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"DESIGN CONSULTANT": A NETWORK-BASED CONCURRENT DESIGN ENVIRONMENT

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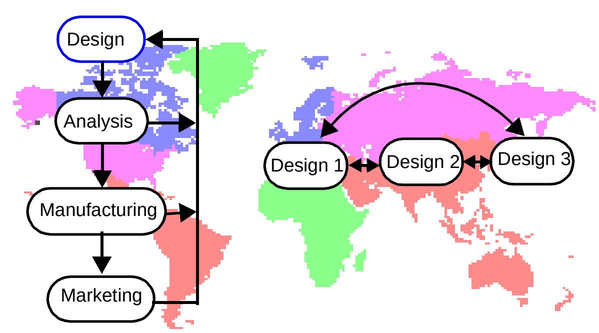
ABSTRACT

In today's globally distributed business environment, resolution of the communication problems between team members is a critical issue. A project named the Design Consultant has been launched to improve inter/intra-departmental communications. Leveraging available Internet technology, the Design Consultant enables designers to share design information with other team members including colleague designers, CAE analysts, manufacturing engineers, and marketing engineers. The network accessible DFX modules assist designers to simulate manufacturability and to estimate cost and time for fabrication resulting in faster product development. Building blocks of the Design Consultant were established based on a 3-tier client/server architecture, and feasibility tests were successful. As part of the feasibility tests, the Design Consultant for Part Reuse and the Design Consultant for Rubber Molding were implemented to prove the concept of the network-based Concurrent Engineering.

INTRODUCTION

"Globalization" is one of the main trends of today's business organization. Globally distributed design, analysis, manufacturing, and marketing facilities provide competitive advantages of technology, natural resources, and culture. However, at the same time, in the fields of design and manufacturing, a globally distributed business environment introduces potential communication problems that must be resolved.

Two kinds of communication problems are expected. One is *vertical* communication which is based on the sequence of product development, i.e. from the design of a new product to Computer Aided Engineering (CAE), manufacturing, and marketing of the product (Figure 1a). Although the communication problems between different departments have existed even before the introduction of distributed business environments, it is certain that communication between geographically distributed departments is far more complicated, and it may delay information flows.



(a) Vertical Communication (b) Horizontal Communication

Figure 1. Two kinds of communications in a distributed business environment.

Another potential problem is in *horizontal* communication between the people performing the same nature of work (Figure 1b). For example, a designer in the US may find it difficult to collaborate with other designers working in Europe and Asia. Considering the design environment in many of large corporations, seamless communication is not readily available partially due to the limitation of the localized network environment (Ethernet or Local Area Network, LAN, Figure 2). Engineers within the same network may share the design information, but the engineers working at remote network cannot easily access the information.

In addition to the communication problems, integration and deployment of software between heterogeneous platforms are becoming issues in the distributed business environment (Prasad 96). When there are multiple design sites working on the same kind of product, the deployment, modification, and maintenance of the software are not trivial problems.

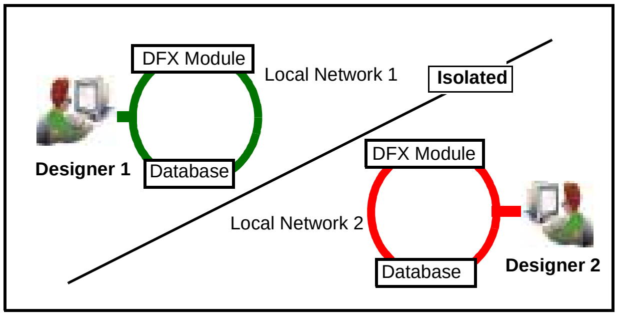


Figure 2. Isolated design environment with localized networks.

In this paper, a solution for the potential problems is proposed applying today's Internet technologies (including Intranet and Extranet) and the concept of Concurrent Engineering (CE). The network-based Design For X (DFX) modules and data access will accelerate both vertical and horizontal communications in distributed design and manufacturing environments, resulting in reduced product development time and cost.

