPD allows users to create, share, and review, in a collaborative way, the virtual prototype of the product. A commercial

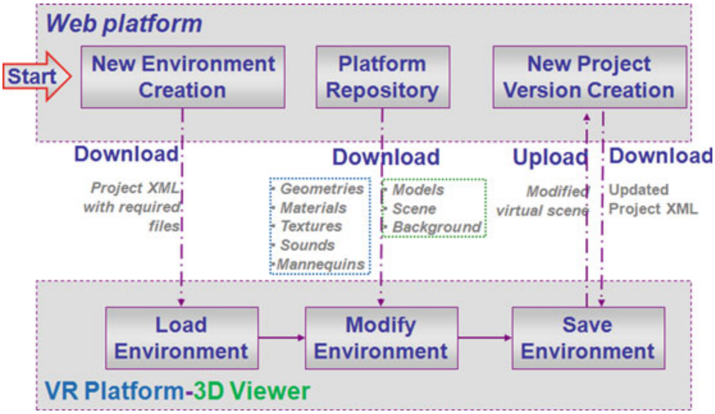

Fig. 3.7 Web platform-VR tools integration

VR platform (DIVISION Mock-up web pages http://www.ptc.com/products/division/mockup) and a non-commercial 3D viewer (GIOVE) (Vigano et al. 2007) have been integrated into the CPD platform and have been tested with different design review use cases. Customized user interfaces have been developed to facilitate user interaction with the virtual prototypes and CPD-related functionality.

The interface of the VR tools to the collaborative platform is implemented through the exchange of formed XML files. The users have the capability of downloading and uploading a virtual environment and their basic elements through the web (Fig. 3.7).

The VR tools are seamlessly integrated into the web platform, so as to be directly accessed through the platform's GUI. Through the web platform, users can initialize the VR tools in both a standalone and/or a client/server mode. The flexible and modular architecture of CPD allows the integration of other commercial or research VR tools that fit better to the design review needs.

3.4.4 Multi-Criteria Decision Support Tool

Based on some background research work (Chryssolouris 1987; Chryssolouris et al. 1994; Chryssolouris et al. 2000; Alexopoulos et al. 2007), an MCDS tool has been developed to provide decision-making assistance to a group of experts, in the final phase of their collaborative product design, by evaluating and comparing alternative product designs. The MCDS workflow is separated into three distinct phases:

- *Configuration phase*: In the configuration phase, a user may configure the details of an evaluation process. The details include:

– *Criteria and their weights*: Based on the decision policy, the manager of the design project identifies a set of criteria $CR = \{cr_1, cr_2, \ldots, cr_N\}$ by their weights $W = \{w_1, w_2, \ldots, w_N\}$, where N is the number of criteria. A criterion may be a benefit or a cost one. Should it be a benefit criterion, then the high values indicate its good performance, whereas if it is a cost one, high values indicate bad performance.
– *A list of alternatives* $A = \{a_1, a_2, \ldots, a_M\}$, where M is the number of alternatives. The alternatives indicate the different design solutions that should be evaluated.
– *A list of evaluators* $E = \{e_1, e_2, \ldots, e_S\}$, where S is the number of evaluators. The estimators may be other users that will evaluate the alternatives to the configured criteria. Moreover, for each evaluator, a list of weights $EW = \{ew_{11}, ew_{12}, \ldots, ew_{1N}, \ldots, ew_{S1}, ew_{S2}, \ldots, ew_{SN}\}$ is defined for each evaluator/criterion pair, depending on the evaluator's role and technical background.

