Parts Design and Manufacturing Process Support System Based on Stereolithography Manufacturing Knowledge Database

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ABSTRACT

Although rapid prototyping technology has a strong point that complex parts can be manufactured easily, it is difficult to satisfy further higher precision if designer isn't familiar with the technological know-how of the manufacture. This research aims to develop a design support system for realizing higher precision of RP easily in consideration of manufacturing know-how.
The function of this system is as follows: the knowledge of manufacturing know-how such as the preferred manufacturing direction for higher precision is stored in database. The complex shape of solid form is analyzed in the middle of design stage, and then preferred manufacturing processes or compositions are advised by this system.

1. INTRODUCTION

As for the Stereolithography technology, it has a strong point that we can manufacture a complex form easily. Because of this, a designer can manufacture it even if he isn't detailed to the technology of the manufacture. But, it isn't easy to satisfy higher precision, and the manufacture knowledge to enhance precision synthetically is required.

As for the general method about the design for the manufacture, a series of research about "design for assembling (DFA)" by Boothroydt and Dewhurst is known well [1]. Research on the precision improvement of the Stereolithography has been done since the old days [2], and the efforts to manufacture a part in the higher precision are being continued. For example, about the design for the manufacture of the Rapid Prototyping research, D. Frank and G. Fadel research the problem which the direction of the part in the manufacture is decided as with a viewpoint of the surface roughness [3].

On the other hand, there are many cases when the experiential knowledge of the manufacture and know-how are necessary to fabricate parts in the higher precision. In other words, the experience of the skilled person of the manufacture is often necessary. For example, when the trial production of the high precision should be realized, the part structure which we aimed at should be divided how, and what kind of production method should be adopted, such an experience is necessary. Because of this, we think that the approach that the know-how of the manufacture taken into consideration is effective, too.

This research aims at developing the design support system for the part manufacture of the Stereolithography. Experiential knowledge and know-how are inferred, and the knowledge of the manufacture to reduce a problem in the following process is provided for the designer.

The fundamental concept that this research aims to be realized is shown in the Fig. 1. The experiential knowledge of the manufacture or know-how is accumulated by a database as the relations with the basic shape. A design shape is taken to the basic shape, and checked with the database, and the manufacture know-how which relates to the shape is provided for the designer.

To check the validity of this system, we presumed the design of the probe, and carried out a system for the purpose of the choice of the shape of the probe. We did the fundamental experiment to accumulate the manufacture know-how of the Stereolithography. Then, we applied the knowledge which accumulated with this system. This example showed possibility as a tool which is effective in the design which took a production method into account.

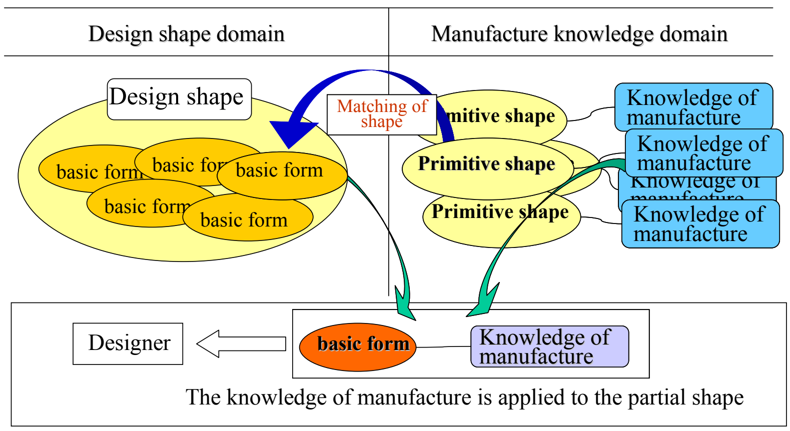


Figure 1. Fundamental concept of manufacturing support system

2. SYSTEM OUTLINE

This system has the following function to enable manufacture evaluation.
(1) Manage data on the design shape acquired by three-dimensional CAD.
(2) Change a design shape into the primitive shape.
(3) The reasoning of the occurrence place of the problem and the occurrence conditions.
(4) The acquisition of the manufacture knowledge.
(5) Result output.

