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FREEFORM SHAPE MANIPULATION USING CONTEXT-DEPENDENT CONSTRAINTS AND PARAMETERS

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1. Introduction

This research concerns shape modification during the ideation phase. In this phase the description of the concept is not complete nor concrete. CAD tools need both complete and concrete data. What tools would be more appropriate during ideation, and which requirements must they fulfil? To answer this question, we need more insight in the way designers exteriorize shape. Which activities they perform, and how successful these are. We focus especially on one specific dilemma: Designers want full freedom of shape generation, however, for many shape modifications they want to impose specific shape constraints.

This paper describes how a designer modifies a shape from step to step, before ending up with a satisfactory concept. For example, a clay modeler may start with a block of clay, and than remove material to round the edges, and add material to create additional shape elements. This micro-level of activities is investigated by comparing how designers ideally could create shape, to how they do it in practice, when using clay. Furthermore, we identify the situations in which clay modeling is effective or in which other methods might be more appropriate.

2. Free form versus parametric shape design

A shape parameter can be regarded as the opposite of a shape constraint. A shape constraint defines a shape aspect that should not be modified, a shape parameter describes a degree of freedom. E.g. when a mug is made on a turn table, rotational symmetry is a constraint, while diameter and height are parameters. The rotational symmetry is useful for the generation of the mug body, but not for its ear. This example illustrates that a shape constraint should be switched on or off depending on the context of the shape modeling process. Furthermore, it shows that, though full freedom of shape may look ideal, it is often advantageous to impose certain constraints.

Constrained-based design is already known in detail design. Most work on parameterized shape design concerns regular shapes, see e.g. [Shah and Mäntylä 1995]. In conceptual design of consumer products, however, free forms play an important role. Specific cases of free form shape modification have been investigated, e.g. by [Elsas and Vergeest 1995], [Bidarra and Bronsvoort, 2000] and by [Marsan ea. 2001]. However, a model for completely free form shape modification would require an infinite set of parameters. It is not possible to implement such a model, nor would it be a great help for a designer. We hypothesize that shape constraints can reduce the set of parameters to a manageable number, giving the designer better control over a shape aspect in a specific shape context. For example, a simple modification like scaling a clay model, virtually means the designer has to redo the whole modeling work. For parameterized models in CAD the same modification may be achieved by changing the value of just one parameter.

3. Research method

To develop constraint based freeform shape modification tools, at least the following problems should be solved.

1. First, shape modifications should be described in a way that is appropriate for the designer's current shape modification activity. This requires frequent re-interpretation of the shape. The designer may chose different approaches to each individual activity. Different views on the same shape may be the result. Recent empirical studies throw light on shape modification activities. Terms used for verbal shape exteriorization are investigated by [Sperna Weiland and van Gorkom 2000]. [Van der Vorst and Veldhuizen 2000] studied for which activities speech, sketching, clay modeling and gesturing are used. Where the selection of one of these methods depends on is researched by [Teeuwisse and van Weelderen 2000]. [Baak and Groeneboom 2001] noticed that design-educated people in several cases use other activities than novices.
2. After the description of shape modifications, we need to describe explicitly which parameters play a role during the shape modifications. Complementary, we need to specify which aspects of the shape should not be affected, in other words which shape constraints should be in effect. In future research these descriptions can be used for the development of improved CAD.
3. Finally, besides the technical implementation issues, ergonomic issues and choices like numerical input, direct manipulation, and the types of input devices play a role. These issues, however, are not the concern of the research at hand.

To gather empirical data on shape modifications, an experiment was set up in which a test subject had to perform three clay modeling assignments.

Assignment 1: A real soap box was shown to the subject, who had to create a copy using clay.
Assignment 2: Scaling up the clay model by 20%.
Assignment 3: Adapting the shape of the clay model, so that it can contain the large piece of soap (Figure 1).

Fifteen subjects were video taped while performing the assignments. From the video tapes the subject's activities were inventoried, as were the shape constraints the subject implied on the shape, and the parameters (s)he varied.