CONCURRENT ENGINEERING BY DFX MODULES

In the last three decades, a number of valuable paradigms have been introduced to reduce time to market and manufacturing cost: they range from Computer Integrated Manufacturing (CIM) to Agent Based Manufacturing and Concurrent Engineering(CE). Studies shows that about 70 to 80 percent of the total cost of a product is determined in the design stage (Hundal 93). Considering the significance of the design stage, CE concepts such as Design for Manufacturability (DFM), Design for Assembly (DFA), Design for Cost (DFC), and in general Design for X (DFX) have been introduced to pull downstream manufacturability information upstream to the design stage. Consequently, various DFX modules are often integrated into legacy and commercial CAD systems in today's design environment, e.g. Ford Motor Company's DFM Design Advisor (Liou and Riff 94). A typical DFX module contains knowledge about the manufacturing, assembly, quality, or cost of a specific fabrication process. With help of the DFX modules, a CAD designer can perform various simulations to detect potential problems of designed parts. The simulation process at the design stage saves time and cost that would be spent later in design iteration to meet the requirements of manufacturability and cost. Figure 3 shows the benefit of using DFX modules in terms of product development time.

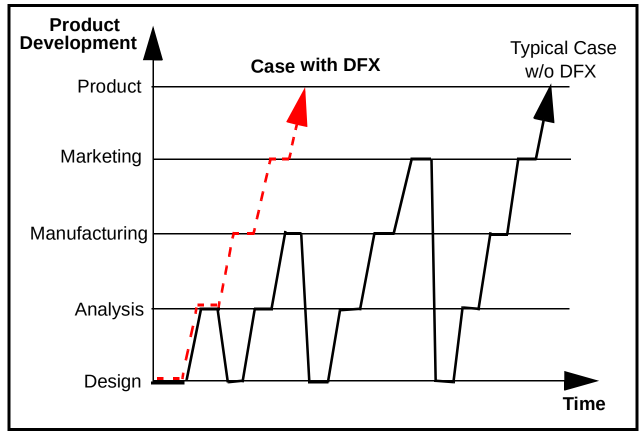


Figure 3. Schematic improvement of product development time from applying DFX modules.

APPROACHES

Sharing information between team members within a corporation is possible when they have the *willingness* and *capability* (Jagannathan, *et al* 94). Assuming that team members have willingness to communicate and to share information during product development, provision of communication capability is an important prerequisite to make distributed design and manufacturing possible and more effective. Three key approaches to promote effective communications in distributed design environment are discussed in the following sub-sections.

Network-Based DFX Modules

To cooperate in the distributed design environment, DFX modules must be accessible via a network. A number of researchers have proposed Internet-based communication and coordination architectures for a distributed design environment (Frost and Cutkosky 98, Dabke, *et al* 98, Sands and Raja 98). For example, Huang, *et al* have begun work in creating a standard Internet-based DFX shell which provides a framework in which many types of DFX tools can operate (Huang, *et al* 99). Pahng, *et al* and Dabke, *et al* have built extensive systems to facilitate Internet based design modeling and optimization (Pahng, *et al* 98, and Dabke, *et al* 98). Others have designed and built systems whose focus is to integrate the design process with a particular manufacturing process (Karne, *et al* 98, Wang and Wright 98, Rajagopalan, *et al* 98).

Each of these efforts has a particular focus and uses a different mode of integration, however they all coordinate distributed design and manufacturing modules over the Internet. One interesting feature of almost all of the work cited here is that for a software agent to interact with the overall system the agent has to be designed specifically for the integration system, or extensive programming needs to be done in order to create a piece of software acting as an interface which mediates between the agent and the integration system. As will be discussed later, an effort is being made to develop a generic interface to the system in order to allow for diverse types of DFX modules to connect to and interact with the system without extensive re-coding.