A system configuration is shown in the Fig. 2. Data on the design shape which we acquired from the three-dimensional CAD are managed with this system by (1). Data for the inference are made by the data for the inference creation module of (2). The inference module of

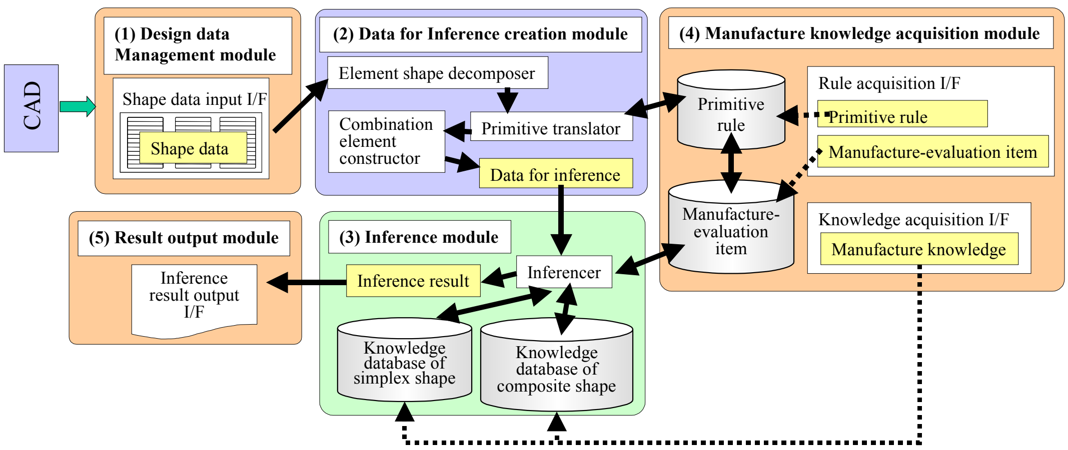


Figure 2. System configuration

(3) carries out the inference of the occurrence conditions of the problem by checking a manufacture knowledge database with the data for the inference. Then, return a result of an inference of (5) to the designer. The manufacture knowledge acquisition module of (4) stores the knowledge of the manufacture in the database.

3. THE PROCESS OF THE MANUFACTURE EVALUATION

As for many present three-dimensional CAD systems, a designer designs a shape by piling up a shape building command to satisfy a product function and the shape of the requirement. The following method is adopted by this research because manufacture evaluation is reflected easily to the design: A primitive shape is acquired by three-dimensional CAD, and then the knowledge of the manufacture which coped with it is provided for the designer.

This paper defines the basic shape which appears in the shape design frequently as the primitive shape. This primitive shape represents the part of the characteristics of the design shape.

The following information is contained in each of the shape building commands: There are attribute information which becomes the characteristics of the design shape, and geometry information of the shape. We can manage geometry information in every characteristics region of the shape by acquiring a shape building command unit from the data on the design shape. A primitive shape is transformed from geometry information of the shape building command.

We can form the group of primitive shapes based on the shape building command from the designer's three-dimensional CAD data by this method. On the other hand, the knowledge of the manufacture is given to relation with the primitive shape, and accumulated to the database. We can provide the knowledge of the manufacture for the designer by checking this mutual primitive shape. From now on, the shape building command to build a design shape is called an operator, and the shape which an operator forms is called a feature.

4. INFERENCE DATA CREATION MODULE

4.1 The acquisition of the design shape data

An operator has the ID which is a characteristic identifier, and attribute data and geometry data (feature). These are acquired by an operator in the CAD data with this system.
Attribute data consist of operator's "type", "attributes" and "classification". "Attribute" has the value of "+" or "-". The value of the attribute becomes "+" in the case of the processing that an operator adds a region. The value of the attribute becomes "-" in the case of the processing to remove a region.
"Classification" has the value of "main operator" or "sub-operator". The case that an operator has a "+" attribute, and it forms a main shape in the part shape, is called "main operator". The case that the operator forms details from the main shape is called "sub-operator".
The data structure of the design shape data is shown in the Fig. 3.

