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# Virtual Reality in Product Design and Manufacturing

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## Abstract

The article presents integrative approach in application of virtual reality technology in design of products and production processes for their manufacture. Virtual reality technology is key for product design and development together with impacts on manufacturing production. The paper first describes the generally virtual reality knowledge, modelling and manufacturing application. Finally, virtual reality technology is focused on reverse engineering technology for virtual environment construction in the reengineering of technological processes.

**Keywords**: virtual reality, virtual environment, reverse engineering, product design, manufacturing

## Introduction

Manufacturing competitiveness of the 21st century is associated with computerization in the development of new products and processes which are dependent on relevant information. Virtual reality (VR) provides a computer-generated environment for product design or manufacturing process simulation. VR integrates technologies of computers, information, image processing, communication and control with features of immersion, interaction and information intensity. VR technology has been successfully applied in a wide area including entertainment, product development, space exploration, health care and military simulation. Engineering is an important field of VR applications. The traditional iterative product analysis leads to a long product development time and a high cost [1].

Natural continuation of the 3D computer graphics are the new VR technologies with advanced input-output devices, which were being developed intensively in the past decade, and are being applied in the leading research centers in the world. Through VR technology one generates synthetic, namely virtual environment in which is enabled the three-dimensional presentation of the product, tool, process in the real time, in the real conditions and interaction with the user. Interaction and its power contribute to the powerful feeling of immersion – inclusion into the actions within the environment in which the user is placed. By the application of the VR technologies those problems are eliminated, considering that the designer in immersive VR environment has the feeling of the real interaction with product and process model, which can be of natural size. That is especially significant in product detailed design phase, virtual mounting of assemblies, or in checking characteristics of the complex products in the automobile and aerospace industries [2].

## Virtual reality knowledge

There is a variety of definitions for virtual reality, but they are similar, such as a computer-generated surrounding, an interactive three-dimensional (3D) computer graphical interface, or an immersive interactive environment. The feature of VR can be summarized as "three I's": immersion, interactivity, and information intensity. The meaning of immersion is that VR user has a feeling that he/she is located in a real world, but actually it is a computer generated virtual world. The interactivity comes from advanced input/output (I/O) devices that provide much powerful interactive ability than conventional CAD systems. The information intensity means that a VR system uses all information related to the human sense. Therefore, VR technology is a natural extension of 3D computer graphics with advanced input and output devices. VR users can interact with a simulated immersive 3D environment in real-time through multiple sensorial channels. Virtual reality system consists of three parts: VR engine, VR database and model base, and I/O devices. The VR engine is a graphic modelling and processing system.

It is used for object modelling, texturing, mapping, lighting, rendering and finally displaying 3D scenes in real time. It is the infrastructure of VR. The VR database and model base stores virtual objects that are ready to be loaded in the scene whenever required. I/O devices provide the human-machine interface for the VR system control and communication. Therefore, based on the VR definition and components, VR knowledge can be delivered from three aspects: VR hardware and software, VR modeling, and VR applications [1].

Virtual reality modelling includes geometric modelling, kinematics modelling, physical modelling, and behavior modelling. The topics of geometric modelling include: virtual world space definition; virtual observer location, perspective projection, 3D modeling and clipping, 3D space curves, 3D boundary representation, geometrical transformation, and modelling transformations for translate, scale, reflection and rotation. The topics of physical modeling include: illumination models, reflection models, shading algorithms and collision detection. The topics of kinematics modelling include: picking, flying, scaling virtual environments (VE), and the dynamics of numbers. The topics of behavior modelling include: free-form deformation, shape and object in between, the animation of objects, animating the virtual environment, particle systems, interactive using navigation, selection, or manipulation for a convincing simulation.

Virtual reality technology provides an integrated approach including feasibility analysis, iterative design, and systematic evaluation in product development. The applications related to product design and manufacturing include: digital rapid prototyping, design reviews, human factor studies/ergonomics studies, digital assembly, learning and training, manufacturing process simulation, tele-operation and Web-based applications.

## Data exchange and communication in virtual reality

Virtual reality (VR) hardware and software are developed separately without a universal standard. When selecting a VR system, not only VR hardware such as I/O devices, but also the VR software, i.e. development tools, have to be considered. VR software serves as a toolkit that provides a development environment for VR hardware to support VR applications. The VR software may be run on different operating systems, and may support different VR hardware.

