Towards Immersive Modeling - Challenges and Recommendations: A Workshop Analyzing the Needs of Designers

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Abstract. Among the many applications now available in virtual environments (VEs), a modeling application to generate geometry is gaining in relevance. Immersive modeling in VE involves generating drafts and manipulating geometry within an immersive environment such as a CAVE, a Responsive Workbench or other immersive projection technologies. It is a field which will supply product design with new perspectives. This paper describes a workshop in which thirty-six design professionals, active in various branches of product design, tested three different types of prototype modelers. The analysis of their experience will help to improve such modeling applications and to further develop immersive modeling in general.

Introduction

Following visualization and the possibility of implementing simulation results, the development of interaction in virtual environments (VEs) is becoming more and more relevant. The next logical step is the development of productive immersive modelers to generate geometry. In general, modeling in VEs might appear to be superior to desktop systems as far as characteristics such as ‘intuitive working’, ‘real-time interaction’ and ‘full-scale modeling in a 3D immersive environment’ are concerned, but a truly effective, user-friendly immersive modeling tool has yet to be developed. Many questions still need to be answered, such as which constraints are necessary for the exploitation of human fine motor skills and whether the level of functionality of current CAD systems makes sense in modeling systems within VEs. A comparative study would be of great value in this early stage of tool development. To this end, we invited a representative group of designers, the potential end-users, to test and evaluate three different prototype modelers, developed at the Fraunhofer Institute for Industrial Engineering (IAO) and the German National Research Center for Information Technology (GMD) during the ‘designDesign’ workshop at the IAO in Stuttgart.

The ’designDesign’ Workshop

Thirty-six designers from different design fields and professions, were invited to participate in a two-day workshop which involved testing three different modeler prototypes for the duration of an hour. A CAVE was included and since this environment is not a typical work environment, the sessions were conducted with each participant individually under laboratory conditions. Each individual session was recorded on video.

Query Techniques

In half-structured pre- and post-interviews (no closed answers categories) and written questionnaires personal details, motivation, previous experience and any physical or mental reaction experienced during the session were recorded The aim was to gain insight into the participant’s personal design process not only regarding work-time, the use of tools and visualization techniques but also the applicability of the three prototype modelers. The participants could rate the modeler, make statements on their strengths and weaknesses during the test and report on any problems. The interview was streamlined so that a predefined set of questions were posed in such a way that the participant could express herself freely and informally. This is an ideal technique to provoke comments during an informal conversation which would possibly have been suppressed in a formal interview.

As earlier experiments have shown [8], [9] the objective of the workshop was not necessarily to reach quantitatively or statistically valid conclusions but to obtain a purely qualitative feedback on the modeler approaches from a representative group of potential end-users. The results of the interviews and questionnaires throw light on how state-of-the-art immersive modeling techniques satisfy user’s needs regarding issues like functionality, devices, interaction concepts, acceptance and applicability and will also be of use in the further development of similar tools.

Testing the Modelers

The three modeler approaches were different in implementation, internal data representation, interaction concept and functionality. Obviously there were restrictions in the level of usage. Data transfer was not possible and the participants had to commence in an empty work space in all three applications.

In the actual CAVE test the participants were given between one and three minutes instruction on each modeler. An assistant was present throughout the session, any queries were answered immediately. There was no specific task to be fulfilled by the participants. They were completely free to explore the scope of each modeler. The modelers functioned using bimanual interaction using the 'MIKE II' [3] device (6 degree of freedom tracked button device; 2/3 buttons left hand, 2 buttons right hand) similar to the better known 'Wand'. The test started with the volumetric modeler 'Naegeli RT' since it is the simplest modeler in the test, being equipped with only three buttons and needing no menu. The next modeler was the 'lotus'-sketcher which included more functions analogous to the ‘paper, scissors and glue’ metaphor in working methods. The last modeler tested was the 'VE-CAD' which requires the use of menus to select functions similar to CAD. This was the modeler with the highest complexity.

The Participants

Of the thirty-six participant six were female and thirty male with an average age of 31,1 years. 47% of the designers had former experience with VE. The group was homogeneous, consisting of both design experts and students. The design fields represented were in industrial design, product design, car design, jewelry design and others. Some of the designers work in different design fields simultaneously e.g. both industrial and product design. Most of the designers (61%) were involved in product design, 31% in industrial design, 25% in car design, 8% in jewelry design and 11% in others. The participant’s degree of involvement in the design process varied. 83% were involved in the complete design, 17% in partial design. A differentiation was also made between a focus on conceptual work (61% of the participants) and design elaboration (39%).