4.2 Primitive shape creation module

Data for the inference consist of primitive shapes, element shapes and combination elements, and is hierarchically controlled. The structure of the inference data is shown in the Fig. 4. A design shape is changed into the set of the primitive shape so that data for the inference may be made. A design shape is divided into the plural in every characteristic, and each partial divided shape is defined as the element shape. An element shape is changed into the set of the primitive shape, and that primitive shape is managed in each element shape.

An element shape is composed of one main operator and some sub-operators. The example that the sample model shown in the Fig. 5 is divided into the element shape is shown in the Fig. 6.

A combination element is defined as the shape which an element shape is combined with as shown in the Fig. 7. It is built based on the connection relations with the main operator whom each element shape has. A combination element has two main operators. The building example of the combination element is shown in the Fig. 8 and Fig.9.

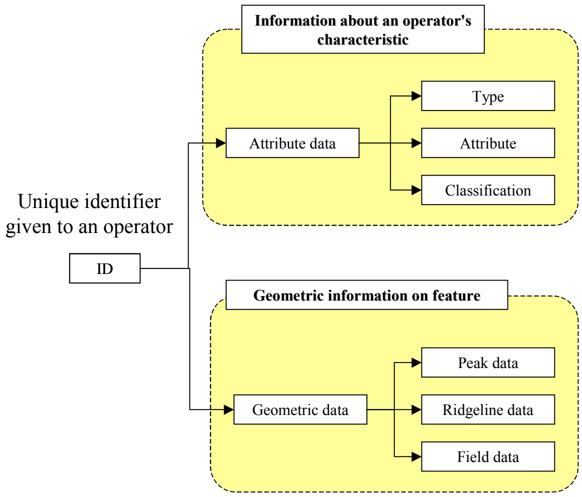


Figure 3. Data structure of shape construction command.

5. INFERENCE MODULE

5.1 Inferencer

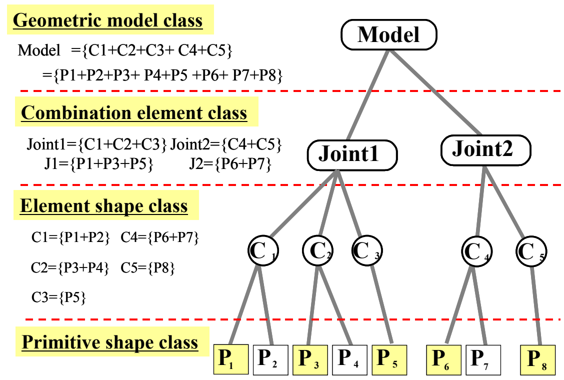


Figure 4 Data structure of class data for inference.

An inferencer evaluates manufacture in consideration of the difference in the manufacture direction of the part in the manufacture. It is checked with the knowledge database about the case that the direction of the manufacture is wrong. As for the direction of the manufacture, we mean a direction to go from the bottom to the surface at the time of the manufacture with this system. The principal axis direction which aligns with the direction of the manufacture is defined as the manufacture direction when the direction of the x-axis, the y-axis and the z-axis is decided as the design shape. (Fig. 10)

An inferencer checks an element shape and a combination element about the case that a manufacture direction is different by the knowledge database based on the inference data. The functional block diagram of the inferencer is shown in the Fig. 11.

5.2 Knowledge database

An inferencer has the knowledge database of the simplex shape and the composite shape corresponding to the primitive shape. Contents of an occurrence of the problem and the condition when a problem occurs are stored as knowledge.

Knowledge about the primitive simplex shape is stored in the simplex knowledge database.

Knowledge about the shape which combined a primitive shape with the composite knowledge database is stored. Each database item is shown in the Table 1 and the Table 2.

