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Interactive Geometric Modeling Using Freehand Sketches

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Abstract. CAD software and similar modeling systems can show 3D object models created by designers, but these advanced 3D systems demand precise data about the 3D object, especially in the steps of inputting data and making free-form surfaces. Although it has become common to use CAD/CAM systems to increase the efficiency of the industrial design process, traditional sketching is often more efficient in the early stages of concept design. Since it is difficult to design a CAD system which can create 3D objects from a concept sketch directly due to ambiguous information, recently sketch systems have been introduced to bridge the gap between concept design and computer-based modeling programs, combining some of the features of a pencil-and-paper sketch.

This survey paper deals with a freehand sketch based geometric modeling for constructing complex 3D objects. In addition, many useful sketch systems and methods are classified. The following sketch systems are shown: (1) A sketch-based modeling system based on descriptive geometry is proposed to generate a model from a variety of 3D solid objects and surface objects. (2) The contour line method to propose a sketch interpreter system for designing 3D freeform objects. (3) A method using a template topology library as an essential tool to reconstruct and modify 3D objects with sketch lines.

Key Words: Sketch systems, geometric modeling, freehand sketch, descriptive geometry, interactive modeling

MSC 2000: 68U05, 51N05

1. Introduction

Although it has become common to use CAD/CAM systems to increase the efficiency of the industrial design process, traditional sketching is often more efficient in the early stages of concept design. Since it is difficult to design a CAD system which can create 3D objects from a concept sketch directly due to ambiguous information, recently sketch systems have been

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introduced to bridge the gap between concept design and computer-based modeling programs, combining some of the features of a pencil-and-paper sketch and some of the features of CAD systems to provide a lightweight, gesture-based interface to "approximate" 3D polyhedral modeling.

Concept Sketch is a concept design process for the designer. It is used to draw contours of products on paper by pencil step by step. In order to get 3D shapes, it is required to recognize these shapes from the concept sketch. Currently many CAD systems can show the object model created by designers, but these advanced 3D CAD systems demand precise data about the 3D object, especially in the steps of inputting data and making free-form surfaces. Designers can not use or feel very uncomfortable to use these systems for realizing their idea sketches. It has now become a big area of research to increase the flexibility of the 3D data input techniques for CAD systems.

In this paper, first we will explain classification of related work in the field of sketch modeling. *Sketch modeling system* is a new type of modeling system as compared to traditional CAD systems. Next, five parts of concept sketch will be shown to draw 3D objects. These parts are very important to input a 3D object using a sketch interpreter system. In Section 4, our proposed *"Sketch Interpreter"* system is shown. This is an interactive system based on the perspective projection theory of descriptive geometry and, in Section 5, a sketch interpreter system by using shading and cross section lines. Last, we will explain a sketch-based modeling system for interactive modeling of a variety of 3D solid objects and surface objects based on the box method.

2. Related work

Sketch-based systems are a relatively new area in modeling. Their main goal is to allow the creation of 3D models by using strokes extracted from user input and/or existing drawing scans. We can distinguish five approaches as shown in Figs. 1 and 2.

S. Sugishita et al. [35] proposed 1994 a sketch-based modeling system. The system creates a basic cube-like shape. The basic shape is operated either by adding parts or cutting off pieces from the basic shape. A cutting plane is defined by three points which are points of intersection between additional cutting lines on the basic shape. But the modeling process is tedious to the designer. R. Zeleznik et al. [40] introduced 1996 a gesture-based interface for rapid modeling of CSG-like models consisting of simple primitives. However, the modeling process was not intuitive.

Teddy by T. Igarashi et al. [12] 1999 is a sketch based system that allows the user to easily create free-form 3D models. The system allows creating a surface by inflating regions defined by closed strokes. Strokes are inflated, using chordal axis transform, so that portions of the mesh are elevated based on their distance from the stroke's chordal axis. *Teddy* also allows users to create extrusions, pockets and cuts to edit the models in quite flexible ways. However, it is difficult to model prismatic objects. J. Mitani et al. [24] proposed 2000 a 3D sketch system with a simple template which uses one projection and applies mirror symmetry to reconstruct a surface model. However, only a single hexahedral model can be constructed. Varley [36] proposed *RIBALD*, which can convert a sketch to a B-Reps solid model. However, for *RIBALD* several conditions are necessary at sketches in order to perform this conversion, and thus it cannot directly accept the sketch input by designers.