A client/server model is desired to effectively accommodate multiple users at the same time. In the model, the server contains DFX modules with many different functionalities while the client software has the ability to access the server via the Internet. When a client-user wants to estimate the cost of a component made by machining and injection molding, for instance, the client connects cost estimation modules on the "machining server" and "injection molding server" to the local CAD system.

Network-Based Access to Design Information

Exchange of design information and prompt access to existing designs are issues in a large manufacturing corporation (Sheng and Pan 98). To address these issues, standard exchange formats such as the Standard for the Exchange of Product Data (STEP) (STEP 92) and Initial Graphics Exchange Specifications (IGES) (IGES 92) have been used with distributed databases (Sands and Raja 98, and Kim, *et al* 98). Additional product and process models have also been introduced (Bettig and Shah 98, Shah, *et al* 96). The RaDEO project was largely concerned with the data management concerns that arise in distributed systems (RaDEO 99). Dong and Agogino (Dong and Agogino 98) have also proposed a tool to more easily exchange CAD files. Many commercial Product Data Management (PDM) systems allow designers to publish their designs and also allow other engineers access to the designs during product development (Miller 98 and Metaphase 98). One recently released commercial tool actually allows users at different geographic locations to modify a single design together over the Internet (OneSpace 98).

While one of the desired formats to *exchange* designs and to store them in databases is STEP, a platform independent neutral format such as Virtual Reality Modeling Language (VRML) is considered as a *viewing tool* for non-designers who do not usually have access to any legacy CAD system or STEP Viewer. A study by Szykman and Sriram indicates that using VRML over the Internet is a highly effective way to communicate design and manufacturing information (Szykman and Sriran 98). VRML, as the format both to carry DFX results and to access design geometry, will benefit most of the engineers involved in a particular product development. Even without high-end workstation, anyone can see and interact to limited extent with the part design on a personal computer (PC).

Platform-independent User Interface

A platform-independent user interface is critical in a heterogeneous platform environment. Effort and cost for the system integration, software deployment, and maintenance can be reduced applying platform-independent programming and modeling languages. The Java programming language offers a platform-independent run-time environment, and a Java applet can be downloaded by any Java compatible web browser on any hardware platform (Camione and Walrath 98). Developed as an industry standard, Common Object Request Broker Architecture (CORBA) infrastructure makes codes written in different programming languages interoperable (Siegel 92). Another platform independent language, VRML, (Hartman and Werecke 98), can convey manufacturability information associated with DFX modules to the users of the Design Consultant.

OVERVIEW OF THE DESIGN CONSULTANT

Based on the above system requirements, a project named the "Design Consultant" (DC) has been developed. A Design Consultant is a Java applet connecting remote DFX modules and databases to a local CAD system. In a wider definition, the Design Consultant includes a communications architecture, DFX capability, and a methodology for sharing design information, promoting Concurrent Engineering in a distributed environment.

Architecture

The typical communication structure of the Design Consultant implements a three-tier client/server architecture that offers multiple users access to the same server as well as easy modification of its functionality. However, a two-tier architecture could be applied for simple and light-weight applications. The detailed components of the Design Consultant may vary depending on its user; in particular, designer vs. non-designer. Figure 4 shows a schematic architecture of the Design Consultant for an expert designer while Figure 5 represents components for a non-designer. The CORBA connection in Figure 4 enables the Design Consultant to be plugged into a CAD system to access CAD geometry. The client for non-designers (Figure 5) requires only a Java-compliant web browser, which provides easy access to the design information stored within the network.