Figure 5 Sample model

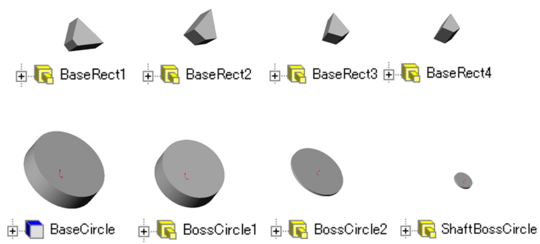
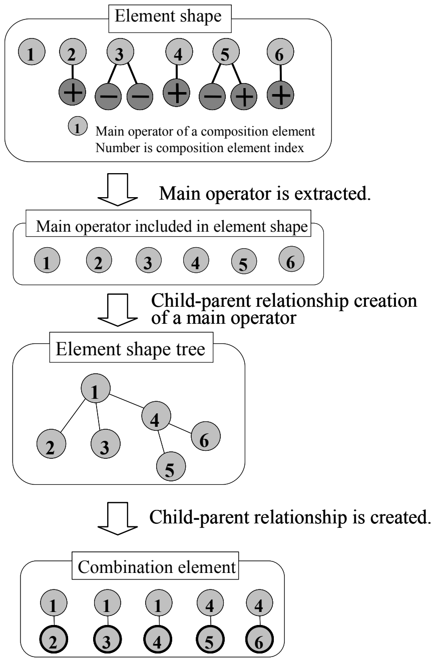


Figure 6 Example of element shape



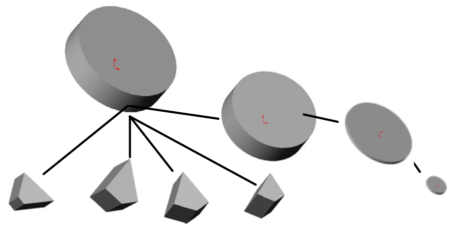


Figure 7 Child-parent relationship of main operator

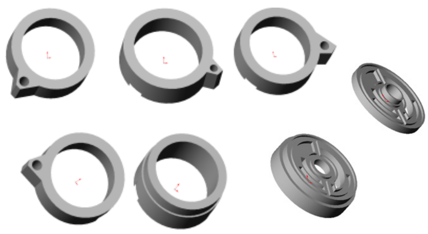


Figure 9 Creation of combination element

Figure 8 combination element

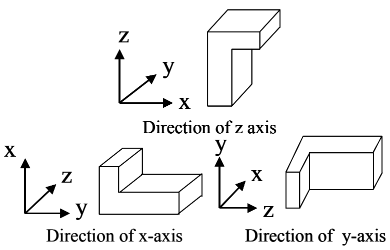


Figure.10 Manufacture direction

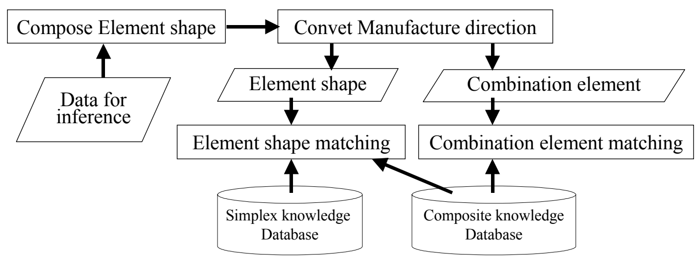


Figure.11 Block diagram of Inferencer

5.3 Matching with the element shape and the knowledge database

The primitive shape which has "classification" of "a main operator" in the element shape is given to *Pmi* (i=1..*n*.;*n* is the number of element shapes.) The primitive shape which has "classification" of "sub-operator" is given to *Psj* (j=1 .. *m*.;*m* is the number of sub-operators.) And

Table 1 Knowledge database item of simplex shape

Input item	Explanation
Primitive shape	The name of primitive shape
Reference key to a primitive rule	The primitive code of a primitive rule
Reference key to evaluation criteria	The evaluation-criteria code of a manufacture-evaluation item
Discriminant	The condition formula which applies knowledge
Kind of manufacture knowledge	Classification of manufacture knowledge
Manufacture knowledge	The text of the knowledge of manufacture and know-how

Table 2 Knowledge database item of composite shape

Input item	Explanation
Shape name	The name of the compounded shape combining primitive shape
Parent primitive shape	The name of primitive shape
Parent primitive shape attribute	Attribute data of parent primitive shape
Parent primitive rule reference key	The primitive code of a parent primitive rule
Parent primitive evaluation item reference key	The evaluation item code of the manufacture-evaluation (for parent primitive shape)
Child primitive shape	The name of the primitive shape of child primitive shape
Child primitive shape attribute	Attribute data of child primitive shape
Child primitive rule reference key	The primitive code of the primitive rule (for child primitive shape)
Child primitive evaluation item reference key	The evaluation item code of the manufacture-evaluation item (for child primitive shape)
Discriminant	Condition formula which applies knowledge (using the evaluation item of parents and a child)
Kind of manufacture knowledge	A Classification of manufacture knowledge
Knowledge of manufacture knowledge	Knowledge and know-how of manufacture

the shape which combined a sub-operator with the main operator is given to *Ck* (k=1..*l*.;*l* is the number of sub-operators whom an element shape has.) Each element *Cik* of all the combination sets *O* of the element shape becomes:

