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Virtual Prototyping – Design and realistic presentation of industrial products

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Abstract

In this paper we present a concept for the general application of an integrated Engineering–system (CAE–System) in an upholstery–enterprise. The expositions describe a system–independent solution and an exemplarly implementation by using standard–software–tools. This paper focusses on the design–stage of the product development process. The benefits for enterprises by designing upholsteries with an integrated computer–based system are shown, for example drastically reduction of conventional manufacturing of specimen and reduction of product development time.

Keywords

CAE–System, 3D–Modeling, Virtual Prototyping, Product development

1 INTRODUCTION

Problem

Enterprises are acting in surroundings, which are characterized by radical changes over the past years. The fulfillment of customer needs is now the fundamental basis for the competitiveness of enterprises. However their products shall be very reasonable, of first rate and also developed, manufactured, and delivered in short time.

One start to achieve these goals and to enhance the competitiveness is the reduction of the product development process, in the following called CAE[1]–process. Enterprises like furniture–manufacturers, car–makers, clothing industry, aircraft–manufacturers, and shipyards, which all

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produce consumer goods with high importance of excellent product design have to transform the following activities to shorten the time of the CAE–process:

- Use of computer–aided design–tools to develop virtual (computer–based) prototypes, which fulfill the customers needs and also achive a drastical reduction of the conventional production of specimen.
- General support of the product development process with CAE–applications based on an integrated product data model.
- Provision and utilization of standardized parts to reduce and control the variety of modules and parts.
- Integrated project– and process management tools to plan, control and supervise development projects in one or more enterprises.

Goal

Goal of this paper is to present a concept for a drastically acceleration of the CAE–process. The focus of this paper is the application of a computer–aided design–tool and the general information flow based on a product data model. Using suitable design–tools enables the development of products which correspond to the customers needs in short time. Additionally they can be placed and configurated directly with the customer. The product development time can be drastically reduced and the so far indispensable production of specimen can be avoided as far as possible.

Procedure

The following chapter presents the concept to integrate virtual prototyping into the CAE-process. Chapter 3 describes a successfully realization of our concept for the design of upholsteries and the benefits of the realisation for manucfactures of upholsteries. The final chapter 4 gives an overview of possible further developments on virtual prototyping of consumer goods.

2 CONCEPT FOR VIRTUAL PROTOTYPING IN THE PRODUCT DEVELOPMENT PROCESS

Virtual Prototyping as a component of the Integrated Engineering –System

The fundamental for the presented concept and the realized case study forms the integrated engineering-system (CAE-system), presented in figure 1 and explained in (Gausemeier, Frank, Genderka, 1993) and (Gausemeier, Frank, Genderka, 1994).

The CAE–system provides non–application–specific tasks as system-configuration, user-interface, user-management, general CAE-applications (e.g. process-, cost-, quality-management) and data-management (Rammig, Steinmüller, 1992). Additionally specific CAE–applications are integrated into the framework of the CAE–system. These CAE-applications solve special tasks in the product development process, for example FEM (finite element method), technical

1. CAE – Computer Aided Engineering

design modeling, drawing, etc. A suitable design tool, which uses the full functionality of the CAE-system has to be integrated into the CAE-system as the central component of virtual prototyping.

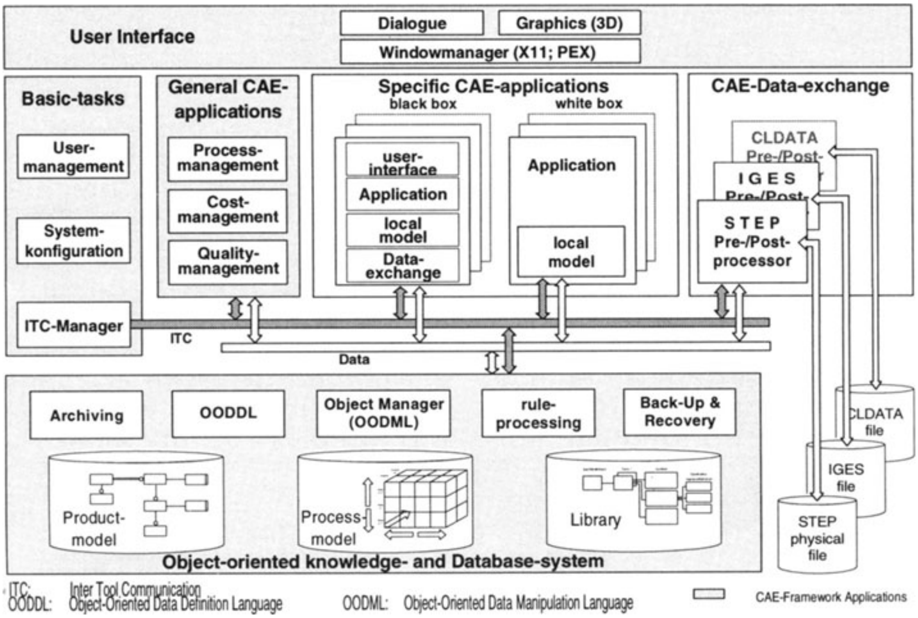

Figure 1 Structure of an integrated engineering–system (CAE–system).

