

Virtual Modeling and Prototyping in Collaborative Product Design

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INTRODUCTION

Computer-aided design/computer-aided engineering (CAD/CAE) tools are a valuable resource in today's product development process. Among other features, these tools enable collaborative development, reduce costs, and improve the efficiency of the development process (McGrath, 2004). Virtual and networked organizations should explore these computational tools to the utmost.

Among CAD/CAE tools, virtual modeling and rapid prototyping are very pertinent for virtual and networked organizations due to the large impact those tools can have here (Wright, 2001). Adequately used, virtual modeling allows collaborative development to its full extent, either among team members inside a company or between companies involved in the development of a specific product. It is necessary to emphasize that CAD/CAE tools, particularly those for simulation of virtual models (either process simulation or structural modeling), can be very dangerous when used as a black box; a sensible analysis of results is a prerequisite to prevent complications in later stages of the process.

This article starts by describing the main stages of product design and engineering. The concept of virtual modeling and a comparative overview to traditional product development methods are provided. The current rapid prototyping techniques and their advantages and disadvantages are described. Last, some of today's main applications for CSCW within the framework of product design methodologies are analyzed.

PRODUCT DESIGN AND ENGINEERING

The development of any new part or product is a complex operation, as it varies from product to product (Ulrich & Eppinger, 2004). However, the basic methodology employed is common to (nearly) every project. The main stages of this procedure include:

- a. Defining the qualitative and quantitative requirements that will comply with the user needs and any predefined technical and technological specifications.
- b. Establishing the project goals, milestones, and deliverables, including a detailed timetable;
- c. Selecting the team that will implement the project, promoting communication and a collaborative environment, typically including designers, engineers, and production managers, aside from marketing personnel.
- d. Conceptualizing the part through brainstorming aesthetic concepts, functional issues, ergonomics, and cost aspects.
- e. Hand-sketching components, parts, and assemblies, including projections, cross-sections, and perspectives.
- f. Creating detailed 3D virtual models that can be used for the multiplicity of purposes described in detail in the next article, including interaction with clients.
- g. Prototyping the product (e.g., through rapid prototyping) and producing a prototype mold that can be used to make the final validation for very small series or even for a single item, allowing minor adjustments before starting production. This will also be useful for market testing.
- h. Commercializing the product, including marketing, advertisement, and distribution.

Although each of these stages is vital to product design and development, the present discussion focuses on stages 6 and 7, due to the significant advances made in these areas over the past couple of decades. These advances, coupled with the increasing availability of computational resources such as high-speed data exchange, now allow an entirely different approach to collaborative and networked product development, allowing a virtual organization to undertake and successfully implement projects they would have been unable to tackle only a few years ago.

VIRTUAL MODELING

Virtual modeling consists of representing a physical object on a virtual environment. The virtual model is in fact a digital description of the physical object (Baxter, 2006). Any object can be considered here, from a vase to an automobile to a human body part. Usually, the virtual model is created and later visualized on a computer through 3D rendering, or in specific cases, through 2D projections.

Some of the issues that arise when creating a virtual model include:

- a. **Accuracy:** Ensuring that the model is an accurate representation of the physical object. Although in some parts, it may be relatively simple to ensure this feature, the market trends and the need for innovation keep pushing for more complex geometries, the use of organic shapes, and the application of various textures and patterns on the surface of the objects. In some cases, if working from an existing part (reengineering or upgrading it), the use of 3D scanning technology is required in order to guarantee that the physical object features are accurately captured in the model. Note that typically accuracy in current 3D scanning technology can be around $\pm 0.025\text{mm}$.
- b. **Resolution or level of detail:** This is usually only meaningful when discussing a model captured from a physical object, for example, through 3D scanning. While a laymen would probably suggest that the virtual model should have the highest possible resolution (meaning, how many data points or pixels are captured per unit length or per degree), there is a delicate balance between the minimum level of detail required to capture all the vital object features (this associated with the previously discussed accuracy) and how complicated the procedure becomes when working with very high resolutions. Note that 3D scanning technology offers typical resolutions ranging from 0.1 mm to 0.003 mm.
- c. **Time to model:** There are two cases to be considered here: (1) creating a virtual model directly on the computer, often at a point when there still is not a physical object and (2) 3D scanning for digitalization of an existing object. For the first case, the user should ponder which features of the object can be ignored at each stage of the develop-

ment process. In the early stages, when function and form are still being discussed, it might not make sense to include a surface texture or an embossed logo. However, for the development of new products, at some point, it is necessary to have the part fully described. Obviously, the time required to create the virtual model is highly dependent on the expertise of the user and the complexity of the model. In the case of digitalizing an existing object, the time required to obtain the model is only related to the technique (equipment) and the selected resolution.

- d. **Purpose of the model:** As mentioned in the previous topic, a simpler model should be created for the preliminary discussions, however, it should always include the characteristics and features that affect its function that limit the use of specific manufacturing processes. The model should evolve in complexity concurrently to the evolution of the concept and to the details on which final decisions have been made. In an analogous way, when sharing a model with possible collaborators, the model should only include as much information as absolutely necessary to obtain a useful and accurate feedback from the people receiving it. If serious issues of intellectual property are associated with the product, even a simple model might call for a confidentiality (or a nondisclosure) agreement.
- e. **Size of the digital data:** Although in today's information society, it is easier to exchange large amounts of data, very large models can complicate cooperative development. Most e-mail accounts still have limitations on the size of attachments, and using a repository can solve this problem in some cases. Note that models resulting from very detailed 3D scans can have very large sizes, and collaborative product development among virtual enterprises should not be dependent on exchanging data on physical media via mail. In the case of complex assemblies, it can be useful to have the model split into parts and update only the modified parts.
- f. **Intercompatibility of models:** One of the most complex problems nowadays is the use of proprietary file (model) formats by most modeling software. There are a few standard file formats for solid models that work moderately well after a mesh exists, which transfer information on the

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