Figure 1. The soap box to be modified and the pieces of soap that should fit in

4. The hypothetical shape modeling system

Before looking at the observed activities performed by the subjects, lets imagine which activities could have been performed if, in stead of clay, an ideal shape modeling system could be used. The three assignments then could have gone as follows, see Table 1. The activities 1.*, 2.* and 3.* concern the assignments 1, 2 and 3 respectively. The hypothetical shape modeling system has technical capabilities as listed in column 4 of the table.

Table 1. Using a hypothetical shape modeling system

	Activities	Parameters	Constraints	Technical assumptions
1.1	Select a block Specify dimensions with hands	Length, width and height	Right angles	Shape library Gesture recognition Result will be displayed
1.2	Round an edge with a finger	Radius of the roundings	Rounding follows edge	Tactile feedback Force control
1.3	Say "all edges should be rounded that way"	Radius of the roundings	Roundings follow edges	Speech recognition Interpretation of terms
1.4	Press groove with finger parallel to long sides	Profile of the depression	Depression connects to surface	Force control
1.5	Say groove should go through symmetry axes	Course of the depression	Along symmetry axes	Terms are recognized
1.6	Repeat last two steps parallel to short sides.	Profile and course of depression	Connect to surface Along symmetry axes	
1.7	Indicate a path around the box with a finger.	Course of the increase	Along symmetry axes	Path will be displayed
1.8	Say 'along the path there should be an increase'			Increase will be displayed
1.9	Indicate profile dimensions	Profile of the increase	Connect to surface	Increase will be adapted
2.1	Select soap box			
2.2	Say "increase by 20%"	Scale factor	Selected part only	Increased with all details
3.1	Raise center of top face of soap box	Height of center	Selected part only	Center point will be shown above rest of the surface
3.2	Say edges of surface should remain in place.		Preserve edges	
3.3	Say surface should bend smoothly along top	Height course	Don't change depression Radius of the roundings	Depression profile shouldn't change
3.4	Tune by pressing from the inside out	Depth	Selected part only Radius of roundings	

5. Analysis of the actual shape modeling process

The assignments 1, 2 and 3 were carried out by fifteen subjects, using clay. The activities of all fifteen subjects can be categorized as follows:

- Shaping activities: kneeding, pressing, taking away material.
- Finish activities: flattening a surface, smoothening a surface, rounding an edge.
- Assembling activities: sticking parts together.
- Disassembling activities: cutting.
- Other activities: measuring, watching.

Figure 2 shows typical activities performed by subject number 1. In the first picture, he slams the block on the table to flatten one of the sides. Additional flattening is done with both hands in the second picture. After creating the basic shape, the subject makes a ribbon. The ribbon is wrapped around the box in the third picture. The last picture shows how a groove is made with help of a stick.

Figure 2. Shape modeling activities for assignment 1

Table 2. The actual shape modeling process

	Activities	Parameters	Constraints (Side effects)
1.1	Take amount of clay	Volume	
1.2	Flatten all sides	Surface flatness	Volume (protrusions)
1.3	Round the edges	Radius of the roundings	
1.4	Create a clay ribbon	Length, width and height	Right angles
1.5	Stick ribbon	Course of the ribbon Ribbon length	Ribbon connects to the faces
1.6	Smoothen the faces	Surface smoothness	Volume (protrusions or gaps)
1.7	Make a groove	Depth and course of the depression	Straight course Depression profile Volume (protrusions)
1.8	Flatten groove sides with knife	Profile of the depression	Course of the depression
3.1	Take amount of clay	Volume	
3.2	Mould the material into a ball		Volume
3.3	Change ball into ellipsoid	Radius of the ellipsis	Volume
3.4	Smoothen the curved faces	Surface smoothness	Volume (protrusions or gaps)
3.5	Cut in two halves	Course of cutting	Flat cutting plane
3.6	Stick on top of soap box	Position and orientation	Flat faces
3.7	Smoothen the connections	Surface smoothness	Volume (protrusions or gaps)

Table 2 lists all activities performed by this test subject. The activities in Figure 2 concern row 1.2 (two pictures), 1.5 and 1.7 in Table 2. The table also includes the parameters and constraints that could be derived. For assignment 2 (enlarging the soap box) the subject started anew. His activity sequence for assignment 2 was about the same as for assignment 1. In the table this sequence is only shown once.