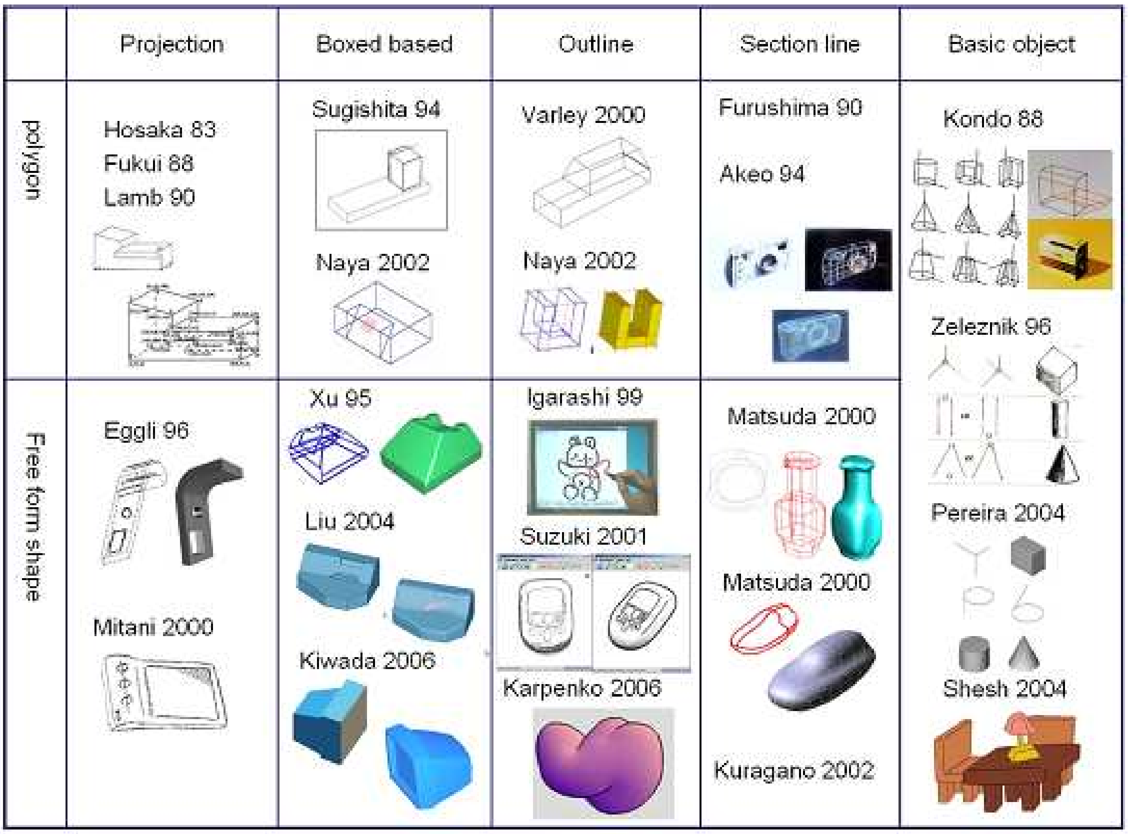


Figure 1: Sketch based modeling methods

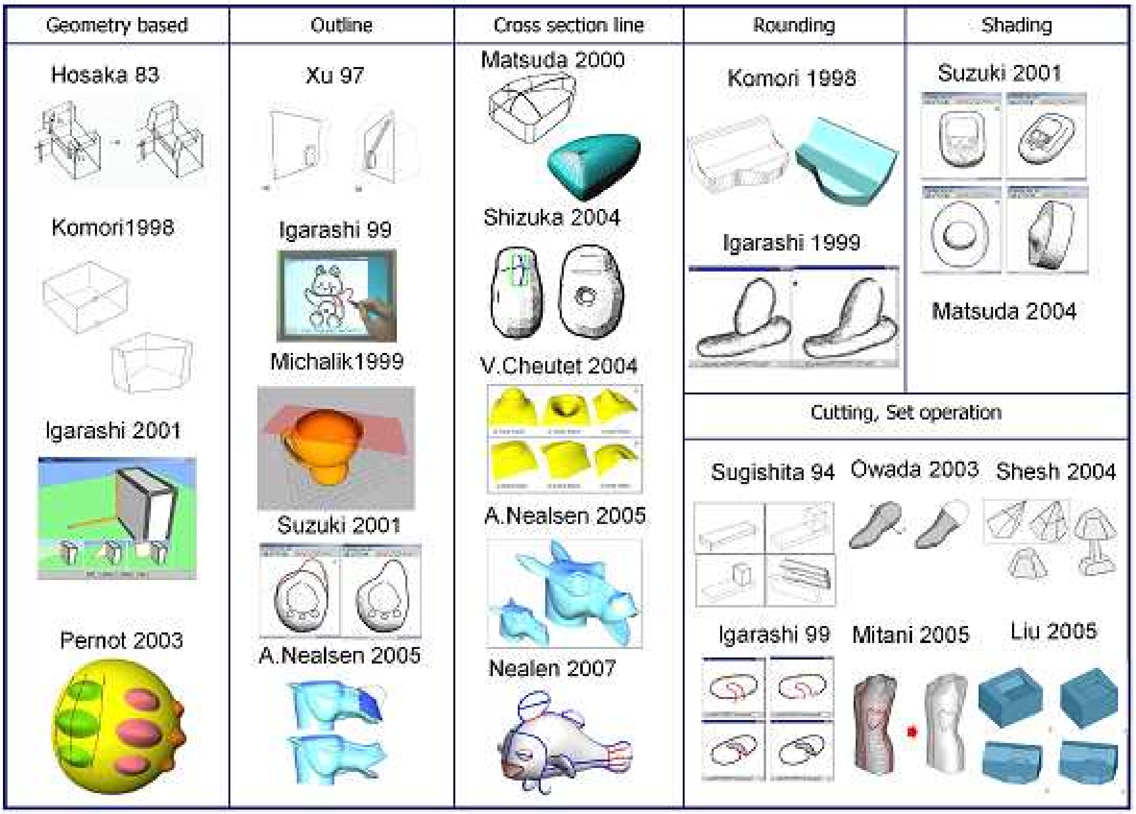


Figure 2: Shape modification methods

3. Sketch analysis

3.1. Elements of the concept sketch analysis

In this section, we extract the primary elements from the concept sketches based on a box method (Fig. 3). The sketch in Fig. 5 shows a voice recorder drawn by the designer. We can regard that it as made up of the following five parts:

a) The outline of the basic shape;

b) The shading lines on the left-bottom;

c) The contour with cross section lines on the top-right;

d) The contour with shading lines on the center;

e) The surface pattern lines on the up-middle.

Its lines can be classified into four chief elements:

- Outline,
- Shading Lines,
- Cross Section Lines, and
- Surface Pattern Lines.

Here, the surface pattern lines are directly mapped on the final surface; it can be done by transferring the 2D lines on the 3D surface. The contours together with shading lines and cross section lines are used for calculating the 3D information. We are trying to add the information of shading and cross section lines to the sketch system for controlling the 3D shape. So in the next section, we will start by analyzing the representations of the shading and cross section lines.