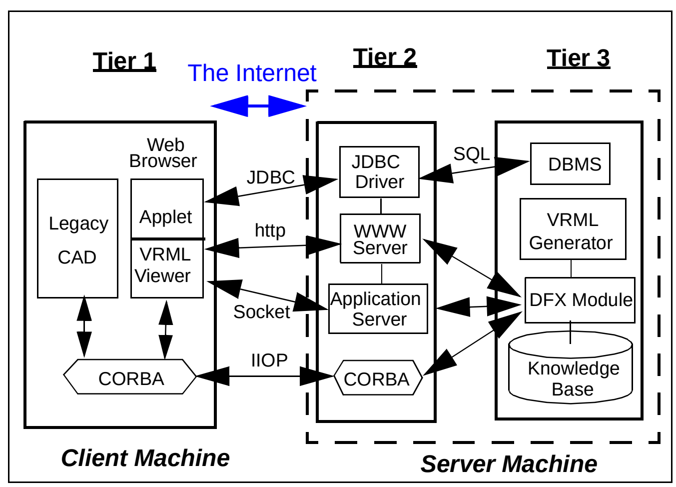


Figure 4. A communication architecture of the Design Consultant for the Designer.

The first tier in Figure 4 and 5 is the "client" consisting of the Design Consultant applet and a user-specific application, e.g. a CAD system for a designer or a Finite Element Method (FEM) tool for a structural engineer. The Java applet is downloaded from the server to the client machine by a commercial web browser. In Figure 4, taking advantage of the platform-independent characteristics of the Java, the Design Consultant is ready to be executed at any platforms, e.g. UNIX, PC, and Macintosh without compiling the codes again. The VRML viewer runs within a web browser as a plug-in application to display a three-dimensional view of the part geometry combined with DFX information which can be annotated on the geometry. The communication via CORBA (Internet Inter-ORB Protocol, or IIOP) allows object communication between the CAD system and the applet, or between the CAD system and the DFX module.

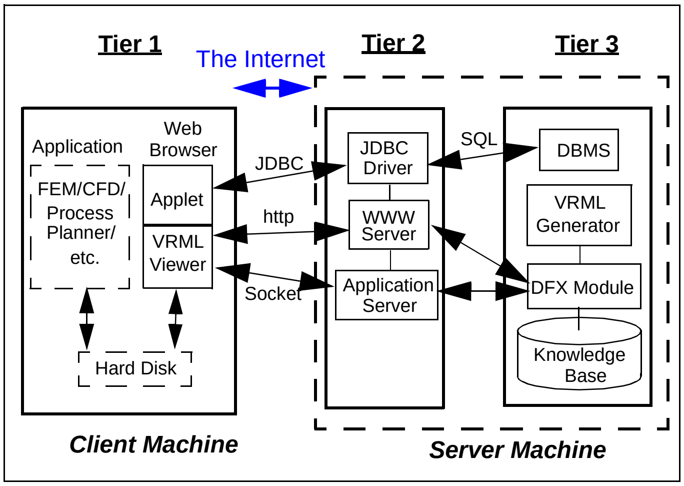


Figure 5. A communication architecture of the Design Consultant for the Non-Designer (*Application* and *Hard Disk* in Tier 1 are optional components).

The second tier, the gateway to the first tier, sends and receives communication protocols via the Internet. As a middle ware, it activates a DFX module upon the user's request and returns query results and design data from the database. Since the Java codes are stored in a World Wide Web (WWW) server in the second tier, deployment of the code, the change of any functionality, and maintenance is easy. The Java Database Connectivity (JDBC) driver provides direct access to the Database Management System (DBMS) from the Java applet (Hamilton, *et al* 98). Another component in the second tier is an Application Server. The role of the Application Server is to communicate to the applet running in the client machine in order to manage activities of the components in the third tier.

The third tier contains the data and knowledge of the Design Consultant. The DFX module accesses the Knowledge Base, which typically is codified manufacturing knowledge such as manufacturability, cost, and time estimation accumulated from experienced engineers. The VRML Generator translates a three-dimensional CAD design into the VRML format to show the design to other engineers. Another important role of the VRML Generator is to include DFX simulation results, such as manufacturability and cost, associated with pure geometry information into a VRML file.