The CAE–system provides non–application–specific tasks as system-configuration, user-interface, user-management, general CAE-applications (e.g. process-, cost-, quality-management) and data-management (Rammig, Steinmüller, 1992). Additionally specific CAE–applications are integrated into the framework of the CAE–system. These CAE-applications solve special tasks in the product development process, for example FEM (finite element method), technical design modeling, drawing, etc. A suitable design tool, which uses the full functionality of the CAE-system has to be integrated into the CAE-system as the central component of virtual prototyping.

Using the "CAE-data exchange" functionality, CAE-applications can communicate with other CAE-applications or external systems by using data exchange protocols, e.g. STEP[1] or IGES[2]. A further characteristic feature of the CAE-system is the object-oriented knowledge- and database-system, which contains product model data, standardized elements, and the underlying process model for the entire product life cycle.

1. STEP – Standard for the Exchange of Product Model Data
2. IGES – Initial Graphics Exchange Standard

Demands on Virtual Prototyping in the Product Development Process

In the first step, requirements on a design–specific CAE–application, which consider the goal „Accelerate the CAE–process by using computer–aided design–tools", now have to be defined:

- The CAE–application „design" has to be realized as a specific application of the CAE–system and has to use the full funcionality of the CAE–system.
- Easy redesign of the model by defining parameters and constraints to enable fast and easy design–variations.
- Configuration–management – by using standardized elements, different models can be easily be generated and changed. Libraries of standardized elements are a prerequisite to reduce and control the variety of modules and parts.
- The designed product has to be portrayed in all possible perspective views by reflecting the particular light conditions (orthochromatic, in perspective, realistic shadow–, and surface–presentation).
- Photorealistic visual presentations enable sales and marketing departments to make strategic decisions without conventional production of specimen.
- The intuitive working method of the designer has to be supported by the application. The designer should not be inhibited in his creativity by using the application.
- The customer shall recieve a paper documentation as well as a presentation of the product on the screen. That means, he will get a rapid visualization of his ideas. Changes can be realized directly at the system. Furthermore the customer can take along colored prints of the product model.
- The data of the outline, which are generated in the design process have to be applied in further process steps, e.g. creating of flattenings, cutting optimization, or drawings. This refers to the use of a standardized product data model and the accessible precision of the data in the design process.

Draft of a Design–Tool for Virtual Prototyping

The above mentioned requirements lead to the conceptual solution which is presented in figure 2. Core of the concept is a 3D–oriented modeler, based on the NURBS–technology[1]. According to the high amount of sculptured surfaces especially in design–applications, the use of the NURBS–technology a prerequisite for the generation of realistic looking models (Mortenson, 1985). All parts and their related components, which were designed by the 3D–oriented modeler are filed in a parts library. The 3D–modeler defines the shape of the objects. Aspects like for instance coloring, surface characteristics, lighting conditions are not considered in this first step of the Virtual Prototpying process.

A further possibility to make the shape of objects available to the system is the later digitizing of physically existing objects. Suitable techniques are for example optical scanning or digitizing with 3D–digitizing–pens by defining of surface–points of the existing objects. The accuracy of the model thereby will increase with the number of grasped points.

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1. NURBS – Non–uniform Rational B–Splines