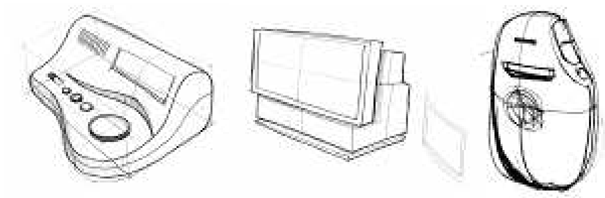


Figure 3: Examples of sketches

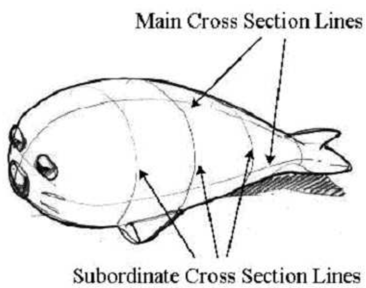


Figure 4: Cross section lines

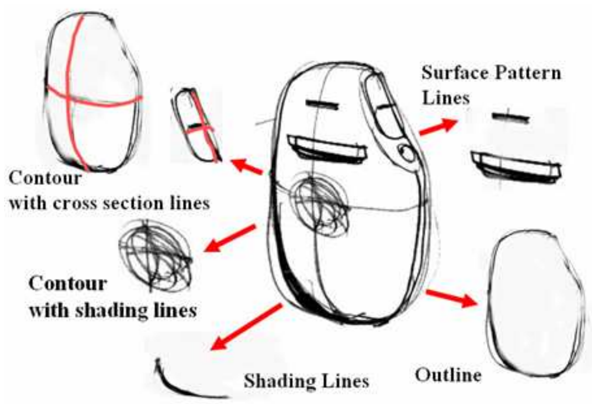


Figure 5: Sketch elements analysis

3.2. Representation of shading analysis

In this section, we show the representation of shading by analyzing the condition of lighting and its expressive effect.

a) *The condition of lighting:*
In order to analyze the condition of the lighting, we have investigated many concept sketches by designers. For most cases and for convenience, we selected parallel lighting and supposed that it is located on the top-left position with a 45 degree angle of incidence.

b) *The different representation of shading:*
In general, the effect of lighting can be classified into three cases: bright, grey and shadow. We can roughly visualize the 3D shape by referring to the different brightness on every face.

In our research, we use the shading mainly for two interpreters processing. For the first case, it was used to generate the basic 3D shape at the very beginning step. The shading lines can be regarded as a parameter which is used to visualize the roundness of ellipses and will be discussed in later sections. For the second case, it is used as a control line together with cross section lines for modifying the 3D shape (Fig. 4). The representations of the control lines can be classified into three cases: convex, concave, upheaving.

4. Sketch interpreter based on descriptive geometry

Typical techniques to recognize a 3D object by a 2D drawing have been using the perspective projection theory based on descriptive geometry [35, 22, 39, 13, 14]. In the case of a perspective projection, 3D models can be created from 2D drawings which are downloaded to a computer by a scanner.

Our proposed "Sketch Interpreter" system is an interactive system based on the perspective projection theory. Sketch Interpreter is unique, since a sketch drawn on a tablet is directly recognized by a computer as a 3D object. Designer can draw idea sketches interactively in Sketch Interpreter in the same manner as drawing sketches on paper.

Figure 6 shows computer aided sketch modeling procedures. Designers use a stylus pen on a tablet in Sketch Interpreter. Geometrically correct sketches are redrawn on the screen from input data on a tablet. No eraser is necessary to modify a 3D object as used in paper sketches.