The Modelers

Preliminaries

Despite the fact that a complete design process cannot be exhaustively specified, a number of typical phases the creative process can be defined:

- conceptual phase: ideas, thoughts and their first visualization,
- elaboration phase: working out alternatives; the quantification and detailing of sketches and models and
- presentation: working out the ultimate shape, character and function of the concept for the general public.

Up until now, a full elaboration of geometry has not been available in immersive modelers since no specific tool can provide the appropriate range of functionality. Immersive modeling is therefore reduced to use during the conceptual phase and early stages in the elaboration phase. Sketching in the conceptual phase has mainly the functions like (a) externalization and memorization of individual ideas, (b) communication of ideas and partial solutions inside a workgroup and (c) the presentation of the conclusion of a complete thought process outside the workgroup.

’Naegeli RT’: a Volume Based Modeling Tool

Volume-based rendering techniques have a long history in computer graphics [1], [2]. The main advantage of volumetric representations is that they model spatial topology simply and directly. Most successful rendering techniques for implicit surfaces actually generate a volumetric representation that is subsequently rendered as an iso-surface.

Interface and Functionality The 'Naegeli RT' (named after the swiss artist Harald Naegeli, the 'sprayer of Zurich') uses only the most basic operations inside a volume to make direct modeling in 3D possible.

Fig. 1. Volume Based Modeling Tool 'Naegeli RT'

The only operations possible are:

- filling small regions of the volume with 'substance'
- locally removing 'substance' from the volume

For convenience, a global load, store and clear is available. These allow some control of the workflow by making it possible to interrupt and continue work on a model.

Substance is rendered as a polygonized flat-shaded (iso) surface model. This gives the resulting visible geometry very rough and unfinished appearance. A very efficient rendering scheme allows the user to update significant parts of the volume and convert the polygonal surface model without having to slow down the rendering loop. This makes all modeling operations instantaneous, providing the user with continuous feedback.

Corresponding to the basic and so to speak, atomic functionality of the modeler, the interface itself is also extremely simple: a bimanual interface has been implemented, letting the non-dominant hand navigate, i.e. grab, move and place the model by means of a button. The dominant hand is used to operate two modeling buttons, one button is used to fill the volume and the other to remove substance from the volume. No other operations are needed to incrementally build a complex shape; the user never needs to provide any hints to the modeler about surface orientation nor the creation and joining of patches. Owing to this spartan functionality, the modeler is extremely user-friendly, allowing a user to operate the system almost instantaneously through hands-on experience with no need for preliminary training or instruction. Filling an empty space with substance is experienced by most people as spraying volume, giving a material appearance to the operation. Because of the high performance of the rendering scheme and the simplicity of the underlying data model, adding functionality to the modeler is a very straightforward procedure and may lead to a ’Photoshop’ with volume.

’lotus’: a Polygon Based 3D Sketching Tool

The simplicity of the ‘paper and pencil’ metaphor led on to the development of a concept based on the analogy ‘paper, scissors and glue’.
The underlying concept of a polygon-based 3D sketching tool ‘lotus’ is the reduction of functionality to a few simple functions. The goal is to develop a user-friendly tool which can shape a space in a sketch-like fashion. All additional functional features should be sacrificed in order to maintain a simple user interface.

Interface and Functionality The user interface is operated bimanual with two tracked 3D Joysticks Mike II. One of the advantages of bimanual interaction is the physical experience of being able to hold a reference point and a tool in both hands, as described in [4]. All functions are accessed via five buttons on the joysticks. No menus are necessary to access concealed functions or switch modes. Only one type of primitives, arbitrary flat polygons, can be created and positioned in space. The primary implementation does not include 3D deformation.