Figure 3. Shape modeling activities for assignment 3

Assignment 3 was solved by adding a rounded part on top of the box made in assignment 2. The rounded part was made by cutting an 'M&M-shape' into two halves, see Figure 3 and row 3.5 in Table 2. The figure also shows the assembly of the additional part (row 3.6 in Table 2).

Most time was spent on finishing activities. For example, in assignment 1 the subject spent 57% on smoothening the surfaces, rounding the edges, etc. This is two times as much as he spent on shaping activities (28%). Generally, the modeling of a shape element started with quick and rough shaping activity, followed by elaboration afterwards. In most cases, rounding the edges took not much time and effort. In some situations it was even skipped, because the created shape appeared to have no sharp edges at all.

Subjects used different approaches to enlarge the soap box. Some of them started completely anew. Others added clay at the short side, then at the long side and finally at the top. After that, the shape details were remade, because they were no longer at the symmetry axes. A few test subjects applied a sort of wrapping approach. They created a 'pancake' and wrapped it around the box. Unfortunately, the shape details disappeared under the pancake. Whatever approach was applied, most of the shape elements had to be generated anew. Generally, the enlargement of the soap box took nearly as much time as its initial creation.

The rounding of edges and the creation of a depression occurred both in the hypothetical modeling system and during the clay modeling. With the hypothetical system, the depression and the increase could be modeled in the same way. In clay modeling, however, we observed that the increase was first modeled as a separate element and then stuck to the basic part.

Many activities from the hypothetical shape modeling system could not be seen during the clay modeling experiment, e.g. selecting a block, applying the rounding of an edge to other edges, automatic application of symmetry, enlarging a complete shape by one simple command, raising a specific point of a surface, and pressing a surface from the inside out. In stead, the following clay modeling activities were observed : taking an amount of clay, molding clay into a ball, kneading into an elliptic shape, flattening faces, sticking parts together, smoothening the connections and cutting shapes into parts.

The first activity of the subjects was taking an amount of clay, with the volume as a parameter. So the volume played already a role before the form giving started.

An effective constraint was the use of a long, straight stick to press a straight groove. Similarly, a straight knife helped to achieve a straight cutting plane. A volume constraint supported molding. Small shape modifications were easily made by pressing the clay, so that it moved to another place. However, the volume constraint showed a drawback during the rounding of edges, when subjects had to remove material to prevent protrusions.

We summarize that in clay modeling the volume plays an important role, initially as a parameter, and later as a constraint. Modeling a rough shape is quickly done. Smoothening the surfaces and edges takes most time of the clay modeling process. Often, when a shape aspect of a clay model was changed, the shape details were unintentionally affected and had to be fixed again. This was especially elaborate in assignment 2 (the enlargement of the soap box). CAD systems often support scaling activities, and the preservation of shape features. A problem in freeform modeling is, that there is no one single, unambiguous way to interpret which features are intended by the designer. This research provides a method to idenify the parameters that are (or would be) varied by designers, and the constraints they impose. Further research will be directed to select a set of parameters and constraints that support modeling activities during shape ideation and can be implemented in CAD software.

6. Conclusions and further research

A method was developed to investigate which shape modification activities are performed during early design. The method was applied to three clay modeling assignments. The activities of the test subjects were observed and analyzed. We were able to derive parameters and constraints that play a role during individual activities. Further research will be performed to find sets of parameters and constraints that describe modeling activities that do not necessarily belong to the idiom of current CAD systems. Furthermore, the parameters and constraints should be chosen in such a way that they can easily be manipulated and controlled by designers. The appropriate set of parameters and constraints may

represent the key functionalities of better CAD systems.
The effectiveness of various clay modeling activities has been discussed. Several times, a comparison with CAD modeling was made. Data on the effectiveness of both types of modeling activities is needed to decide which modeling operations should be added to CAD systems to make them more appropriate for the ideation phase of design. For this reason, a similar experiment has been started, using the same modeling assignments, however performed with CAD instead of clay [Dumitrescu, 2002]. The results of both experiments will be compared and analyzed in a future research.

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