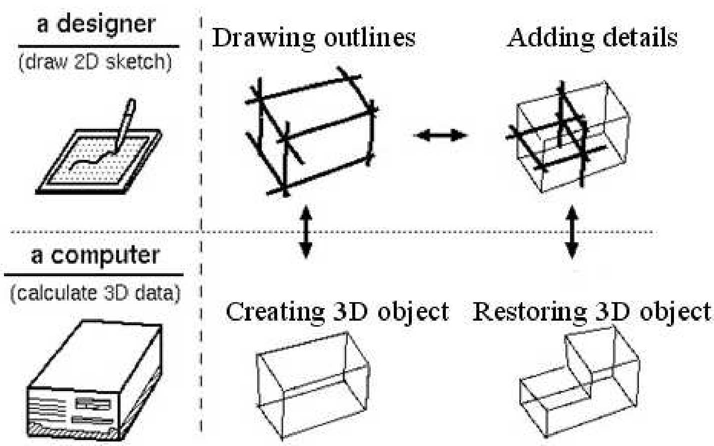


Figure 6: Sketch modeling procedure

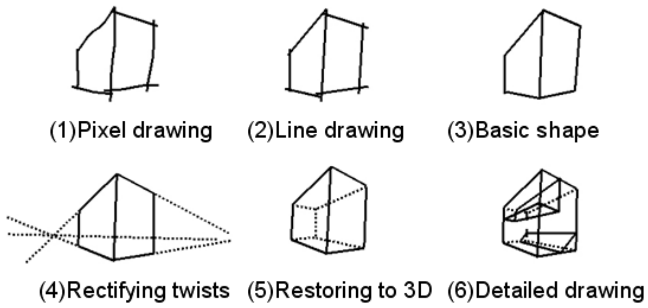


Figure 7: Steps in Sketch interpreter

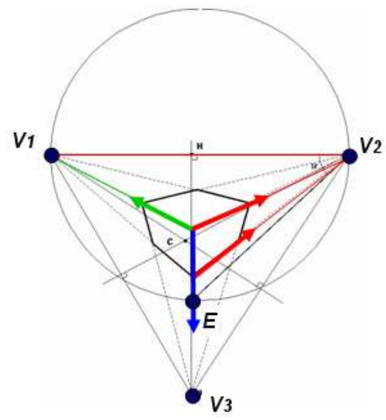


Figure 8: An estimation method of the camera parameters of the projection

Figure 7 shows sketch modeling process in Sketch Interpreter. Fig. 8 shows an estimation method of camera parameters of the projection that correspond to the viewpoint of the designer in order to generate three-dimensional information. First, x-, y-, z-axis, and the vanishing points V_1, V_2 are found in the sketch. By assuming that the camera position is located along a line perpendicular to the sketch plane, the view point is found. Finally, the camera matrix is defined using data of the view point. Fig. 9 shows an example of sketch modeling.

5. Sketch modeling with shading

5.1. Shading analysis

The purpose of our research work is to propose a sketch interpreter system by using shading and cross section lines [23, 33]. As shading and cross section lines are the natural information of the concept sketch, the designer can quickly evaluate their ideas for designing a new object.

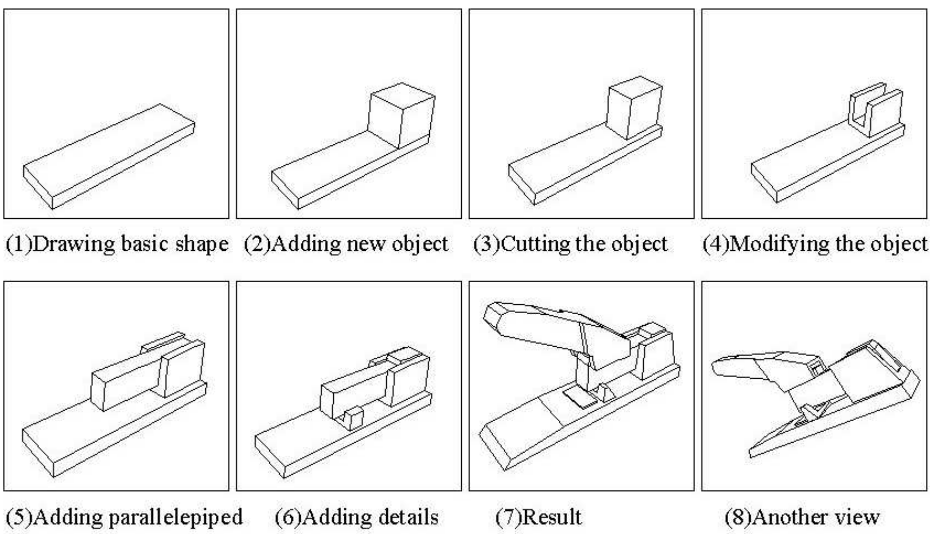


Figure 9: An example of sketch modeling

The freeform strokes are classified into three types:

- outline (contour line),
- shading line and
- cross section line.

The outline with shading lines are used to generate the basic rounded 3D shapes. The shading lines and cross section lines are used as control lines which are drawn inside the contour for modifying the basic 3D shape.

The procedures of the sketch modeling process are described as follows:

Step1: Input the sketch with outline and shading lines;

Step2: Analyze the shading lines;

Step3: Create the basic 3D shape;

Step4: Modify the generated 3D shape by drawing shading lines; cross section lines, or surface pattern lines;

Step 5: Render the generated shape.