FEASIBILITY TESTS

For feasibility testing purposes, building blocks of the Design Consultant and its communication links were established in a distributed environment. Both IBM-compatible PCs with Windows NT and Unix workstations (SUN and HP) played the role of the client while Unix workstations played the role of the servers.

DC for Part Reuse

As part of the feasibility test, a Design Consultant for Part Reuse which has the ability to find previously designed parts which meet user specified geometric constraints was developed. The architecture for this system follows that shown in Figure 4. A Java applet connects to a local CAD system (SDRC's I-DEAS Masters Series 6 in this case) via its CORBA based Application Programming Interface (API) (Open I-DEAS 98). Parts are designed on the CAD system and checked into a remote Oracle8i database (Honour, *et al* 98). Certain key geometric features are calculated and stored in the database with the CAD file. In our test, the bounding box, the slope and curvature of the front face along the principal directions were stored in the database. Additionally the user is able to search for and retrieve previously designed parts in the database which match his/her bounding box, slope, and curvature requirements. As shown in Figure 6, the user specifies the geometric requirements in the Java applet which then connects to the remote database and returns a list of parts that meet requirements. The user can then download any one of these parts into the local CAD system. IONA Technology's Orbix2 (Orbix 97) and OrbixWeb3 (OrbixWeb 97) were used to provide the CORBA connection between the CAD system, Java applet, and remote DFX module. Also, in order to overcome the inherent restrictions of Java applet accessing the local machine (accessing CORBA objects in this case), a signed applet was used (Signed applet 99).

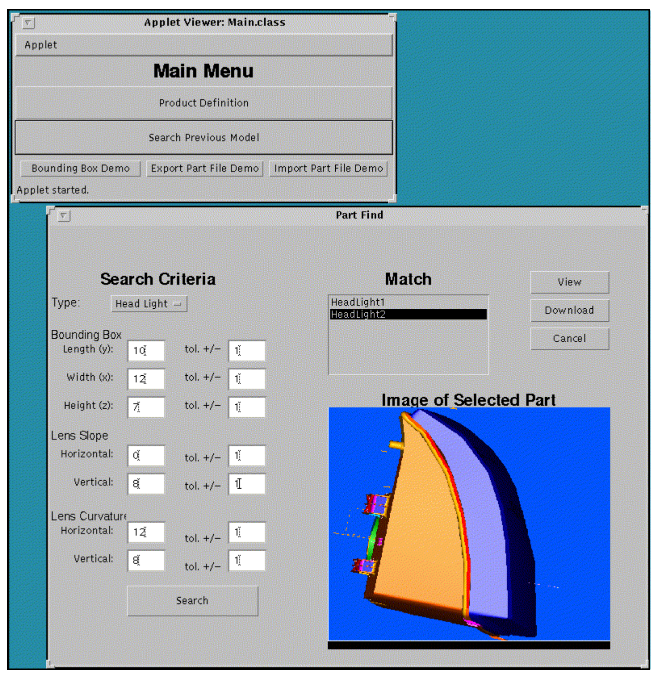


Figure 6. User interface of the Design Consultant For Part Reuse.

DC for Rubber Molding

Another Design Consultant applet has been implemented for the design of rubber molding parts (Figure 7). A rubber molding part is a packaging element that improves the appearance of a mechanical assembly. Single or multi-rubber layers may fill the gaps between adjacent components and may reduce the impacts or vibrations during service. There are several different types of manufacturing methods, and designers and manufacturing engineers have difficulties to determine the proper type of rubber molding for the components with which they are dealing. The Design Consultant for Rubber Molding thus provides a web-based decision making service for the designers and manufacturing engineers. Important design and manufacturing knowledge was accumulated by interviewing a number of product engineers and manufacturing engineers. The knowledge was prioritized in terms of cost and manufacturability and codified as a set of rules to make a final decision as to the manufacturing method and type of rubber molding part. The downloaded applet was able to communicate to the Application Server located in the server side (second tier) in order to dynamically create new web pages which contain previously stored user's input for decision making.