• *Data entry phase*: Following this configuration phase, the participants of the collaborative evaluation session (evaluators) may indicate values for each criterion and design alternative. The output of this phase is a matrix $S_s = \{s_{11}, s_{12}, \ldots, s_{1M}, \ldots, s_{N1}, s_{N2}, \ldots, s_{NM}\}$ for each evaluator s in [1, S] that defines the score for each alternative/criterion pair.
• *Evaluation and report phase*: The final step is the evaluation of the alternatives, based on the evaluators' scores from the previous phase. Initially, the score of each alternative for each criterion is calculated by the average value of all the evaluators' scores. Thus, $SC_n = \{sc_1, sc_2, \ldots, sc_N\}$ is a vector with the scores of alternative m in [1, M] for all N criteria and

$$sc_{mn} = \frac{\sum_{s=1}^{S} (s_{smn} \times ew_{sn})}{S}. \tag{3.1}$$

Then, the values of each alternative/criterion pair are normalized. The normalized values are given in case of the benefit criterion by equation

$$\overline{sc}_{mn} = \frac{sc_{mn}}{\sum_{m=1}^{M} sc_{mn}} \tag{3.2}$$

and in case of the cost criterion by equation

$$\overline{sc}_{mn} = \frac{1}{M-1}\left[1 - \frac{sc_{mn}}{\sum_{m=1}^{M} sc_{mn}}\right]. \tag{3.3}$$

The utility (final score) of each alternative is calculated by the weighted sum of the normalized scores as follows:

$$u_m = \sum_{n=1}^{N} (\overline{sc}_{mn} \times w_n) \tag{3.4}$$

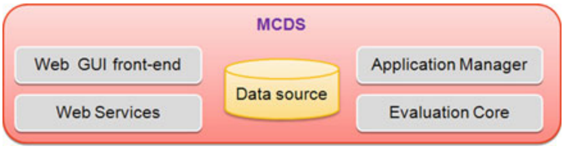

Fig. 3.8 MCDS s/w component architecture

As an output, the decision engine reports a relative ranking of design alternatives u_m.

The MCDS tool is running on a web applications server (Apache Tomcat) and it is composed of the following modules (Fig. 3.8):

- *Evaluation core*: This module is responsible for the calculation of each alternative's score. Its input is a list of alternative solutions, a list of criteria with their relative weight, a list of evaluators, and the scores of the evaluators for each alternative-criterion pair. The output is a ranking of the alternatives, based on the calculated scores.
- *Data source*: This module handles the persistency of the domain data. It uses XML as a means of storing and retrieving MCDS data. It is also responsible for the serialization of the data from the XML format into memory data structures and vice versa.
- *Application manager*: This module is responsible for managing the dataflow among the data source, the external actors (such as end users and other applications), and the evaluation core. Additionally, it provides basic security/login functionality.
- *Web GUI front-end*: This module provides a GUI through a web browser for the end users to use the MCDS functionalities.
- *Web services*: This module provides access to MCDS through the web services interface.

3.4.5 Augmented Reality/Virtual Reality Modeling Language Tools

The authoring module of the web-based collaboration platform enables the users to upload the new product models to the company's online catalogue. VRML and AR viewers have been integrated to the web platform to enable the users visualize these product models for demonstration and customization purposes (Fig. 3.9). A free plug-in (BS contact) has been used to provide the required functionality for a VRML viewer. Through this viewer, users can explore the product's web-based catalogue and interact with it in a 3D mode.

A commercial AR platform (Metaio Unifeye web pages http://www.metaio.com/) has also been integrated into the web platform. Through a lightweight online

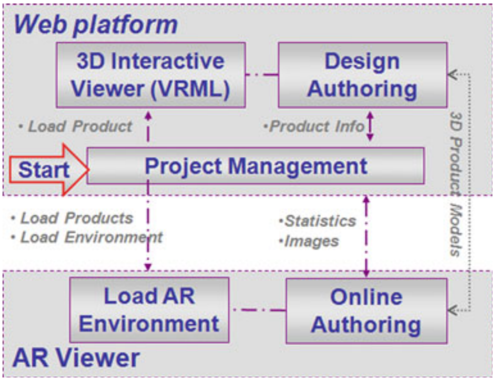

Fig. 3.9 Web platform: AR/VRML tools integration

application, CPD users can visualize the product models within real environments by creating mixed reality scenes that consist of realworld digital image data and virtual 3D models.