5.2. Shape from shading

We suppose that the angle of incidence equals 45 degree from the top-left direction. Referring to Fig. 10, from the gravity of the cross section through X-axis and Y-axis direction, we calculate the two intersection points. And then we calculate two section areas. The numbers of vertices in these two areas indicate the concentration of the shading as shown in Fig. 10 (right). Finally, we calculate the ratio of the two numbers; it is used as a parameter for controlling the generated 3D shape. Fig. 11 is an example of our proposed method with wide bright shading. Fig. 12 shows another example, the design of a voice recorder by our system. Fig. 12(a) is the input sketch with shading lines. In Fig. 12(b) the generated 3D shape is displayed. Fig. 12(c,d) shows the 3D shape after drawing contour and shading lines on its surface. Fig. 12(e, f) is the final generated shape.

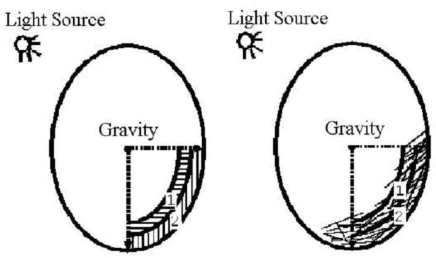


Figure 10: Shape from shading

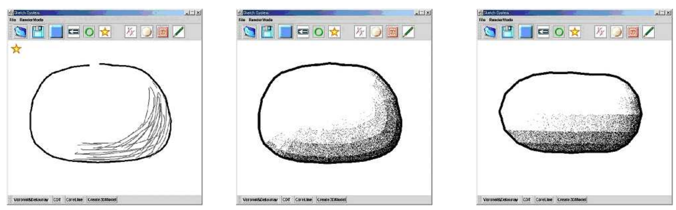
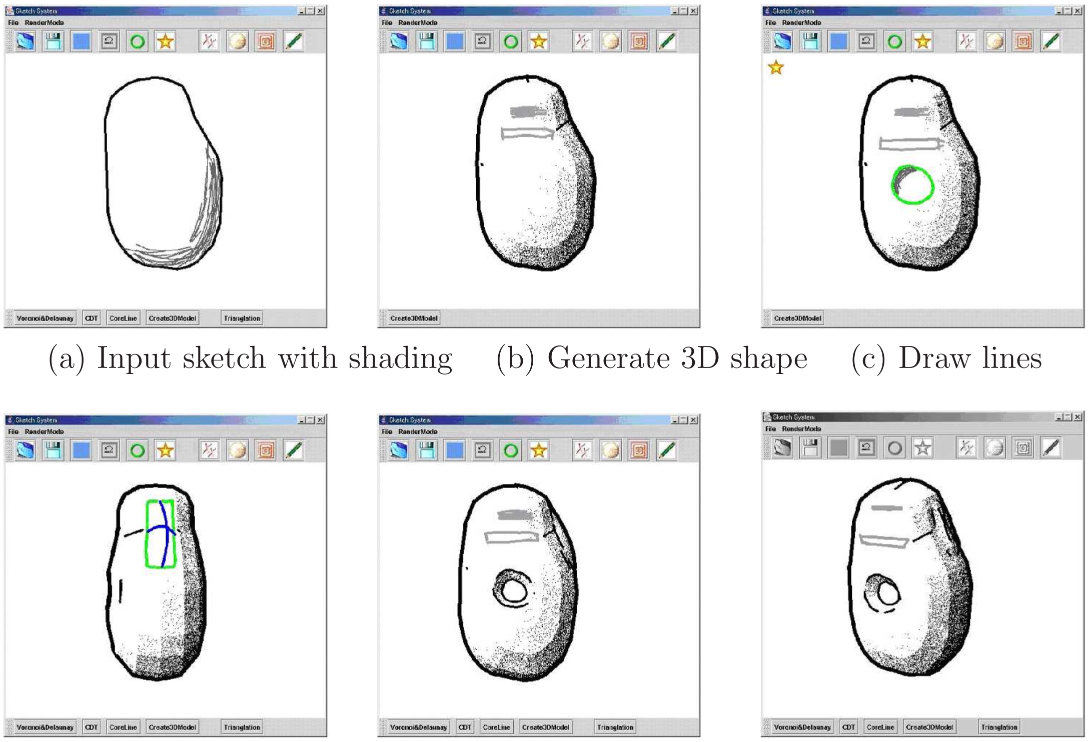