The architectures of VR software range from platform independent languages implemented on low cost desktop workstation to high end systems customized for the high cost computation required for immersive VEs. There is no modelling function available in most of VR software toolkits. An interface is needed to link modeling tools, such as CAD systems. In order to understand the need of data and information exchange in a VR system, a VE is used to introduce the data required in a manufacturing system. The VE is used as an interface between the system and users for decision-making. Data exchange between the manufacturing system and users is required during product review and production evaluation. The architecture of the system is shown in Figure 1. Based on the system presented in Figure 1, users can retrieve data associated with a manufacturing system, including the product modelling, machine layout, manufacturing process, assembly simulation and other processing in a manufacturing system. As shown in Figure 1, data exchange and communication in a manufacturing system are required for product review, VE model generation, product model storage, and connection with Intranet network.

Product review communicates users' request to product database. Product model base provides the VE model generation with information required to construct the product model for review. It also interacts with the VE to ensure that the geometric model representation is consistent with the product definition. A two-way data exchange between the product review and product database is required to communicate changes. The adaptive nature of the product review requires the data exchange with the product review to obtain information and to determine modifications of the product model. Since the VE model generation needs detailed geometric information, this information is obtained from CAD data. The product review is responsible for providing information for the construction of VE. Details of Figure 1 are described as follows.

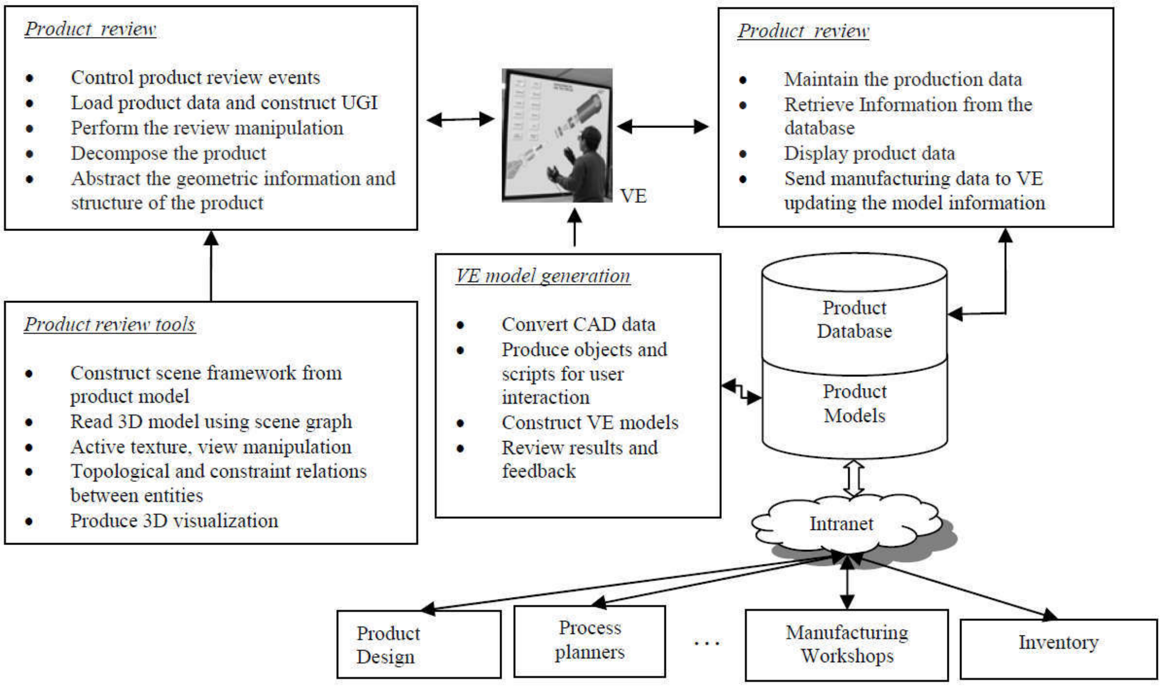


*Figure 1 Data exchange in virtual environment based manufacturing application [1]*

Product review provides the event control for the product 3D model review to perform the review manipulation. It abstracts the geometric information and the structure of products, and decomposes the product into the level of details to support the operation of product evaluation and verification. The model review manages products at the assembly level. When a product is chosen for review, the model review will first retrieve the assembly model of individual components or subassemblies that are defined in product design [3].

Product review tools are responsible for generation of the appropriate product model, for selection of display technologies, for provision of VE creation tools, for evaluation of the models obtained, and for the decision of improving the model. The first step for a product review is to determine techniques used to perform the review processing. The relation is a key to the effective operation of the product model review [4].