3.5 A Test Case

An integrated demonstration of the CME, in which CPD resides, has taken place, based on a real life–like scenario (DiFac 2009).

A manufacturer of laser cutting machines and systems (end user of the IMS DIFAC EU project) has provided the demonstration scenario and participated in the demonstration case study. The company's working practices on product development involve the use of a number of commercial tools (e.g., CAD modeler, viewer, PDM, etc.). The different actors, involved in a company's project, usually have to cope with different environments and with different software platforms. Everyday communications are mainly based on e-mailing and phone calls. When decisions have to be made, all the involved actors, such as R&D people, customers, engineering technicians, and managers, should meet physically. Thus, numerous trips need to be planned during a product development project.

The CPD-related part of the demonstration scenario involved the online collaboration during the modeling, review, and evaluation of new design solutions for specific parts/components of the machine and the interactive web-based demonstration of the new laser machine to customers. The online collaboration during the modeling, review, and evaluation of new design solutions for the tip-nozzle and the air-sensor tube of the new machine laser head is indicatively described hereafter (Fig. 3.10). The scenario framework of the collaborative design process is shown in Fig. 3.11. All the actors that were involved in the demonstration case study had received a daily training on the use of the CPD tools.

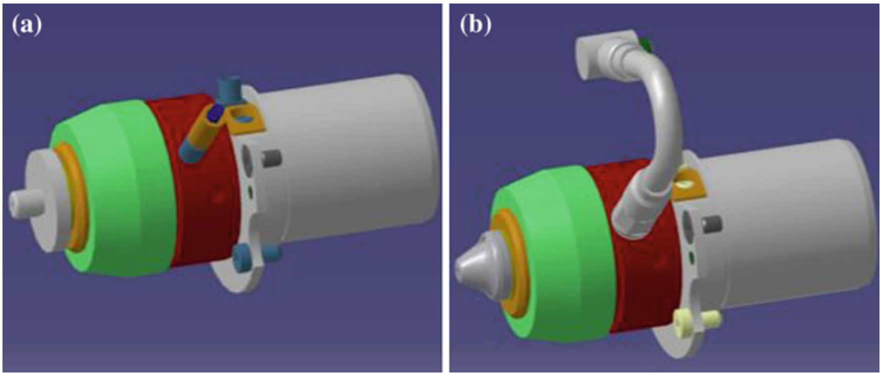

Fig. 3.10 The alternative design options addressed within the pilot scenario

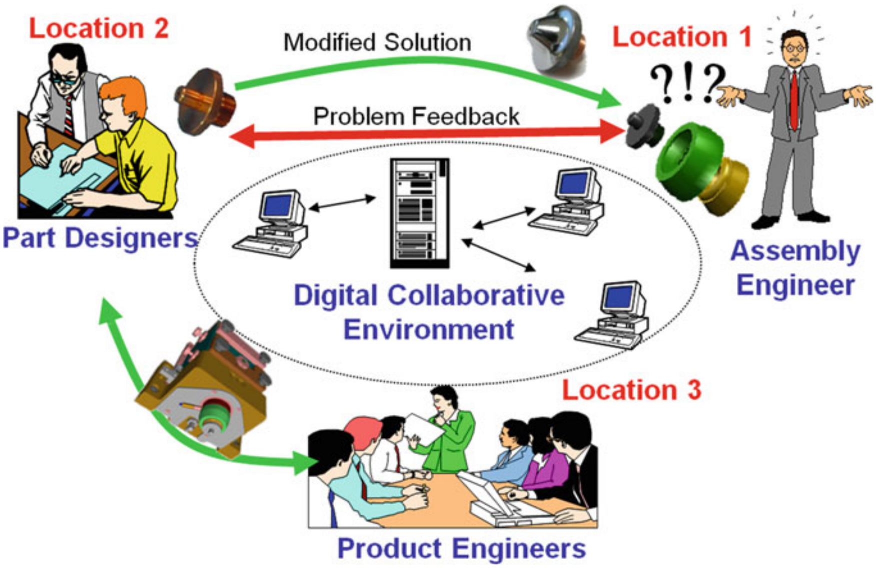

Fig. 3.11 The scenario framework for the collaborative design of a new part of the laser machine

The first step has been the launching of a design project for each new part and the assignment of the appropriate access rights to the people to be involved in it. A series of collaborative design sessions for the new parts of the laser head have then taken place. The web-based collaboration platform of the CPD has provided the users with content management and synchronous communication functionality throughout the overall process (Fig. 3.12).