Implemented Functions:

- *Primitive Creation* The basic function is the drawing of a polygon in a predefined plane. The drawing process is constrained to a plane defined by the three first points of the users hand movement. All following points are projected automatically onto this plane. The plane is visualized after it was defined.
- *Selection* The selection of a polygon is a direct interaction with the manipulator representations of two 3D cursors. If an object is selected, a red sphere appears on the surface as feedback.
- *Positioning* Selected polygons can be positioned or rotated freely in space. To obtain a functional symmetry, they can be grabbed either with the left or right hand using the same combination of buttons.
- *Deletion* Selected polygons can be deleted using a button on the left interaction device.
- *Duplication* Selected polygons can be duplicated using a button on the left interaction device.

Conclusion and Remarks The reduction of the functionality to a few functions has been shown to improve learnability. The user is able to explore the system within a few minutes. This supports the notion of a modeless interaction model. Compared to six degrees of freedom drawing, the restriction to a single plane improves user control.
Major problems in recent implementation is the positioning of the plane itself, which is not immediately clear to the user, and the memorizing of abstract commands, such as copy and delete, on neutral buttons.

Nevertheless, the first impression shows that shape space only filled with flat polygons is uninteresting. The next step would be to test additional simple functions to shape space directly, for example, using a skin function to connect the polygons. Besides this, the addition of an improved constraints control is also required.

Fig. 2. Drawing a Polygon on a Constrained Plane/ Composition of Polygons

'VE-CAD': a Free Form Surface Sketching Tool

In projection-based VEs, a modeling application for free form surfaces is an obvious challenge. The goal is to support designers with a system for sketching free form shapes quickly and directly in 3D. The user draws curves (cubic B-Splines) freely in 3D within a VE using a tracked, pen-like input device, see Figure. 3 The curves are connected automatically in such a way that a curve network develops. A combination of automatic and user-controlled topology extraction modules creates the connectivity information. Objects are currently restricted to 2-manifolds. The underlying surface model is that of multisided patches bounded by closed loops of curve pieces based on work by Kuriyama [5]. A bimanual interaction scheme provides CAD functions for drawing and editing curves and deleting or transforming objects.

Bimanual Modeling An elegant way to deal with curves and surfaces is achieved by bimanual interaction [4], [6]. The non-dominant hand assists the modeling hand in drawing curves by controlling the position and orientation of the modeling coordinate frame dynamically or by fixing it at a preferred place. This techniques facilitates dealing with space curves. Alternatively, the non-dominant hand controls a virtual transparent drawing plane onto which curves are projected, or it applies arbitrary symmetry planes globally or locally. In complex applications like shape modeling where the user requires a large degree of freedom to manipulate curves and surfaces, the selection of tools should be integrated in the work- flow in an unobtrusive way.
The goal is to relieve the user of large arm movements and to reduce having to change the focus of interest when selecting tools from toolbars or menus in a VE. To achieve

this, a virtual toolbar is connected to a tracked pointing device when a button is pressed. To select a tool, the user needs only to turn the wrist slightly and the viewing direction can rest continuously on the area of interest. Different tool sets are assigned to existing object classes that are activated when the user points to an object of the corresponding class.

Modeling Curve Networks In ‘VE-CAD’ B-spline curves can be edited freely in space but new curves have to be woven into the existing curve network. The curve is first drawn directly in space without any constraints. A new curve which is drawn close enough to an existing net curve will generate its intersection points. The final curve is an approximation of the new curve that interpolates the intersection points. A similar technique is used for maintaining the connectivity in the net when a single net curve is changed.

High-Level Curve Editing We implemented powerful curve manipulation tools like curve smoothers or sharpeners that can be applied locally or on larger segments of a curve. Based on variational modeling techniques [7], locality is achieved by controlling the influence of different energy terms on the curve using weight functions, e.g. a gauss function. They provide a high-level interface to a curve and can substitute or at least complete the standard control-point-based editing of a curve.

Extracting the Topology The extraction of the topology is implemented by a combination of an automatic loop-searching module based on geometric criteria and the explicit selection of successive curve pieces that are assumed to form a loop. A closed loop is a set of successive curve pieces that surround a patch.

Fig. 3. 3D Sketching of Surfaces

Applications and Further Development Useful application fields for a free form surface modeler with the described properties include automotive design studies, the initial design stages of industrial design or even architecture. The workshop’s practical sessions have already served to pinpoint shortcomings in the usability of the modeler. For example, the modeler did not support features like drawing planar curves or symmetric drawing. These functions have since been implemented. The test sessions also showed that other related functions, i.e. the subdivision or removal of parts of a model by drawing a curve on its surface and the direct editing of patches would be desirable features.