VE model generation constructs product models for the VE to define the state of the model and information provided by a product design. Today, the integrated system of CAD and VE is typically limited to a one-way transfer from CAD to VR.
The virtual environment (VE) is an interface for users to communicate with products. The interactive manipulation can use tracking sensors and data gloves associated with display devices to generate a product review and operation simulation [1].

Data collection and update is supported by an Intranet network to distribute data in an organization. Considering the data distribution in a business, product design and production information can be accessed through an Intranet network. The VE for product data review can be located in a VE center, data in the database may be located at different departments and workshops for the data use and update. It allows the distribution of product data within a business through the Intranet. When users view and operate a design model on the VE, the related data or models are retrieved. The system searches for related data, models and information, returns searched results to the VE scene, and displays them. There are some plug-in toolkits available for free download from Internet to support a 3D navigation on Web browsers. It is also a useful tool to develop Web-based 3D simulation systems [5]. The model retrieval-based modeling is an efficient way to share the model in different users through a network system.

## Reverse engineering technology for virtual environment construction

Design and manufacturing of a product can be viewed, evaluated and improved in a virtual environment before its prototype is made, which is an enormous cost saving.

Reverse engineering (RE) is a process of digitalization of the existing part, assembly or the whole product, by precise measuring or scanning. Application of this technology is especially useful when the electronic models of technical documentation are not available. The two phases are distinctive within the RE process: the first one which consists of the data digitalizing and the second one, within which the 3D modelling of the object is done, based on the acquired data. Output of the first phase of the RE process represents the digital description of the object in the three dimensional space, which is called the point cloud.

The first important work of VR applications is to create virtual objects for VEs. There are different modeling methods to create a virtual world. Using CAD models to construct VEs is a common method. The reverse engineering method is a fast approach to obtain the geometrical information from an existing object for VEs. Reverse Engineering provides an effective tool for the VE construction. RE is widely used in various areas of product development. The recovery of the 3D shape of an object is the basis of RE. Coordinate measuring machines (CMMs) are traditional RE tools used in manufacturing industry. CMMs provide a high measuring accuracy and stability, but disadvantages are the contact measurement and a point-to-point slow measuring process. There are a number of factors that affect the digitizing uncertainty of CMMs, such as travel speeds of the probe, pitch values, probe angles, probe sizes, and part sizes.

Virtual product development and optimization of technological processes give significantly reduces the development time and costs. In addition, the design teams can produce several solutions for different versions of styling of such products as consumer goods, what gives companies the possibility to competitively position themselves at the market with the redesigned products [6].

As the digital model of the product component is a basis for integrated application of the VE technologies, the applied re-engineering approach consists of the following technologies (see Figure 2):

1. Reverse Engineering (RE) - for scanning of blank shape and free surfaces of handle.
2. 3D CAD (Computer Aided Design) modelling - for 2D model of blank and 3D model of handle.
3. Virtual Manufacturing (VM) - for virtual verification of the proposed technology and design.
4. Rapid Prototyping (RP) - for physical verification of simulation FE model.
5. Quality control (QC) - for comparison between real part and RP of simulation model.
6. Virtual Reality (VR) - for 3D visualization and interaction with virtual models [2].

In integrated virtual engineering environment the user can analyze processes, systems and products. The virtual model of the product can be imported directly to the VR system. The virtual model can be analyzed in more details in the VR environment. For those needs a VR application was developed by the use of the following software and hardware components:

1. Wizard VR Toolkit program for creating the VR environment, where software application was done in the programming. During development of the VR application, available module in Wizard was used, for realization of communication with 5 Data Glove.
2. 5DT Data Glove which enables recognition of gestures for certain operations on the object that is analyzed in the VR environment; are used predefined gestures, to which the following actions on object are assigned: translation, rotation, scaling and initial positioning.
3. Wintracker, magnetic 6DOF tracking device for tracking the data glove movements, namely for manipulating with object in the VR environment. Based on data that are obtained from one of the sensors from the motion tracking device, mounted on the hand, the virtual hand on the screen is moved, and by that movement of the virtual objects is possible by user.

Virtual reality technology can carry out all the main functions of the new product development according to individual customer requirements in the virtual environment. Through presented case study of process reengineering of making handle from the sheet metal, advantages and possibilities of the VE technologies integration were demonstrated, through application of the CAD/CAM/CAE, VM, RP/RM and VR techniques. It was shown that, due to development of the IT technologies, software and hardware components, engineering design and development, as well as other phases of product life cycle, can be very successfully realized, with respect to quality, costs and time, by application of the virtual/rapid prototyping/manufacturing technologies of virtual engineering.