First, a series of collaborative design sessions have been launched each one involving two remotely located designers. Based on previous experience and

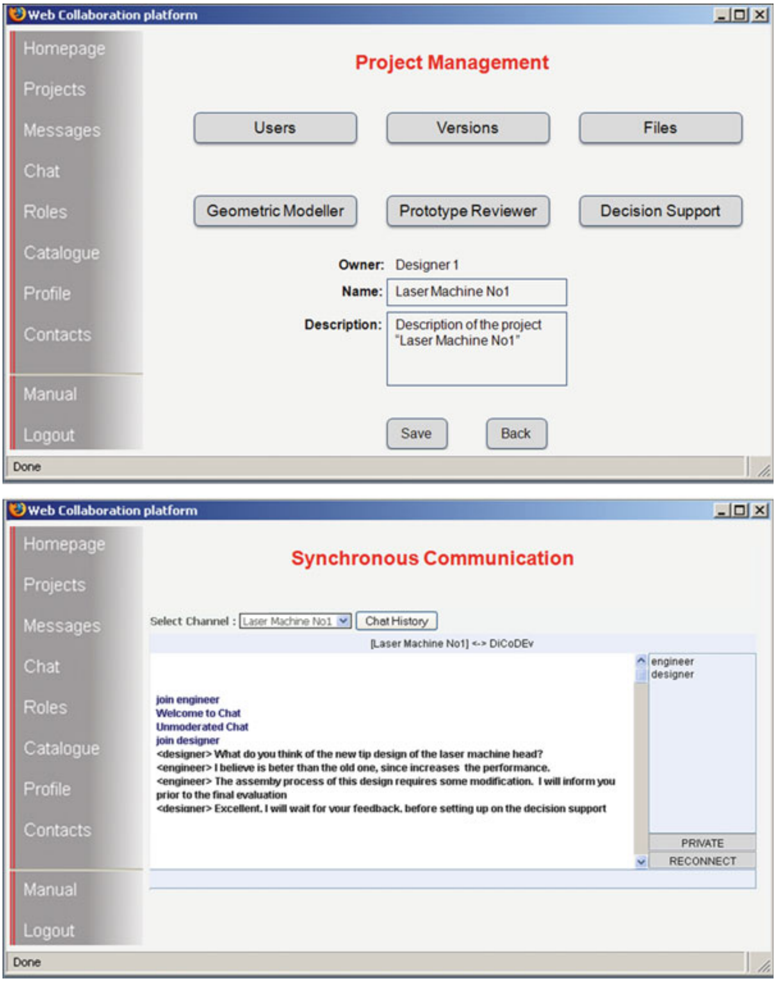

Fig. 3.12 Content management and synchronous communication in CPD collaborative sessions

market requirements about the new machine's features, the designers have used the CoDesigner module of CPD to create together the alternative design solutions for the tip-nozzle and the air-sensor tube. For each part, they worked together on the same model concurrently (Fig. 3.13). Each one creating, in real time, some specific parts of the geometry, while both viewing all the modifications incurred on the model and interacting with each other.

