A Three-stage Conceptual Design Process Using Virtual Environments

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ABSTRACT

A simple conceptual design process that runs in a virtual environment is described. The design process consists of three stages. In each of the first two stages used to create, and after that, elaborate the model, techniques specifically suited to these tasks, are available. In the third stage, using 3D printing technology, a physical prototype is obtained from the digital model.

In the creation phase, an initial model is sketched directly in the virtual environment, by drawing a network of curves, and by fitting in surfaces. In the elaboration phase, virtual clay modeling techniques are used, which resemble the way designers work on such materials in reality. The model is converted into a volume representation at the transition into the elaboration phase, thus there is no need for a hybrid representation.

Keywords
Virtual reality, conceptual shape design, virtual clay modeling, virtual prototyping.

1. INTRODUCTION

The design process for the generation of surfaces of new products is characterized on the one hand through conventional work procedures such as sketching on paper or modeling with clay materials. The technical execution of the model, on the other hand, is dominated by desktop-CAD-systems whose complex user interfaces are not yet sufficiently supportive of the spontaneous transformation of an idea into a form.

Our approach to conceptual modeling enables the creation of a digital model even in the early stages of the design process through the use of an appropriate virtual environment. Designers are able to translate their ideas about the form directly into three-dimensional models in a very early phase. Thus there is no need for a time-consuming and inaccurate

conversion step from a physical model into a computer representation.

An essential requirement on conceptual modeling systems is that they enable the designer to make use of his artistic skills within the environment. This means that the set of tools available both for creation and manipulation of geometry should be based on appropriate metaphors in the field of conceptual modeling. The problem is that the chosen geometric representation is associated with limited interaction possibilities. The most common representations in computer aided design (CAD) are surfaces and volumes. Curves and surfaces are particularly suited for tasks such as "draw", "sweep", or "deform", whereas volumetric representations are strongly associated with tasks such as "add material", "remove material", "push in", etc.

In a conceptual design system that allows the designer the most possible degree of freedom, these toolsets would be available simultaneously. This would result in a hybrid approach, requiring a highly complex model representation.

In contrast to this, our method is based on the combination of two different modeling approaches, followed by a rapid prototyping step, into a two-phase design process that completely runs in the

virtual environment. The different tasks associated with surfaces and volumes are assigned separately to the two successive design phases.

In the first phase, the *creation phase*, the user creates an initial surface model from scratch, by drawing a network of spatial curves directly in the 3D environment. The surface of the model is created by fitting surface parts into closed loops of curve pieces within the network. In the second phase, the *elaboration phase*, the user applies methods of virtual clay modeling to the model, which has been converted into a volumetric representation before. After that, a physical model can be generated using 3D printing technology.

In this way, we establish a design process that provides the appropriate methods and tools according to the stage of development. Note that since we do not propose a hybrid approach, we need to convert the model only once at the transition point to the elaboration phase.

As the basic interaction method for our design system, we use two-handed interaction at the Responsive Workbench virtual environment.

The remainder of this paper is organized as follows: In section 2, we give an overview on related work. We introduce the sketching tool for curve nets and the VCM tool in section 3 and 4, respectively. After that, combining the two applications is described. We import the topology of a seat into the VCM and modify it in section 5. We let a prototype of the seat model be manufactured in section 6 and conclude the paper in section 7.

2. PREVIOUS AND RELATED WORK

Our work combines two modeling systems, which have been described in detail before. Conceptual modeling with curve networks at the Responsive Workbench is described in [12]. In particular, the deformation tools applicable to curves and surfaces, and the underlying variational modeling concepts, can be found in [11]. The virtual clay modeler is described in [6] and [3].

The idea that curve networks are very well suited for the quick input of shapes has been proposed before e.g. by Kuriyama [5]. He describes a method that fits continuous surfaces into a network of curves. With the 3-Draw system by Sachs et al. [10], the user outlines the shape of a model by drawing and connecting curves using two-handed input. Van Dijk developed a similar system [1].