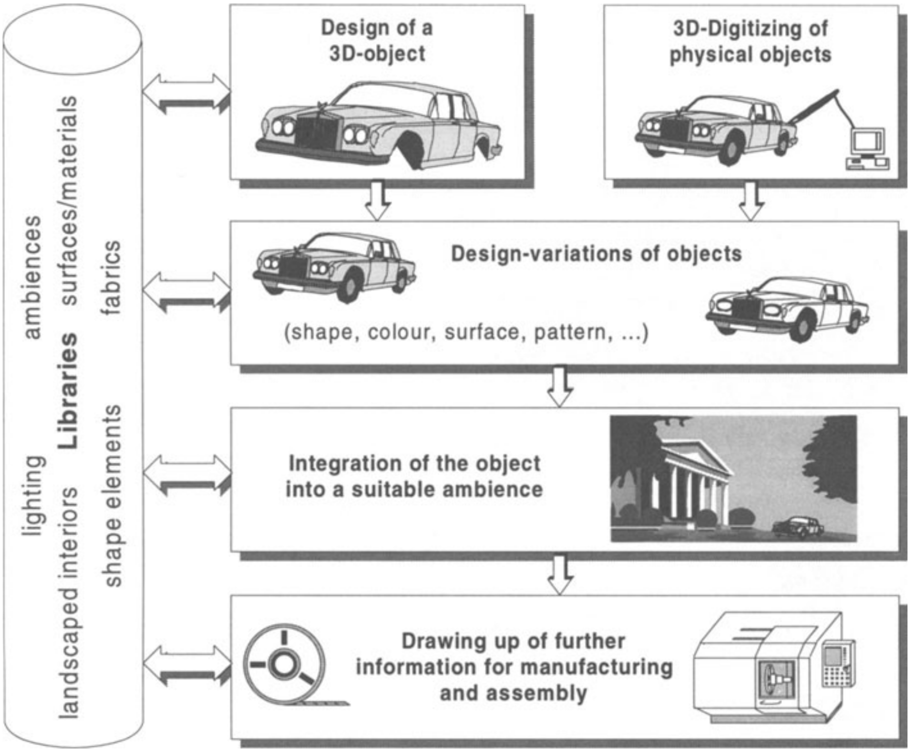

Figure 2 Tasks at Virtual Prototyping of consumer goods.

In the next step information on surface characteristics are attached to the generated components and products. Surface characteristics can be divided into the aspects:

- Materials, e.g. textiles, leather, metal, plastics, lacquer, timber, porcelain.
- Color, with typical characteristics like tone, reflexion, brilliance.
- Structure, e.g. fold, relief, roughness, pattern, texture.

These kind of information are also available in libraries. They are mapped on the surface of the particular components and product models (Texture mapping). In this early design stage a realistic looking model of the later product can already be generarted by assigning surface–characteristics to the objects. Shape variations are possible in every stage of the design process, because the object is modeled with a 3D–modeler which offers the possibility to define parameters and constraints. Visual modifications can be made by changing surface characteristics. Furthermore, the object can be viewed from any direction, because a 3–dimensional body and not a 2–dimensional drawing is modelled with the system.

Up to now the result of the design activities is the complete modelling of an object and the assignment of it´s surface characteristics. The next step is to place these objects into an adequate ambience, which can be fetched from an ambience–library, generated from different ambience–modules (e.g. buildings, landscapes, interiors, ...) which themselves are stored in libraries or at least it can be totally new generated. Furthermore, scanned photografies, e.g. landscapes can be used for special applications. By placing the modelled objects in ambiences the effects of shape and color of the objects can be excellently visualized and a nearly realistic reflection can be presented.

Sources of light have to be defined after positioning the object in an ambience to generate shadings, reflections, and so on. Characteristics for sources of light, which can be positioned in the ambience in any number and at any place are:

- Color.
- Intensity (brightness).
- Radiation characteristics (spotlight, diffuse scattered light, indirect lighting, etc.).

After specifying the characteristics of the sources of light and positioning them in the ambience, techniques for visualizing are applied. Examples for visualization techniques are Shading, Ray–tracing, Anti–aliasing (Muhar, 1992), (Rooney, Steadman, 1990). These techniques consider and convert the effects of the sources of light, for example shadings, hues or reflections.

The result of this process is a nearly photorealistic presentation of the object in a suitable ambience. These photorealistic presentations can be used by the enterprise to obtain decisive factors for strategic planning of products and product families, and further to use as sales– and promotion support for the sales department on the operative level.

According to the fact that the objects are modelled with 3D–oriented modelers, the generated product model data can be processed in the next task „Drawing up of further information for manufacturing and assembly". Examples are the generating of flattenings by using flattening–tools, e.g. for fabrics or sheet metals; cutting–optimization by using interlocking–tools to reduce the need of materials; generating of templates; modelling of the technical design and interior design (e.g. timber frame of an upholstery, ventilator and motor of a hair dryer); FEM–applications and so on. Corresponding CAE–applications are called up by the CAE–framework relating to the underlying work–flow–process.

Integrating a suitable design–tool into the integrated CAE–system drastically accelerates or even enables the Virtual Prototyping process of consumer goods with high requirements on excellent design. The concept for Virtual Prototyping presented in this paper enables the generation of nearly photorealistic presentations of objects. A drastically reduction of the (so far necessarily) conventional production of specimen can be achieved. By using 3D–modeling techniques and libraries for products, modules, surface characteristics or ambiences any changes of the objects will be possible. An adjustment of an object to the customers requirements so will be easy and fast converted.