Concurrently with the design process, a series of collaborative sessions have been launched to be reviewed, at product and process level, the design alternatives being developed. The product manager, a designer, and an assembly engineer have been remotely engaged in each session. They have used one of the CPD VR platforms to share the virtual product models, including the newly developed parts,

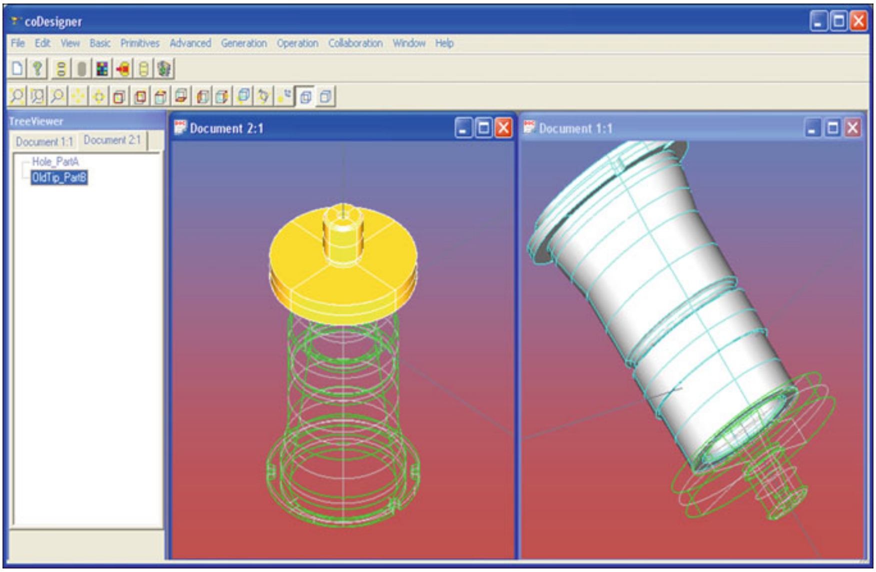

Fig. 3.13 Multiuser collaborative product design session

to visualize and jointly review the alternative options regarding the product structure and the respective assembly process, while interacting with each other for commenting on the design process output (Fig. 3.14).

Having followed the review sessions, it is evident that the selection of the best alternative design option for the new parts of the laser head is not a straightforward task, because several criteria could affect the final decision. Thus, a collaborative evaluation session has been launched for each of the two newly developed parts, using the MCDS module of CPD (Fig. 3.15). The product manager has defined the set of criteria, against which he has considered important the evaluation of the alternative design options, together with their relative weights. Five remotely located product engineers have been engaged in the collaborative session and indicated their expert-based assessment of each option with respect to its cost, performance, ergonomics, and aesthetics. Simulation data, coming from the factory constructor tool of the CME, have also been used for providing values of two additional evaluation criteria, namely, the total throughput and the average lead time. Based on the experts- and simulation-based inputs, the MCDS tool has provided a relative ranking of the design alternative solutions for each new part. Its metrics-based proposition has indicated that the design options shown in Fig. 3.10b are the good ones, with respect to the defined decision policy.

Finally, in the latest phase of the integrated CME demonstration, the CPD has been used for the interactive web-based demonstration of the new laser machine (Fig. 3.16). A product engineer and a potential customer have been remotely engaged in a collaborative demonstration session within the virtual