There are few works about clay modeling [7, 9], but they do not deal with virtual tools that are oriented to real modeling tools used by the conventional modeling process.

3. SKETCHING CURVE NETS

With this system, designers can use their hands at the Responsive Workbench in the same way as they would in a real situation. The non-dominant hand holds the model in a way that will allow the dominant hand to carry out the editing functions in the right places. Cubic B-Spline-curves are being drawn free-hand, edited and automatically integrated into the existing network. Also available are functions like smoothing, sharpening, and dragging providing the designer with a potent interface that is easy to use at the same time masking the complex mathematical representation of the Spline-curves and -surfaces.

3.1 Designing from scratch

The shape design of new products is dominated by spline-based free-form surfaces. Through a multitude of degrees of freedom, this category of surfaces facilitates very flexible deformation preserving, at the same time, the smoothness of surfaces. However, this high degree of freedom makes it difficult to "draw" a surface directly. This task is made easier when the form- describing boundary curves of a model must be drawn as a frame.
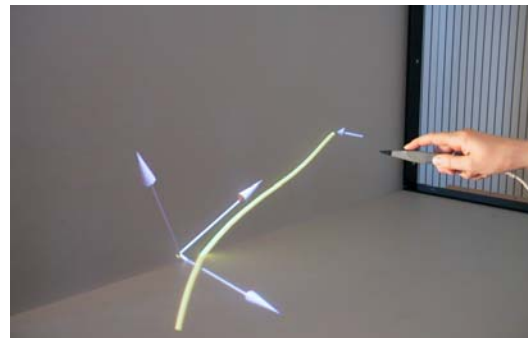

Figure 1. Drawing the curve net

Then the system automatically generates surface parts that reflect the predetermined form. With this procedure only curves have to be designed.

New free-hand drawn curves are being integrated into the existing network in the following way: Points of intersection are being predetermined on net-curves that are being approached by a new curve. The final curve approximates the drawn curve and interpolates the points of intersection.

3.2 Editing the model

Procedures of Variational Modeling, which are based on energy minimization, are used for designing curves and surfaces. Locally or globally performing deformation tools for curves and surfaces have been developed.

Curves can be smoothed or sharpened by moving the stylus along the curve, thereby pointing at the

position where the maximum effect should occur. The degree of deformation along the curve corresponds to a Gaussian-shaped weight function centered at the position where the user is pointing to. Curves segments, being fixed at their connection points with the network, can also be dragged around, thereby maintaining their shape details.

For surfaces, similar tools are available, however, without support for interactive, local deformations, as described for curves.
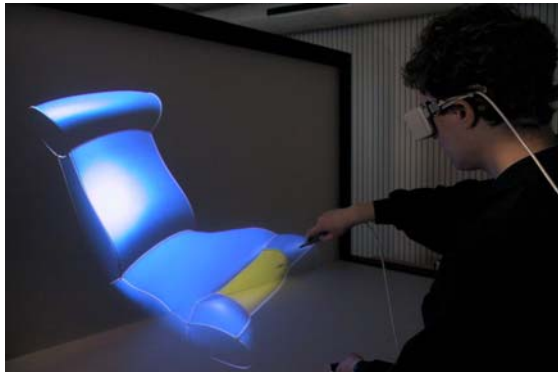

Figure 2: Editing the surface

When the initial sketch is complete, it is ready for the transition into the elaboration phase, for which the model is converted from the surface representation into a volumetric representation.

4. VIRTUAL CLAY MODELING

A prototype of a virtual clay modeling system (VCM-System) was developed and implemented at the Technical University Berlin. This system allows the generation of design models in analogy to conventional clay modeling, providing adequate support for the designer without restricting his or her expressive work [6, 3, 4].

