Determining the effectiveness of shape manipulations by observing designers at work

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Abstract

Little is known about the effectiveness of shape manipulation activities carried out by designers, especially in the early phases of design. For the development of improved shape manipulation tools it is necessary that their effectiveness can be evaluated. We propose a method to gather empirical data on designers' shape manipulation activities and to analyze the effectiveness of these activities. We applied this method and conducted an experiment to observe designers at work. The test subjects worked on three clay modeling assignments. We compared what would be an ideal way for designers to create shape, to how they actually did it in practice, when using clay. We identified the modeling activities the designers performed, how these activities could be systematically described, and which parameters played a role. Finally, we analyzed the effectiveness of some of the activities. Further research could investigate in which contexts an increase in effectiveness can be achieved.

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Introduction

Current CAD systems support shape generation in many ways, but they are not appropriate for the very early stages of shape design. Ideating designers may think of complex shape elements and at the same time leave parts of the shape vague or undefined. They need computer support for easier manipulation of complex curves and surfaces, but not at the cost of reduced freedom of form and creativity (Wiegers and Vergeest 2001).

CAD systems have been evolving for some decades, and they supported parametric design for regular shapes (Shah and Mäntylä 1995). For freeform shapes, researchers have proposed several methods (Elsas and Vergeest 1996; Bidarra and Bronsvoort 2000; Marsan, Chen and Stewart 2001) and new interaction devices (Murakami and Nakajima 2000; Djajadiningrat 1998). But still, reports on effective CAD methods for free form ideation hardly exist. Even empirical data on early free form manipulation is scarce.

To fill this gap, we observed designers to gain insight into their methods of free form modeling. The designers had to perform shape modeling assignments in a laboratory setting. Their performances were video taped and their shape manipulation activities were identified. A geometric description of the change in shape was made, and the required time was noted. Furthermore, it was considered which alternative activities could achieve the same shape.

The ultimate objective of this research is to support the development of more effective and intuitive free form manipulation methods. This paper reports a method to describe observed freeform shape manipulation activities. The method will be used to identify those activities that can be done more effectively if appropriate computer support is developed. Future research will address the feasibility of the proposed support means, and designers' expectations of their relevance and applicability.

Approach

During shape conceptualization, designers often express their ideas in some way, not only to communicate them to co-designers, but also to enable reflection on their own concepts. To express ideated shapes, various methods are used, such as sketches, spoken descriptions, gestures and physical models. Freeform shapes, however, are difficult to describe. Sketching and physical modeling of freeform shapes generally requires much time and effort and therefore interferes with the designer's creative flow of thoughts. Traditional CAD (Computer-Aided Design) suffers from the same problem. It is our goal to develop means that improve the effectiveness of shape conceptualization.

It is difficult to gather generalizable data on a design process. No design can be created twice by the same designer under the same circumstances. If we want to gather data about multiple, similar design processes, we need different designers. Even if their grade is the same, they will differ in experience, personal approach, favorite methods, etc. Another problem is the large variety of products that are conceptualized in different industries. Furthermore, there is the question whether observations should be done in a real, industrial, environment or in a laboratory setting. Companies usually do not perform the same design assignment twice. A laboratory experiment, however, can be questioned on its relevance for the industrial situation.

One approach to minimize the effect of these influences of differences among designers would be to observe hundreds of designers who are performing the same design assignment. However, this would be an expensive and time consuming approach. Another approach is to perform an experiment that demonstrates that at least in some cases the effectiveness can be improved. In the situation where little is known about the effectiveness of individual activities, and about the methods to gather data and analyze it, such a demonstration would be an important step forward. If it can be shown that an increase in effectiveness is possible, further research can be done to investigate in which contexts this increase can be achieved. For these reasons we decided to take the latter approach.

For conceptualizing a satisfactory shape, designers often want full freedom of shape, as with clay modeling. However, for many shape manipulations it is advantageous to impose specific constraints, e.g. preserving the ratios when scaling a shape element. Apparently, which method is most effective depends on the context of the shape modification. To develop effective support for shape conceptualization, we need to know which activities a designer can use to realize the intended shape, and how effective these activities are. The effectiveness of shape manipulation can be improved if ineffective activities can be identified and replaced by more effective alternatives. To estimate the effectiveness of modeling activities, criteria should be specified. These criteria are needed both for observed activities and for proposed ones. The following sections will discuss what criteria can be used and which problems we should be aware of.