3 VIRTUAL PROTOTYPING IN THE DESIGN-PROCESS OF UPHOLSTERIES

The concept presented in chapter 2 was realized in cooperation with Gepade, a German upholsterer and market leader of stylistic upholsteries (Lewe, 1994).

It was the goal of this project to demonstrate the principle feasibility of our concept by using in the first step standard–software–tools and to show the benefits of an integrated CAE–system with design–specific applications for the enterprise.

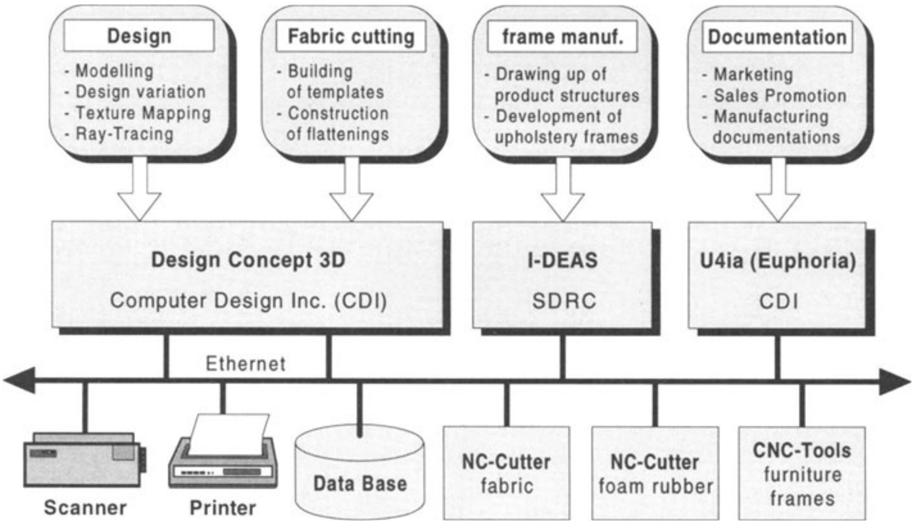

Figure 3 Configuration of the CAE–system for Virtual Prototyping of upholsteries (Lewe, 1994).

The requirements of the concept for Virtual Prototyping and company and industry specific factors lead to a selection and implementation of tools, which are presented in figure 3.

As the CAE–application for the specified design tasks the tool *Design Concept 3D* by *Computer Design Inc.* was applied. *Design Concept 3D* supplies functionalities for generating 3D–surface–models, parametrics, definition of constraints, and definition and application of surface characteristics. Furthermore the tool supplies functionalities for the creation of flattenings, generation of templates, and further functionalities especially for upholsterers, for example definition of cuttings, seams, fabric overlaps. As requiered, *Design Concept 3D* provides libraries for products, modules, fabrics, sources of light, ambiences and so on. Additionally photorealistic presentations of objects, placed in ambiences, can be generated. Applications of *Design Concept 3D* for Virtual Prototyping of upholsteries are:

- Generating the design of upholsteries and their components.
- Design–variations of shape, surface characteristics, lightings, etc.
- Generating of photorealistic presentations.
- Flattenings and cuttings of fabric.
- CAD/CAM–integration of NC–cutter (cutting of fabrics and foam rubber).

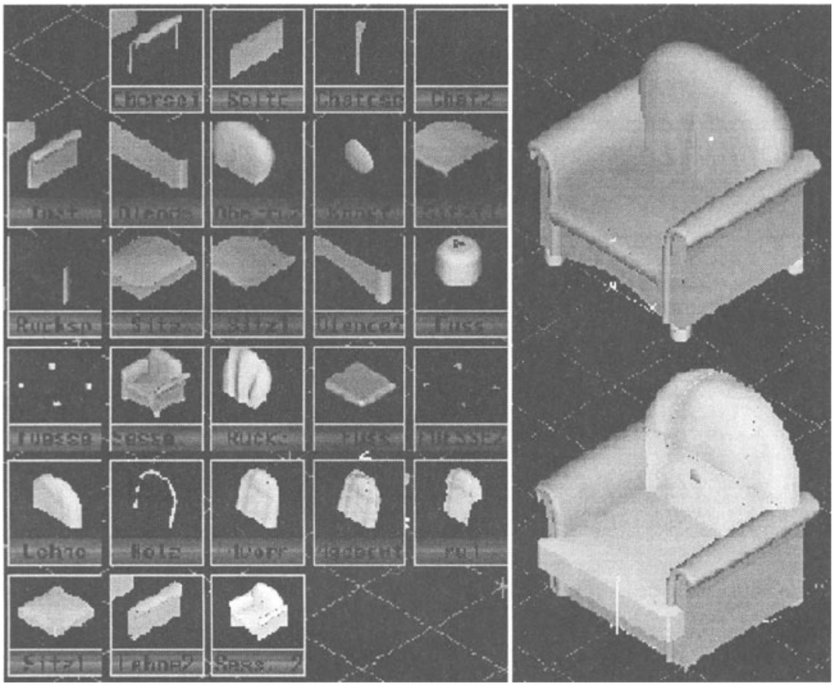

Figure 4 Design–variations by using standardized elements.