The Outcome of the Test Sessions

The development of successful modeling tools for VEs is dependent on the identification those tasks bringing the most significant benefits. The participants were therefore asked to rank the main design features available. This ranking is shown in the figure 4. A comparison of the use of traditional methods and computer-based methods is shown as well. An interesting outcome is that 94% of the participants used 2D sketches, which demonstrates that 2D sketches are the preferred traditional supporting tool in the creative process. The visualization was also ranked, the participants experienced the spatial perception and interaction as helpful and fully satisfactory. However, about half of the participants experienced difficulties in hitting targets within the VE.

The three modeling applications for VE focus on very different modeling aspects. To compare the three, the 'Naegeli RT' generates volume particles, the 'lotus' uses the 2D sketching principle for VE, and the 'VE-CAD' creates free-form surfaces. The participants were asked to rank each modeler as a whole. In a ranking scale of 1-3 (where 1 is unsatisfactory, 3 is excellent), the 'Naegeli RT' and the 'VE-CAD' were ranked with 2.4, whereas the 'lotus' received a ranking of 1.5.

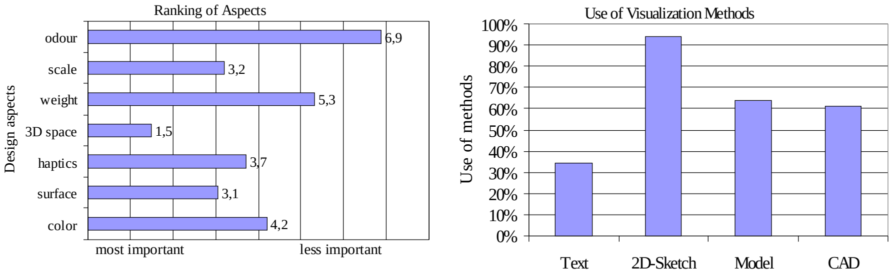

Fig. 4. Ranking of Main Design Aspects and Visualization Methods

The Results of the Analytical Evaluation

The results of the questionnaires were examined for any correlation between different answers. It was particularly interesting to see if participants who have professional working experience with 3D CAD ranked the VE-modelers higher. This proved not to be the case. But the ranking of the 'Naegeli RT' proved significant. Those participants who had experience with 3D (and the same applies for 2D) computer-based modelers ranked this modeler very highly. The correlation coefficient was about 0,5. It is interesting that there was no similar significance for the ranking of the 'VE-CAD'. Neither did participants from different professional fields rank the modelers significantly differently.

Subjective Statements

The participants identified spatial visualization, full-scale modeling and immersion as important criteria for the design process in immersive modeling. The system should accommodate natural human behavior and be as intuitive and easy to learn as possible. Shutter glasses, cables and other interaction devices were therefore identified as hindering features. The button device was mentioned as being inadequate for drawing and sketching.

As far as the modelers are concerned, the participants expressed the need for a combined tool which would support both the conceptual phase and a certain level of elaboration in the elaboration phase. In order to bridge the 'empty workspace syndrome' (having to start from scratch), the participants felt the need to be able to create primitive shapes quickly and easily. These can then be used as reference objects as well to help guess size and orientation in space. Concrete working vs. 'surprise effects' was experienced as disturbing and should be kept under control. 'Concrete' means the plausible transfer of ideas into the digital model. This must be possible at all times. Some participants expressed dissatisfaction that features like the numerical input of metrics were not available. The participants also had problems with completing the generation of spatial objects in 3D. It was difficult to reach the point at which the system automatically 'snaps' the delineation together to complete the desired object. Two possible solutions were mentioned, one could be a switch between the normal and the perspective view, the other a constraint mechanism to enable the user to work in 1D and 2D besides the usual 3D interaction. The participants also expressed a strong need for constraints similar to real life experience where interaction takes place under both continuous and redundant feedback. Sound could be a fast method to provide additional feedback on user actions. The participants also mentioned a need for better orientation in the form of a set of reference objects (planes, rasters, grids, objects).

It was also mentioned that a continuous process chain would be required in industrial usage, e.g. digitization, data transfer, rapid prototyping methods, CAD systems.