The System provides virtual tools which can be applied to the virtual clay. The generation of models is based on free addition or removal of the clay with those spline-based tools, which are oriented to real tools such as Truesweeps, Templates, Planerakes and can be manipulated by a mouse, a spacemouse or a tracking system [6, 3, 4].

The prototype VCM needed to be further developed regarding the requirements of the integrated product development. The main purpose thereby consists of importing models from other systems, modifying them eventually and manufacturing them by rapid prototyping processes.

The VCM System is equipped in the meantime with deformable modeling tools, so that the designer can deform the tool while modeling. Advanced interaction metaphors were developed, and the

system is operated either on a desktop or at the Responsive Workbench. The latter allows the user to interact with the models in a realistic way.

Tool Database

A tool database containing flexible and rigid tools is developed based on Postgres. The rigid tools cannot be deformed, but the flexible tools can be deformed while modeling. The tool database enables as the case may be, a company, a form or a material specific tool selection. Advanced users can choose the modeling tools from a tool list. The user can evaluate the selected tools in a GUI before loading them in the modeling program. This allows a comfortable use also for users who do not know the names of real tools, since the visualized tool profiles allow to estimate whether the target free-form can be achieved or not. The tools can be modified and saved under some other name. For this purpose, the system contains so called tool editors enabling the visualisation and the modification of the virtual modeling tools. The modifications consist of increasing dimensions of tools such as the length, the width, the height and the radius. The parameters are entered through virtual draggers which are objects provided by Open Inventor.

5. IMPORT OF EXTERNAL MODELS INTO THE VCM-SYSTEM

To import files from other systems, the VCM-system needs a file converter. This has to transform the external file into an internally readable voxel model. Since most VR-applications are based on the Open Inventor platform, an interface is implemented to convert .iv-files into "stixel" models. Doing so increases the spectrum of systems the models can be imported from.

The principle of the converter consists of means to acquire the topology of objects and then subdivide it in "stixel". A stixel is an aggregation of voxels which contains the same information along an axis. This enables the data compression and therefore a better dynamic modeling [2, 8]. The user can specify the resolution of the transformed model by giving the voxel length along the axis and the number of segments. The number of segments determines how many subdivisions of the external model are performed before the voxelisation. The higher the number of segments, the more accurate the transformed voxel model is. However, the computation takes longer with larger segment numbers. The seat (Figure 2) was imported into the VCM system with a voxel length of 100 and divided in 2 segments. Afterwards, the seat was modified with a modeling tool called Truesweep (Figure 3).

Figure 3: Modeling the seat at the Responsive Workbench

An advantage of the combination of both modeling systems (curve net modeler and VCM-system) is a decisive step for reverse engineering and goes beyond the possibility to model objects continuously in many VR-systems. Instead of scanning objects with expensive devices such as 3D-Scanners and to invest in the implementation of algorithm for the conversion of the resulting point cloud, it is possible to take the 3D-Pointer around these objects generating 3D-curves. Those curves can then be transformed into a mesh model as operated with the seat. The obtained mesh model can be in turn voxelised and imported in the VCM-System and if need be, further styled and manufactured on a rapid prototyping machine.

6. RAPID PROTOTYPING OF THE SEAT MODEL

The third stage of our process consist in prototyping the designed models, because it is important for designers and engineers to evaluate their products at an early stage of development, in oder to improve them. For this purpose, the voxel model of the seat was converted into STL-file and then manufactured.

7. CONCLUSION

In this paper, we present two design systems based on different approaches that can be combined for an integrated product development. One system is based on networks of curves and the other one is voxel-based and consists of generating models in analogy to the conventional clay modeling. We implemented an interface to import models from the first system into the second one. The advantage of such an integrated product development can be seen by virtual curves being drawn by moving a 3D-pointer around an existing object. The virtual curves can be transformed into a mesh model that is in turn voxelised and imported in the VCM-system and if needed, be modified. After that, a seat model from the first system was imported, modified into the second one and manufactured on a rapid prototyping machine.

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