Figure 4 and the following figures 5 and 6 present functionalities of the choosen design–application. Figure 4 shows the realization of design variations by using standardized elements, for example armrests, blind arches, seats, back supports and so on, which are fetched from specific libraries. After assigning surface characteristics to the upholstery, the object can be placed in a landscaped interior and sources of light can be positioned, presented in figure 5. Whenever the requirements are fulfilled by the arrangement, manufacturing and assembly information can be generated. Figure 6 shows an example for the fabric–flattening of an upholstery.

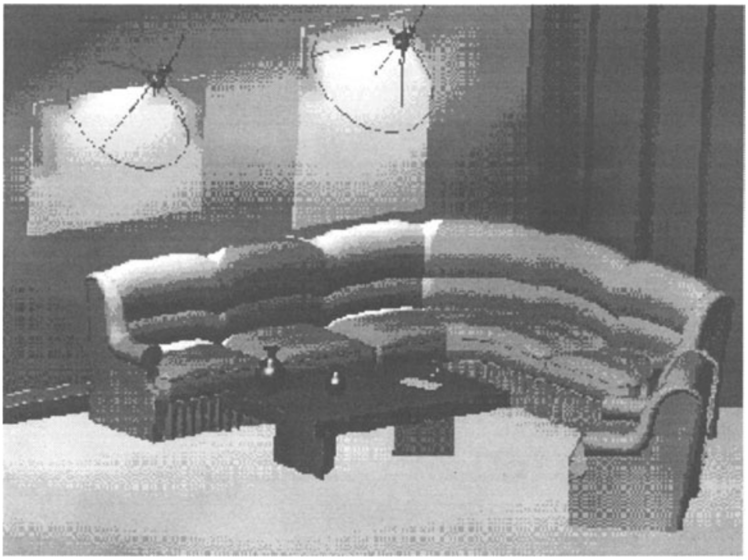

Figure 5 Creation of a landscaped interior and adjustment of lighting conditions.

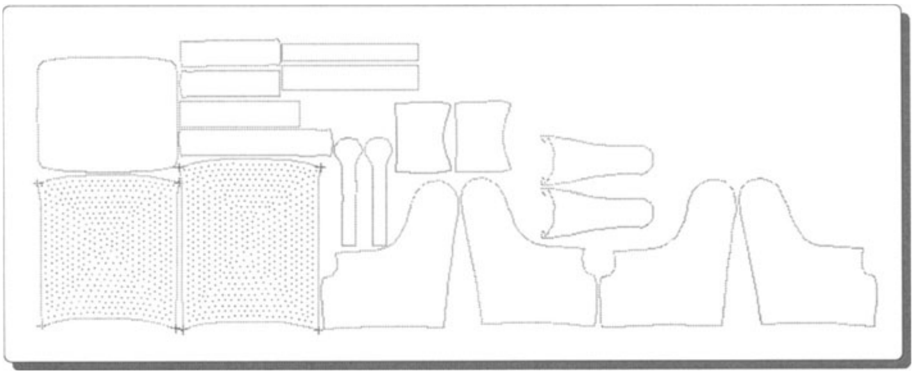

Figure 6 Flattening of the fabric of an upholstery.

In the next step the timber frame of the upholstery has to be developed under consideration of the fixed upholstery–design. Requirements on the frame–design are on the one hand the use of standardized frames or frame–components as far as possible and on the other hand the use of the outer shape of the upholstery as a general set–up for the frame. One guideline of the project was to use standard software–tools as far as possible. Because *Design Concept 3D* does not offer all the required functions for 3D–mechanical design, a further software–tool is choosen for the design of upholstery–frames. Employed is *I–DEAS Master Modeler* from *SDRC*, a 3D–solid–modeler. The coupling between *Design Concept 3D* and *I–DEAS Master Modeler* and the assigned tasks to the tools is presented in figure 7.