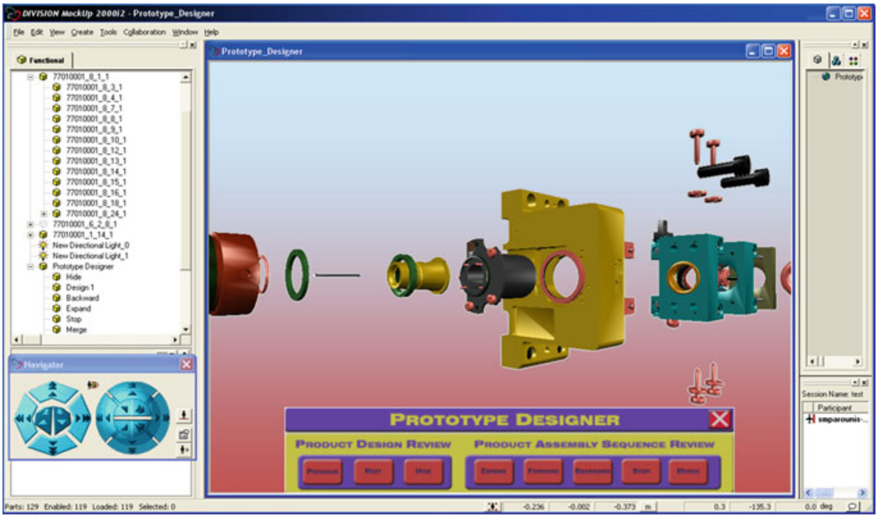

Fig. 3.14 Multiuser collaborative product review session

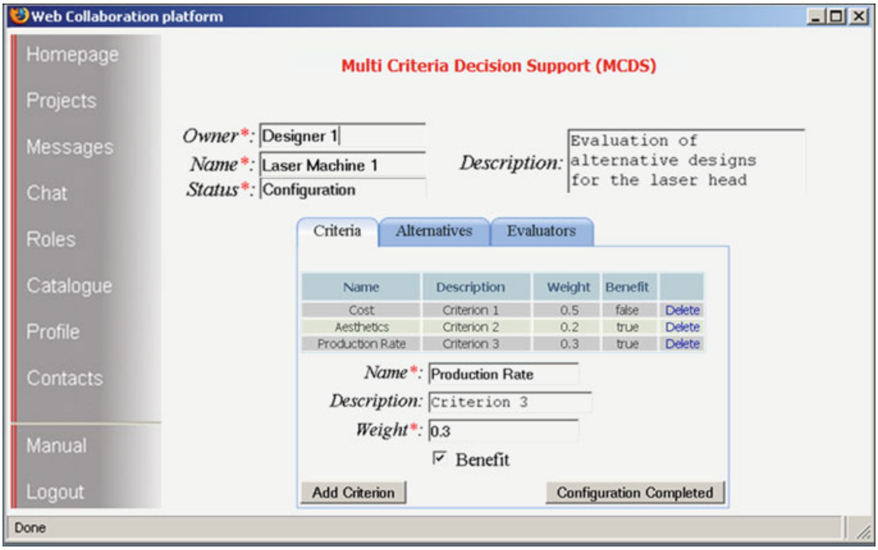

Fig. 3.15 Collaborative decision making for evaluating alternative solutions

showroom of CPD. Using the online product catalogue, offered by the virtual showroom, they have set up together the laser machine configuration. Then, they placed the machine within a virtual representation of the real working environment of the customer's facilities, reviewed together issues related with the work cell layout, ergonomics, and safety, and agreed on some required customizations.