Figure 11: Example of our proposed method with wide bright shading

6. Sketch modeling with 2D T-LIB

In this section we propose a sketch-based modeling system for interactive modeling of a variety of 3D solid objects and surface objects based on the box method [19, 20]. The idea of this method is to create complex 3D object with a template topology library. The library is called T-LIB which consists of 2D Edge Graphs and the corresponding algorithms to create and modify 3D objects. The local part of a 3D object around the sketch lines is analyzed as a 2D Edge Graph. Once the Edge Graph can be matched to a template of T-LIB, the 3D



(a) Input sketch with shading (b) Generate 3D shape (c) Draw lines

(d) Draw cross section lines (e, f) Results

Figure 12: A voice recorder shape designed by our proposed sketch system

object can be generated in a basic shape reconstruction procedure, or modified in a 3D shape modification procedure.

The system procedure is shown in Fig. 13. It consists of 5 parts:

(1) Edge Graph analysis;

(2) T-LIB and new template definition;

(3) 3D shape reconstruction;

(4) 3D shape modification;

(5) Fillet operation, subdivision and etc.

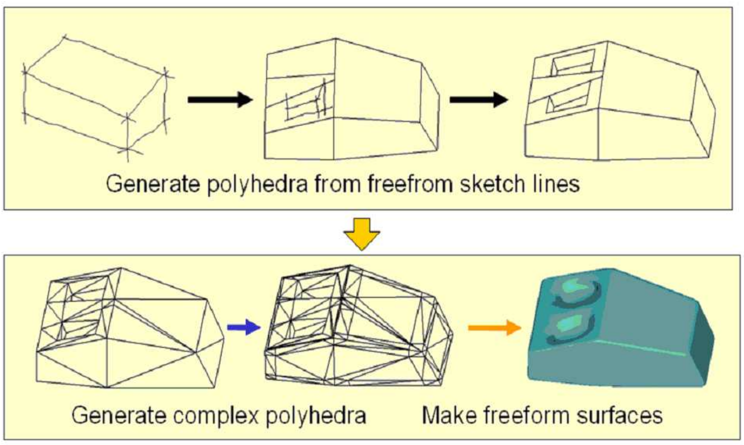
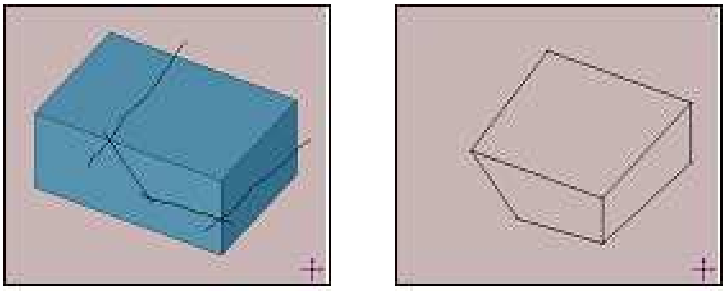


Figure 13: Overview of the proposed system



(a) (b)

Figure 14: Edge graph analysis: (a) Input stroke (b) Build 2D edge graph from (a)

Our system is based on a box method. With T-LIB the 3D geometric components can be constructed or modified directly with sketch lines. Compared with traditional CAD systems the features of our system are described as follows:

(1) It does not require precise data input;

(2) The modeling process is very simple;

(3) This system is extendable since T-LIB is not limited.