Estimating effectiveness

Shape models often support a kind of discussion between a designer and his ideas. If the shape a designer intends is available as a tangible model, the designer can evaluate and further develop his ideas, without the need to keep all the details of the current shape in his mind. An ideal situation might be when a designer can have an exact, tangible model of the intended shape, as soon as he has conceptualized it. However, in practice, such a model is often not exactly as intended, and it may take much time and effort to generate it. The more time is taken up by generating the model, the longer the ideation task will be delayed. Similarly, the more mental effort the modeling takes, the more the designer's attention will be focussed on the modeling instead of the ideation. Also, the more a shape model differs from the intended shape, the more awareness is required from the designer during the evaluation and the subsequent development of the shape. In summary, the effectiveness of a designer's modeling activity depends on its duration, on the amount of cognitive effort it requires and on the degree to which the result of the activity reflects the intended shape.

Measuring the duration seems relatively easy. However, it is not always clear where a specific modeling activity ends and where the next one starts. Another problem arises when a designer combines activities, e.g. a designer may press a clay model to flatten its top surface and simultaneously shrink its height. In such cases, an estimation can be done, based on the data available on a video tape and the expertise of the researcher. For a systematic description of modeling activities, activity sequences should be selected that do not contain many ambiguities for interpretation. The designer's mental effort too cannot be seen from the video tape. Therefore, the test subjects will be interviewed after they have finished the assignments. For each assignment, the subjects will be asked whether they thought the task was difficult. Also, the resemblance of the model to the intended shape will be tested through an interview question.

Elaboration of the research method

To gather the required data and analyze it, the method should contain the following steps:

1. Conducting an experiment in which designers work on modeling assignments.
2. Comparing the ideal way for designers to create shape, to how they actually did it in practice.
3. Identifying the modeling activities the designers performed, and the parameters that played a role.

4. Describing the modeling activities as a mapping of an initial shape onto the resulting shape.
5. Analyzing the effectiveness of the different shape modeling activities.

The experiment

An experiment was conducted in which the test subjects had to perform three clay modeling assignments:

1 Modeling an existing soap box in clay. The modeling was only concerned with the appearance of the outside. The box could be modeled as one solid, without a hollow inside or a separable lid.
2 Enlarging the box by 20%, for a larger bar of soap.
3 Rounding the top of the box, to make the box suitable for holding a larger, rounder bar of soap.

Figure 1: The soap box and the bars of soap to which it had to be adapted

The original soap box is shown in Figure 1, together with the bars of soap to which it had to be adapted.

Figure 2: Results of assignments 1, 2 and 3 respectively

The experiment was performed by 17 test subjects, all students of the Delft University of Technology. All sessions were video taped and analyzed. The results of the first analyses are reported by Baak and Groeneboom (2001) and by Toledo and Weelderen (2001). Figure 2 shows the clay models generated by one of the subjects. A comparison was made between how designers ideally could create shape and what was observed during the experiment (Wiegers, Vergeest and Dumitrescu, 2002).

For this study, one of the sessions was selected for a more detailed analysis. The analysis concerned the identification and the description of the subject's shape manipulation activities. We zoom in on a part of the subject's work to record his activities in detail. The observed activities have been described by recording:

- the initial shape, i.e. the shape before the activity started
- the shape the subject intended

- the shape the subject actually achieved
- the operations the subject used to achieve that shape
- the duration of the activity
- the shape parameters that were changed
- the effort it took.

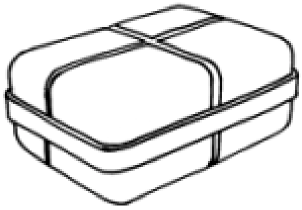


Figure 3: A depression along the length axis and the width axis of the box

The shape manipulation activities described in this paper are part of a sequence that was performed by the first test subject. These activities concern the generation of a depression, which runs over the length axis all around the box, and also along the width axis, see Figure 3.

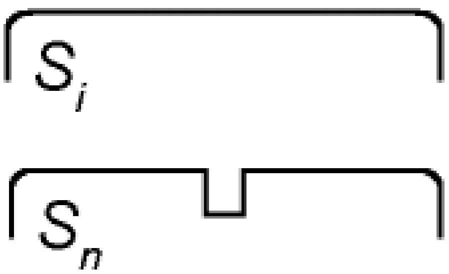
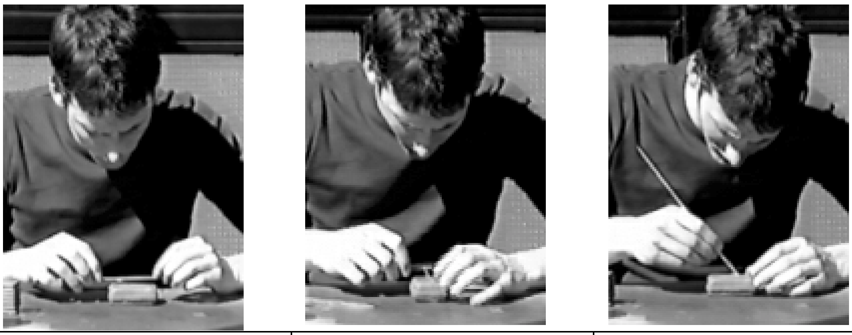