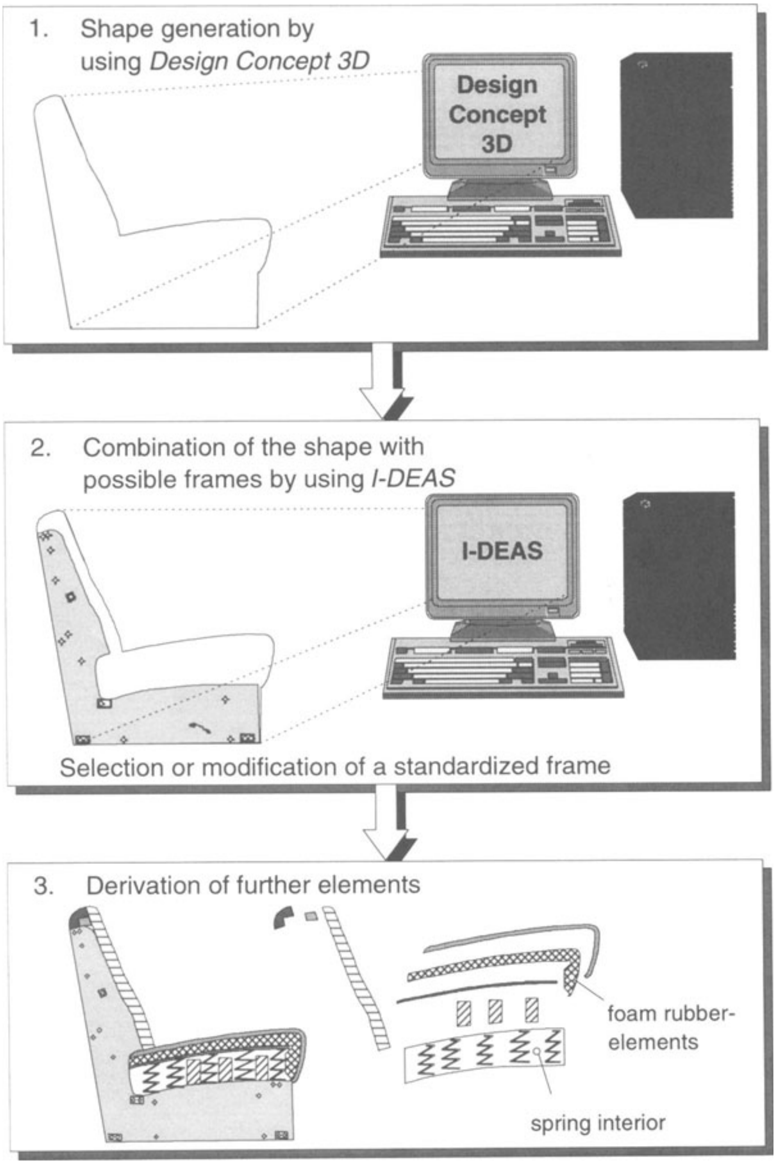

Figure 7 Coupling and allocation of tasks between Design Concept 3D and I–DEAS Master Modeler.

The *I–DEAS Master Modeler* has to fullfil the following tasks in this project:

- 3D–Frame–design by using as far as possible standardized components.
- Frame–variations by using parametric– and constraint–functionalities.
- Product data management.
- CAD/CAM–integration to manufacturing of frames (CNC–machine tools).

Figure 8 presents a timber–frame for an upholstery which was modeled with *I–DEAS Master Modeler*:

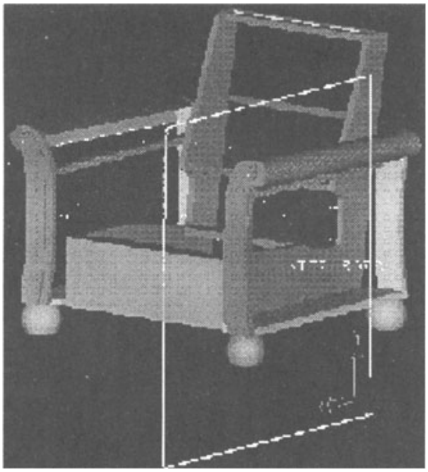

Figure 8 Upholstery frame modeled with I–DEAS Master Modeler.

For the graphically output of the photorealistic presentations of the modeled objects, generated with *Design Concept 3D* is used *U4ia (Euphoria)*, a software–tool also provided by *Computer Design Inc.* In this project it is employed for generating sales– and promotion documentations. A high–performance color–printer provides paper–printouts, edited by *U4ia*.

A further requirement on the concept for Virtual Prototyping was the ability to work with fabrics, which are used by the upholsterer to assess realistic optical effects (e.g. color, alignment, pattern–structures, ...) of different fabrics on upholsteries. This functionality is absolutely necessary for the supply of fabrics in the right size.