Conclusion

Configuration of the Virtual Environment

One of the most important prerequisites for the unencumbered use of immersive systems is cordless head- and hand-tracking. It is important to coordinate both hard- and software components in order to achieve a necessary high level of usability.

A number of cordless input systems and the corresponding interaction techniques which could be integrated in the modeler environments are being investigated. High quality visual presentation, a large working volume, and cordless interaction give users a much appreciated sense of control and presence in the VE.

Interaction Methods

It is probably best to analyze user interfaces that are not even recognized as such, e.g. pencil sketching. Zeleznik [11] approaches this metaphor by three interface concepts: (a) emphasizing 2D interaction, (b) co-locating interaction and display and (c) interacting with idiomatic gestures. Although for immersive modelers there are different characteristics and requirements, some things in common with a number of Zeleznik’s statements were observed during the test sessions. One major problem with 3D modeling, that the participants criticized, is the lack of resting positions to exploit precision fine motor skills. This is one of the reasons why 3D immersive modeling is not naturally superior to desktop modelers. To overcome this drawback, a suitable force feedback hardware could be integrated into the VE. It could serve as the basic interface to the model space in an analogous way as in pencil sketching on paper. We found a strong need to split intrinsically 3D operations from operations that are ideally suited to 2D due to the necessary constraints and feedback redundancy. But we assume that force feedback interaction methods could be developed that provide the necessary constraints in a comfortable way.

One method to meet this requirement would be the use of automatic constraint mechanisms. This approach in 'lotus', however, did not prove to be very successful. The difficulty is to find an appropriate mechanism that is transparent for the user. Parsers have the same problems when selecting the best joint interpretation of a multimodal input or implementing context sensitivity. Nevertheless, it is clear that features such as bimanual interaction, speech recognition, context sensitivity and an efficient definition method of constraint interaction and dimension are essential to expanding the functionality of immersive modeling .

Bimanual interaction needs to be supported by small pen-like devices or even a tracked finger ring which is currently under development at the Fraunhofer IAO.

It is interesting to note that, on the one hand, the participants require an intuitive and easy-to-learn interface but on the other hand, there is also a strong need for CAD-like numerical input.

The Immersive Modeler

A general problem in desktop modeling systems is the fact that a complex CAD interface forces the designer, at an early stage in the design process, to think in mathematical terms. Towards the end of the elaboration phase, where the degree of freedom for the designer is low owing to a broad level of constraints, the supporting tool should provide basically elaborative functions. An immersive modeler should support the creative phase to a certain grade of elaboration according to Lüddemann [10]. To identify the point of inflection in the design process where the degree of freedom is low and the grade of elaboration is high, the indicative value was set at 70% elaboration. Up to this point, support by an immersive modeler makes sense in the middle-term phase of a design process (based on the present state-of-the-art).
The primary goal should be to make use of the strengths of immersive modeling in the conceptual focus of the design process:

- Direct and real-time interaction
- representation of objects at full scale as well as full scale interaction and
- immersion.

These attributes, in contrast to desktop systems, allow the designer to get subjectively close to her design idea and allow her to intuitively work on its representation. In general, an immersive modeler in the early stages of design should conceal the complex mathematical representation of objects from the user. It should provide high-level and intuitive operations on the supported object classes and provide an efficient interface. At the same time, the high level of constraints/ boundary conditions at the end of the elaboration phase should be avoided.

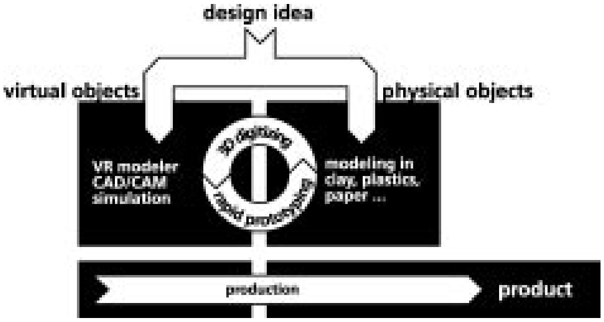

Fig. 5. Modeling System including Interfaces

The basic modeler needs to be equipped with a wide selection of tools in order to optimize the design process and support the designer in her work. Besides this, more effective and efficient interfaces on physical- and desktop-modeling as well as creative tools such as generative transformations, will help to establish a continuous computer supported process.

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