Figure 4: Initial shape S_i and intended shape S_n

We consider in particular the profile of the depression. Before the subject generated the depression, the top of the box had a cross section as shown in Figure 4. We call this the initial shape S_i. In the same figure, S_n depicts what we assume was the intended shape.



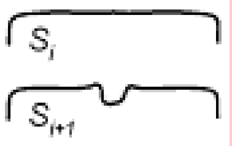
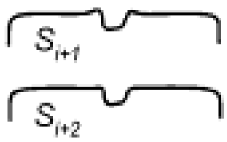
	Press	Cut	Push & Cut
Activity	Press	Cut	Push & Cut
Tool used	Stick	Knife	Stick & Knife
Duration (seconds)	71	46	78
Initial shape Achieved shape			
Parameters (geometric)	Depth Width	Smoothness	Rounding radius
Parameters (physical)	Force of pressing Width of stick	Knife position and orientation	Tool position and orientation
Effectiveness issues	Depth independent from width.	Prevent cutting too deep.	Prevent widening of groove.
	Depth independent from course, if surface is flat.	Prevent pushing down the surface.	Groove guides tool.
	Depth depends on course at roundings.		

Figure 5: Experiment data

To achieve the intended shape, first a metal stick was pressed into the top surface of the clay model, see Figure 5. This resulted in the shape S_{i+1}. The intended shape can be recognized, but there are some imperfections. At the top, some clay protruded and at the bottom the surface is irregular. Furthermore, the walls of the depression are not quite perpendicular. The subject used a knife to remove the protrusions at the top. This results in shape S_{i+2}. Next, the stick and the knife were used to remove clay and sharpen the inner edges of the depression. The subject ends up with shape S_{i+3}, which shows a slight deviation from the intended shape.

The activity sequence described above contains some simplifications. Actually, several repetitions of activities occurred. For example, the stick was first pressed into the top surface of the box, along its length axis and along its width axis. The stick was also pressed into the side walls of the box and into its bottom surface. Other simplifications are:

- The course of the depression is not considered. However, some manipulations influenced the profile and the course at the same time (e.g. the pressing of the stick into the surface).

- The cross sections S_n in figure 5 are not precise. Actually, the cross section of the depression varied along its course.

- The geometric expressions of the achieved shapes are not exact; they are an approach to describe the basic problem.

- The order of the activities is not analyzed in detail. For example, pressing the stick into the clay model had to be done in several steps.

- Transitions from one activity to the next were sometimes gradually, not discrete.

Geometric description

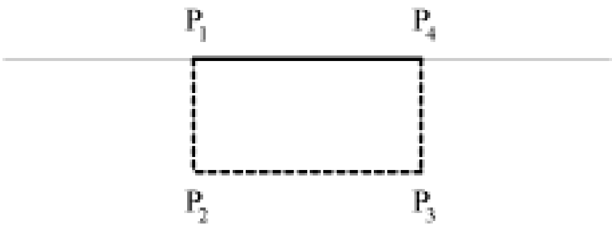


Figure 6: The change from S_i into S_n

P_1, P_2, P_3 and P_4 (Figure 6) are points in R^2. P_1 and P_4 define the line S_i, $S_i \subset R^2$. S_i can be described as a mapping from the parameter space u ($u \subset R$) as follows:

$$S_i(u) = (1-u)P_1 + uP_4$$
$$u \in [0,1]$$

S_n is the polyline defined by the points P_1, P_2, P_3 and P_4, where $S_n \subset R^2$. S_n can be described as a mapping of u as follows:

$$S_n(u) = \begin{cases} \frac{u_2 - u}{u_2} P_1 + \frac{u}{u_2} P_2 & if\, u \in [0, u_2] \\ \frac{u_3 - u}{u_3 - u_2} P_2 + \frac{u - u_2}{u_3 - u_2} P_3 & if\, u \in [u_2, u_3] \\ \frac{1-u}{1-u_3} P_3 + \frac{u - u_3}{1-u_3} P_4 & if\, u \in [u_3, 1] \end{cases}$$
$$u, u_2, u_3 \in [0,1]$$

where u_2 maps the parameter space to point P_2 and u_3 maps the parameter space to point P_3.