Gepade does not produce fabrics itself and computer–based fabric–patterns of the used fabrics are not available. Hence a large size color–scanner is employed to generate computer–based patterns of the desired fabrics. Furthermore the color–scanner can be used to scan photografies, for example portraits, landscapes, frontispieces or clippings of magazines and newspapers to improve the realistic impression of ambiences.

Benefits of the implementation for an upholsterer

The implementation of the above presented concept "Virtual Prototyping for the design of upholsteries as a component of the integrated CAE–system" opens up a lot of benefits for an upholsterer. These benefits can be classified as general benefits for the enterprise and as department–specific benefits (Lewe, 1994).

General benefits:

- drastically acceleration of processes
  - generation of a high number of design–variations in very short time;
  - utilization of the product model data in the complete product development process;
  - reduction of manual data exchange processes and coordination–processes.
- drastically reduction of the conventional manufacturing of specimen.
- flexible consideration of customer requirements and convertion in product–design.
- improvement of the utilization of standardized elements in every stage.
- enhancement of product– and process–quality.

Department–specific benefits:

- Design
  - easy, fast and interactive possibilities for computer–aided variations of shape and surface–characteristics of designed objects;
  - nearly unlimited design–variations by using standardized elements for components, fabrics, surface–characteristics and so on;
  - direct visuell control of the realized tasks.
- Development / technical design
  - manufacturing of specimen only for promising variants after Virtual Prototyping;
  - derivation of suitable timber–frames by using the design and standardized frame–components;
  - direct computer–aided generation of manufacturing and assembly–information, e.g. templates, flattenings, cuttings, NC–programs.
- Sales department / marketing
  - generation of photorealistic presentations of upholsteries for sales–negotiations;
  - reduction of misunderstandings between customer and sellers;
  - higher flexibility by changed customer requirements or customer tastes;
  - planning and assessing of the success of new product families without expensive manufacturing of specimen (drastically reduction of time and costs).

4 DEVELOPMENTS OF FUTURE VIRTUAL PROTOTYPING-SYSTEMS

This chapter describes developments of tools and process–innovations, which are suitable to improve and increase the benefits of Virtual Prototyping. It has to be distinguished between developments, which reference to the general Virtual Prototyping–concept was presented in chapter 2 and developments which are particularly interesting for Virtual Prototyping of upholsteries, refered to chapter 3.

Application of Virtual Reality–techniques (VR–systems)

Virtual reality is a new kind of computer technology, which makes the user believe he or she is immersed in a computer–generated world, the so–called "Cyberspace" (Foley et al, 1992), (Wexelblat, 1993). The development of VR–systems is currently in the beginning stage. Due to capital intensive hard– and software, industrial applications are only practical in special areas, for example the space industry or the military sector. Because of the high range of applicabilities, the VR–technology will also be applied in future research and development of standard industrial products (Gausemeier, Ebbesmeyer, Grafe, 1994). When adjusted VR–systems are fully technical developed and economically justifiable, an enterprise can use these techniques to support the Virtual Prototyping–process and for the presentation of its products to the customers.

In the upholstery–example it will be possible that a customer supplied with suitable VR–equipment immerses himself into a landscaped interior, created on his requirements. In "his" landscaped interior the customer can move totally free, shift upholsteries or other furnitures to desired places, change the arrangement by using other upholsteries from libraries, change fabrics, colors and so on. If other catalogues are available, the customer can check the composition of different types of furniture e.g. upholsteries, chairs, tables, cupboards with carpets, curtains, wallpapers, paintings, and other design elements like flowers or art objects.

Up to now 3D–modeled and photorealistic objects are presented in a 2–dimensional medium, for example a screen or on paper documents. By using VR–techniques, these 3D–modeled objects can also be presented to the user on a 3–dimensional medium. The user can model and view 3D–objects in a 3D–medium. The clarity and graphic nature of the scene will tremendously increase and the design quality will improve significantly.

Electronic sales catalogues

A further revolutionary change will emerge by electronic sales catalogues, which will remove the current paper catalogues. The electronic sales catalogue will not contain examples of available products with accessory charts of permissible combinations of e.g. furnitures, fabrics, colors, or optional extras. An electronic catalogue contains standard elements and eventually combination rules, which will be arranged according to the customers requirements. The salesperson analyses together with the customer the customers needs and arranges afterwards components, fabrics, materials, colors, and so on, which are available from libraries of the sales catalogue. Thus all available combinations, which are supplied by the enterprise can be presented. By using large size projectors the modeled objects can be presented life–sized, which will furthermore improve the clarity of the object.

Data transfer systems

The so far presented concept focusses on Virtual Prototyping for one enterprise as an approach to increase the competitiveness of the enterprise. The cooperation of different enterprises enables a further increase of competitiveness and offers new possibilities on the market.