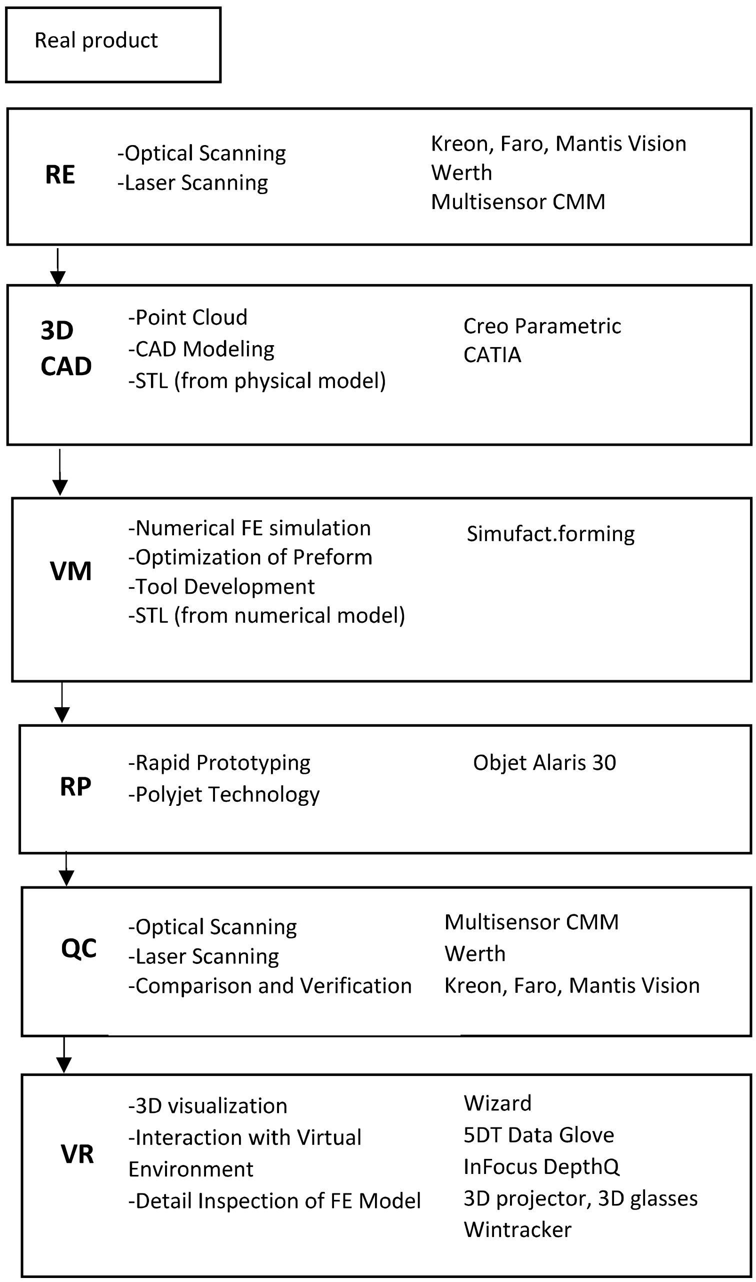


***Figure 2 Approach reserve engineering procedure in virtual environment***

## Conclusion

This paper presented products of virtual environment system, which generates and/or uses the virtual/rapid prototypes of products and processes, whose analysis are possible both in the physical and virtual sense. Each product of VE system has its advantages and disadvantages, thus the integrated approach, which assumes their complementary application, became the powerful tool for designers and researchers. The initial part in the integrated development of products and processes by application of virtual environment technologies could be a 3D CAD model prepared by the designer or modeled after the 3D scanning/digitalization of an object by application of the reverse engineering device. The virtual model occupies the central position in the collaborative environment for support to the integrated VE system considering that is also used and improved through application of the virtual manufacturing, rapid prototyping, virtual quality control and finally, virtual reality system.

Engineering in virtual environment helps to save costs and time of the product and process development. The key point of engineering in virtual environment is virtual prototyping with 3D systems for a new product design, and appropriate software for the production system design.

Virtual reality has become an important and useful tool in science and engineering. Virtual reality applications cover a wide range of industrial areas from product design to analysis, from product prototyping to manufacturing.

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