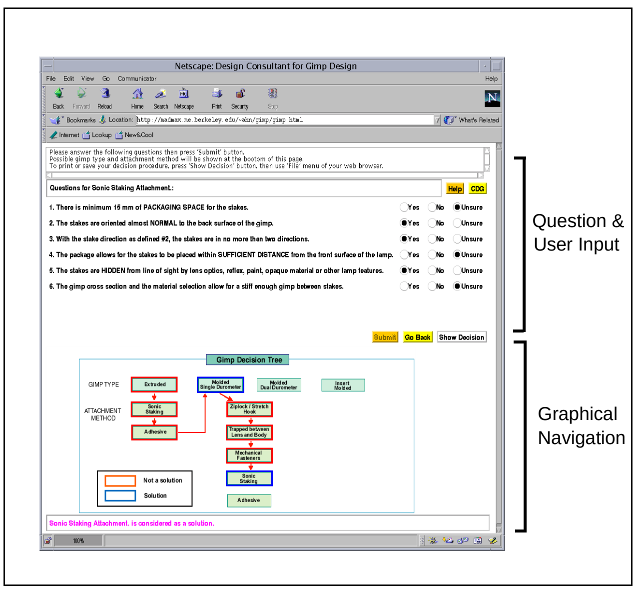


Figure 7. User interface of the Design Consultant For Rubber Molding.

As shown in Figure 7, the user interface consists of "Question & User Input" and "Graphical Navigation". Given the user's answer for each question on manufacturing constraints, the Graphical Navigation panel shows a map of the decision making process and the status of the current decision. To assist a user's decision making, the user interface provides hyper-link to other websites including design guide lines, picture files of typical samples, and descriptions of previously manufactured parts.

SCENARIOS

The Design Consultant can promote vertical and horizontal concurrent engineering when they are combined with the network-based access to design information. The following scenarios explain how the Design Consultant implements vertical and horizontal CE to reduce product development time.

Vertical Concurrent Engineering

In this scenario, a designer (Design A in Figure 8) creates a 3D CAD file of a part with aid from DFX modules to examine manufacturability and to estimate cost and time for fabrication of the part. After some possible redesigns to meet the manufacturability, cost, and time requirements, he/she can publish the design to the corporate database server. Once published, the design is concurrently available to non-designers (CAE, manufacturing, and marketing engineers in Figure 8). In addition to the part geometry, useful information from DFX modules can be accessible to the non-designers. By obtaining the information simultaneously, each of the engineers may proceed with his/her task in a parallel fashion (Figure 9,*).

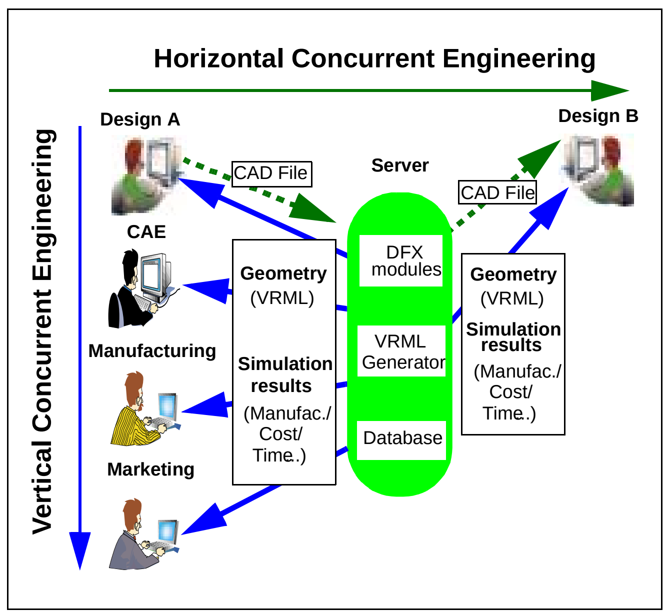


Figure 8. Vertical and Horizontal Concurrent Engineering via network.