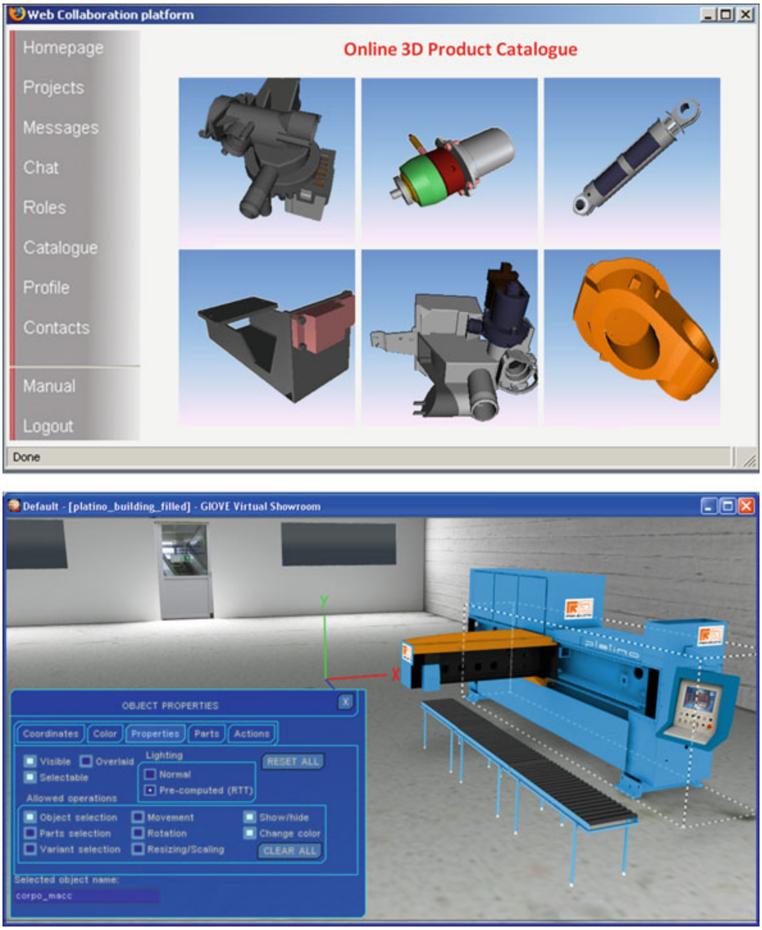

Fig. 3.16 Online product catalogue (3D interactive) and multiuser showroom

Besides this demonstration case study, further testing of the CPD has been carried out in the context of the IMS DIFAC EU project activities. The overall testing phase lasted approximately 1 year, including the evaluation of several versions of the related tools. This testing involved:

- Two industrial partners of the project, namely, a manufacturer of laser cutting machines and systems and a carpet manufacturer;
- A *users group*, comprising external industrial companies (mainly SMEs), which has been set up to account for a broader evaluation scope of all the tools developed by the project.

The main strong points of the CPD, as reported during the evaluation, included the collaboration functionality, the capability for multimode (CAD/VR/AR) visualization, and the overall user friendliness of the web- and VR-based platform. The main recommendations for improvement referred to the CAD functionality, the user interface of the integrated system, and the seamless integration of the individual tools. The industrial companies that participated in the evaluation process reported that the CPD clearly demonstrates a big potential to shorten the development cycle and reduce the development cost of their products. On the other hand, they reported that a couple of challenges still exist for the use of such tools by SMEs, such as the required customization to fit to their special needs and the high costs associated with the use of sophisticated hardware in case of special visualization needs.

3.6 Conclusions

The CPD provides different functionalities for real-time collaboration among geographically dispersed user groups during product design activities. It is an integrated solution for collaborative product modeling, review, evaluation, and demonstration. The CPD has a flexible architecture, which integrates design activities, processes, methods, and tools into a modular feature, easy to be used and further extended. It may be used for a wide range of products. As such, it may be considered an appropriate tool for SMEs that cannot usually afford in their processes to integrate a suite of sophisticated, large-scale, off-the-shelf tools. The CPD provides an integrated set of tools for:

- Real-time geometry modeling of the same part/component by multiple users (CoDesigner)
- Online interactive review and demonstration of mechanical and non-mechanical products (VR/AR/VRML tools)
- Systematic decision support within a collaborative product design environment (MCDS)
- User-friendly communication and PDM (web-based collaboration platform)

In the context of the DiFac project, the CPD has been tested by using realistic design scenarios for both mechanical (e.g., laser machine) and non-mechanical (e.g., carpet) products.

In the short term, further work will mainly focus on extending the CAD functionality of the CPD. The CoDesigner has been providing so far only standard 3D CAD functionality (compared with other world-class tools), because the focus has been mainly on the real-time collaboration capability. A real-time integration with other CAD systems, using the "command-based" approach, will be investigated for its usability to be further extended. Providing collaborative product review functionality, with respect to engineering analysis activities, would be important as well.

In the longer term, the aim would be to extend the CPD functionality to addressing some key relevant challenges of the future Digital Factory frameworks, such as:

- Interoperability, and consistency of data, information, and knowledge, across the different stages of design
- Extracting, interlinking, and using of knowledge from different simulation results and domains to support decision making
- Use of more intelligent product/process models providing predictive capabilities to further reduce the need for physical prototyping
- Synthesis methods to account for sustainability and holistic life cycle assessment during product development.

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