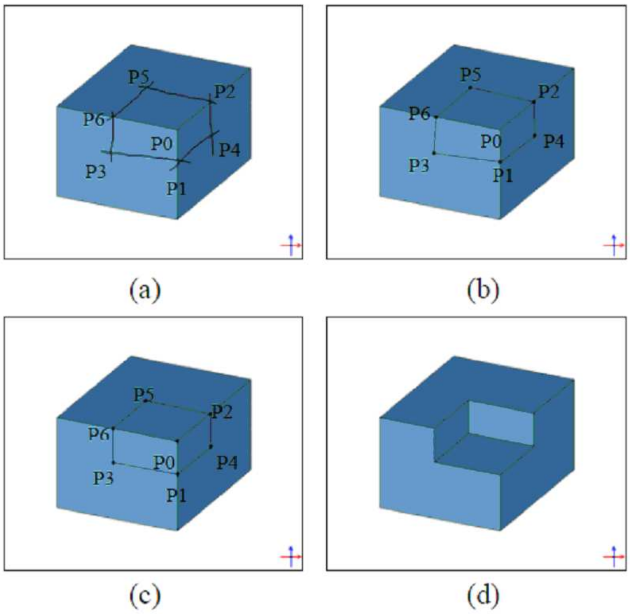


Figure 15: Modification process

7. Conclusions

This paper described a freehand sketch system based on geometric modeling for constructing complex 3D objects. In this paper, many useful sketch systems and methods are classified. The following sketch systems were shown:

(1) A sketch-based modeling system based on descriptive geometry;

(2) A sketch interpreter system for designing 3D freeform objects with shading;

(3) A sketch modeling method using a template topology library.

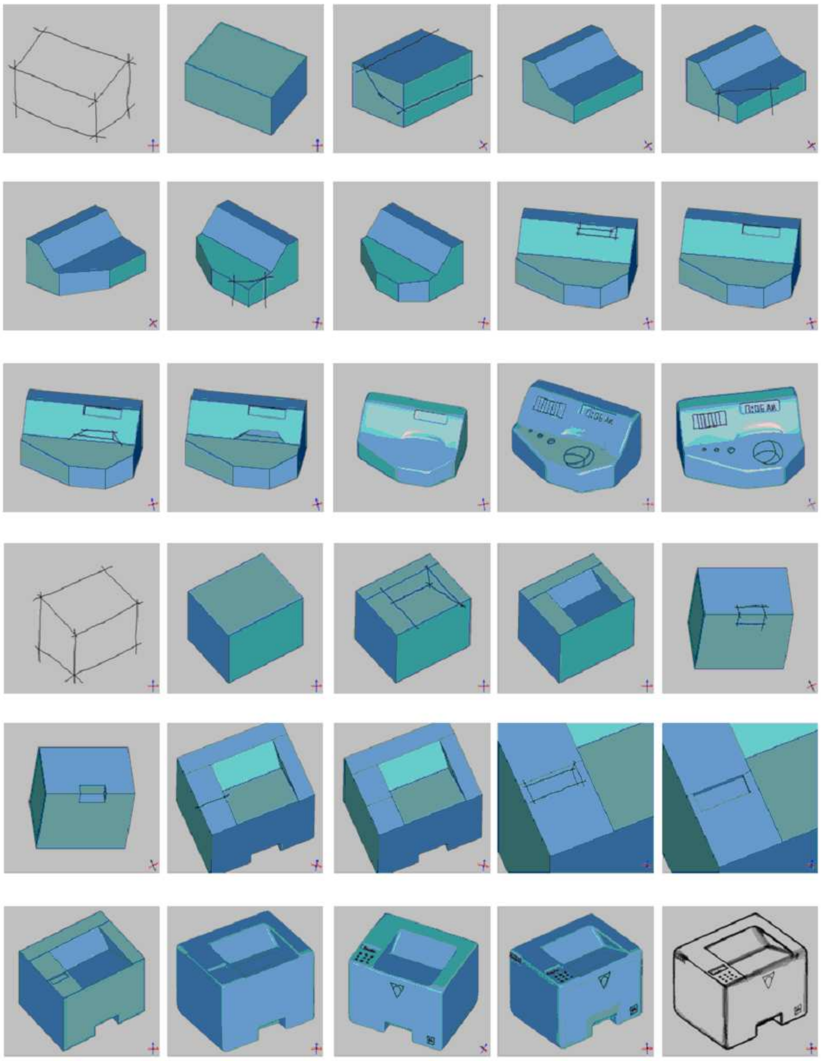


Figure 16: Examples of sketch modeling

At these systems we are interested in the interpretation, by which the computer creates the 3D objects step by step. The designer can feel more comfortable to quickly evaluate their ideas for designing a new object compared with the traditional CAD system.

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