Horizontal Concurrent Engineering

Horizontal CE allows designers to share their design information with other design team members. During the design process of a component, a designer (Design A in Figure 8) populates the design by storing it in the corporate database. Other designers working on the same project but remotely located (Design B in Figure 8) may open a web browser to run the Design Consultant applet in order to retrieve the CAD file of the component via the Internet. If there are such design constraints as total cost or delivery due date for entire assembly, the designers can run a DFX simulation for the other designers' components using the Design Consultant, then modify their components to meet the requirements. The horizontal concurrent engineering may reduce the time required for a design team to design an assembly with multiple components (Figure 9, **).

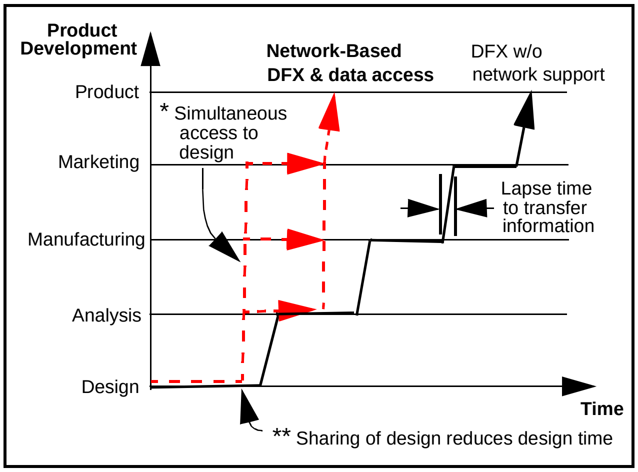


Figure 9. Schematic improvement of product development time from applying DFX modules.

CONCLUSION

In this paper, we introduced a network-based Concurrent Engineering architecture to accelerate product development. To promote Vertical and Horizontal Concurrent Engineering, a project named the "Design Consultant" was created providing network-based DFM and database access. The Design Consultant allows designers i) to access DFX capabilities via the Internet, ii) to share design information with other designers resulting in reduced design effort and time. Another functionality of the Design Consultant is to share designs, manufacturing and cost informations simultaneously with other team members in downstream product development allowing them to perform their tasks in a parallel and concurrent manner. Implementation of the concept in a distributed corporate environment was possible utilizing today's Internet technology. The construction of components and integration between each component were successfully achieved during feasibility tests. The Design Consultant for Part Reuse and the Design Consultant for Rubber Molding were created and demonstrated the potential effectiveness of the network-based Design Consultant in distributed business environment.

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FUTURE WORK

During the development of feasibility tests we quickly realized the need to further standardize the interfaces between the DFX modules on the server side, the Java applet on the client side, and the database. Like most other distributed DFX environments, the interfaces for each feasibility demonstration are specific to current project. When a new project starts, extensive re-coding needs to be done to adapt the middle ware which mediates communication between the client, DFX modules, and the database, to the current project. With this need in mind, we are working on a generic framework for the integration of distributed design and manufacturing tools. This framework is called the Design Consultant Shell (DCS).

Using the DCS, a designer or group of designers can access and integrate DFX modules, which are made available on the internet, into a unified design environment without having to re-code the DFX module, the client applet, or any interface software. Unlike many distributed environments, software modules do not have to be specifically designed to run within the DCS system. Legacy software that is made available on the Internet can easily be integrated into the system by specifying a few communication parameters. The goal is to develop a framework that will allow easy integration of DFX, CAM, CAPP, etc. services over the internet making sophisticated analyses widely available to companies and individuals with limited computing resources. It will also make the creation and deployment of distributed design and manufacturing systems in large globally dispersed companies much faster and easier.

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