A hypothetical shape manipulation activity that changes S_i into S_n can be described as a mapping of α from S_i to S_n as follows:

$$M(S_i, \alpha) = (1-\alpha)S_i + \alpha S_n$$
$$\alpha \in [0,1]$$

where α ($\alpha \subset R$) is a new parameter space that maps the initial shape to the intended shape. Parameter α in this expression controls the depth of the depression to be made. α takes over the function of the applied force and duration of pressing the stick. Below the expression is elaborated for the separate parts of S_n.

$$if\ u \in [0,u_3]\quad M(S_i,\alpha) = (1-\alpha)((1-u)P_1 + uP_4) + \alpha\left(\frac{u_2-u}{u_2}P_1 + \frac{u}{u_2}P_2\right)$$

$$If\ u \in [u_2,u_3]\quad M(S_i,\alpha) = (1-\alpha)((1-u)P_1 + uP_4) + \alpha\left(\frac{u_3-u}{u_3-u_2}P_2 + \frac{u-u_2}{u_3-u_2}P_3\right)$$

$$If\ u \in [u_3,1]\quad M(S_i,\alpha) = (1-\alpha)((1-u)P_1 + uP_4) + \alpha\left(\frac{1-u}{1-u_3}P_3 + \frac{u-u_3}{1-u_3}P_4\right)$$

The line P_1P_4 is mapped onto the polyline $P_1P_2P_3P_4$. The distance between the original line P_1P_4 and the new line P_2P_3 is controlled by α.

The above expressions describe the change from S_i into S_n. Other shape manipulation activities can be expressed in a similar way.

Discussion

The actual performed activity sequence appears to be rather complex. A large part of the time was spent on activities that were in fact only refinements of the first activity, which was pressing a stick into the clay box. That activity itself could be considered in more detail as a process in which the groove grows in depth. The activity could also be subdivided into separate subactivities, each generating a part of the groove, at different positions on the clay box. After the first activity, an intermediate shape S_{i+1} was achieved (Figure 5). In S_{i+1} the intended shape can already be recognized, though extensive elaboration was done on S_{i+1}. This recognition can be considered as a quick feedback and may help the designer to evaluate already while manipulating the shape.

We note some differences with other common methods. In many CAD systems, for example, the details of a shape element must be defined completely, before a 3D representation can be shown. However, once the shape element is fully defined, no additional smoothening is necessary, like with clay modeling.

Which method is preferable depends on the context. If the designer already knows the exact shape and dimensions, using a CAD system may be appropriate. This method may be especially advantageous for large models, because working a shape element in clay requires more time if the shape element is larger.

If the designer is just playing with the shape, clay modeling may be used because the designer already receives tactile and visual feedback while manipulating the model. This immediate feed back enables early evaluation, while the designer need not yet worry about exact details. At the faculty of Industrial Design of the Delft University of Technology, one of the assignments is to design a new product and build a working model. During this assignment, several student teams choose clay modeling for their shape ideation. Also, in the automotive industry small clay models are used for ideation. By creating small-scale clay models, designers exploit the advantages of clay modeling and minimize the time needed for smoothing the surfaces and other finishing activities. CAD models are often generated in a later phase, when more has already been decided about the model.

This study shows that it is possible to describe designers' shape manipulation activities by geometric expressions. Computers can easily calculate these expressions. This paper presents the description of activities that were actually performed with traditional modeling methods. However, for the description of modeling activities, it is not necessary that the activities actually have been performed, or can be performed with traditional methods. Sometimes, a physical modeling activity is very laborious, but its geometric description is simple. For example, the second assignment in our experiment was the enlargement of the soap box that had just been made. The subjects had to re-model virtually every detail. The scaling can be described geometrically as a mapping of α from S_i to S_n. The scaling can then be controlled by only varying the value of α.

Conclusions

A method was presented to describe shape manipulation activities. The shapes before and after the activities are recorded in geometric expressions. The activities themselves are characterized as a change of a parameter value within the expression. The effectiveness of the activity sequence is influenced by multiple characteristics, such as the durations of the activities, the amount of effort that was required and the degree to which the generated shape reflects the intended shape. The method was applied to describe a sequence of activities that were actually performed by a test subject. The results show how the time spent was divided over the identified activities, and how these activities contributed to the generation of the intended shape. The proposed method can be used to describe not only activities that can be actually performed, but also hypothetical ones. Some shape ideation activities are laborious when performed by physical modeling, while their geometric description can be simple. Such activities are good opportunities for the development of more effective support methods.

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