A manufacturer can for example endow his direct customers, the specialized dealers, with the above explained electronic sales catalogues. Using data exchange technologies between manufacturer (e.g. upholsterer) and specialized dealers, the data about prices, delivery dates or terms of delivery can be transfered immediately. The manufacturer can include new orders directly in his production planning system and the customer will get exact delivery–information.

Standards to enable data exchange for commercial information are for example "EDI"[1] (Banerjee, Golhar, 1994) or "EDIFACT"[2] (Scholz-Reiter, 1991), which are yet available or in the development process.

Layout planning systems

By integrating further manufacturers into the data transfer system, for example manufacturers of carpets, curtains or cupboards, entire systems can be planned, e.g. living rooms, kitchens or offices. Using layout planning systems enables the arrangement of landscaped interiors, which are adjusted in color, style, and size.

Customers will profit from thus layout planning systems, because their desired landscaped interior is planned according to their requirements and they can get immediately a presentation and information about the latter appearance in reality but also about prices and terms of delivery. Manufacturers and specialized dealers can increase their planning–accurancy combined with a decrease of delivery periods.

5 SUMMARY

The involvement of a design–application into the integrated CAE–system ist the key component of the presented concept for Virtual Prototyping in the product development process. To gain the competitive advantage, a very close teamwork of task–specific CAE–application, embeded in the CAE–system is essential. This is reached by an integrated product data model which covers the whole product life cycle.

The presented concept for Virtual Prototyping was realized for the design of upholsteries by using standard software packages. The expected benefits of Virtual Prototyping for enterprises could be proved and confirmed.

Finally developments are presented, which have to be integrated into the general concept and into the example "design of upholsteries". These developments are Virtual Reality (VR), electronic sales catalogues, data transfer systems between one or more manufacturers, suppliers and customers and layout planning systems.

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1. EDI – Electronic Data Interchange
2. EDIFACT – Electronic Data Interchange for Administration, Commerce and Transport, IS 9735

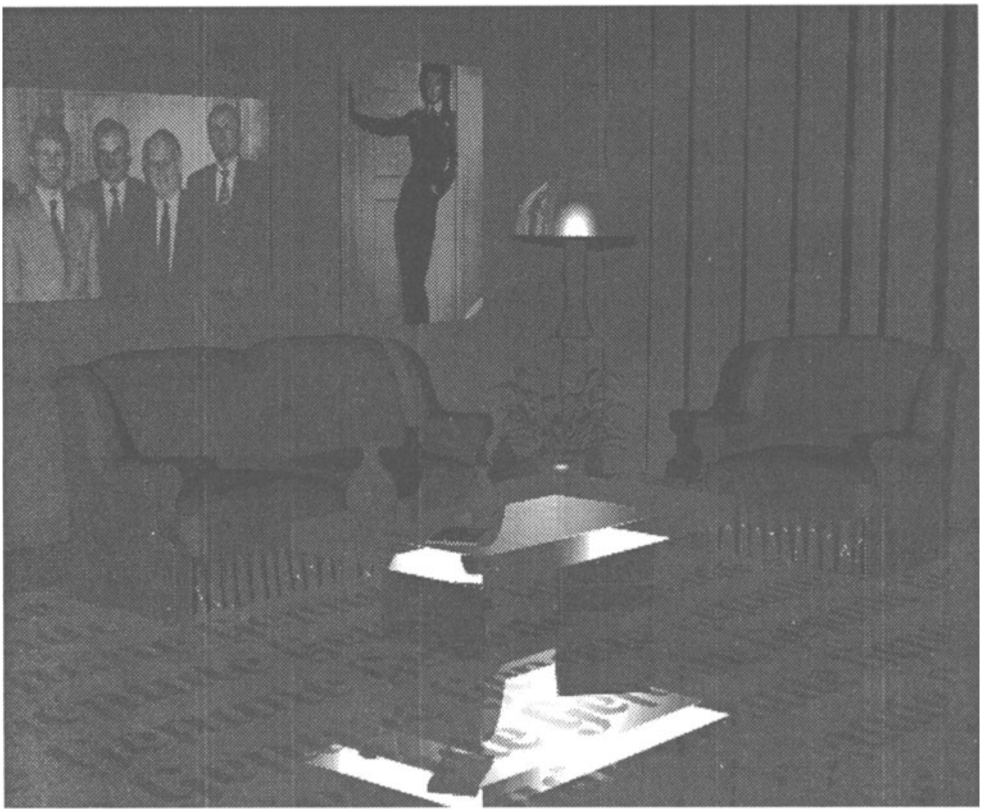

Figure 9 Example for a virtual landscaped interior, modeled with the presented implementation.

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