Cik=Pmi+Psj

As for the matching of the element shape and the knowledge database, a simplex knowledge database is checked with Pm first. Next, a composite knowledge database is checked with all *Ck*'s contained in *O*. A matching process with the shape element and the knowledge database is shown in the Fig. 12.

The primitive shape which has "the classification of "the main operator"" is given to *Pma* and *Pmb*. *Jointh* (h=1..*p*;*p* is the number of combination elements.) which is the combination element of these two shapes is defined as.

Jointh=Pma+Pmb

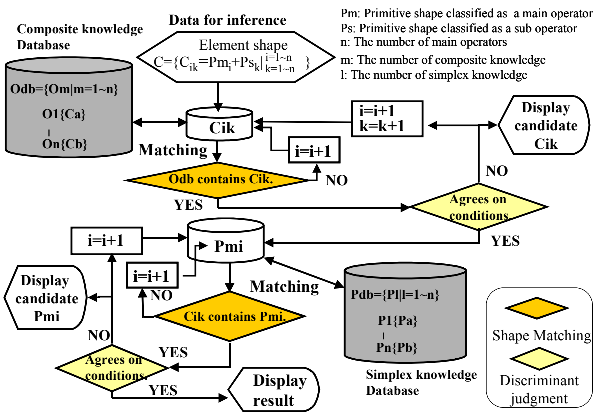


Figure 12 Matching of element shape.

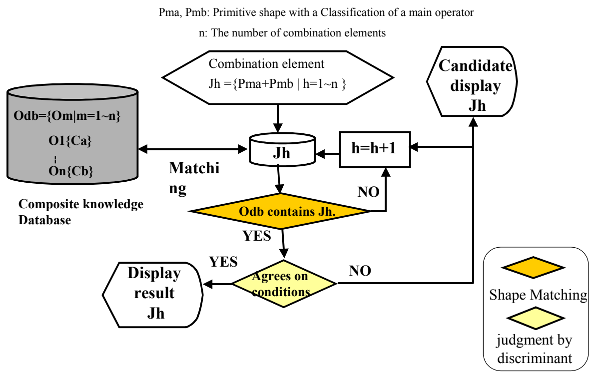
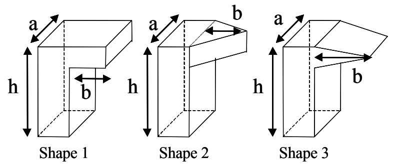


Figure 13 Matching of combination element

A composite knowledge database is checked with *Jointh* by the matching with the combination element and the knowledge database. A combination element and the matching process of the knowledge database are shown in the Fig. 13.



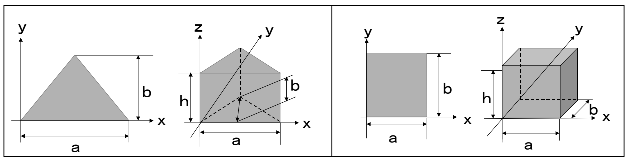
	Dimension(mm)
a	*5, 10, 15*
b	*a/2, a, 2a*
h	*a/2, a, 2a*

Fig.14 Basic shape for experiment

6. APPLICATION EXAMPLES

6.1 The fundamental experiment of the Stereolithography

A fundamental experiment for the Stereolithography was carried out. Manufacture knowledge about whether to require a support shape is accumulated. Accumulated knowledge is stored in the knowledge database of this system.



Rule name example	Primitive shape Shape name	Manu.−eval. item (Primitive variable)	Primitive rule (vertexes, edges, planes)
Rule 1	Hexahedron	(a,b,h)	(8,12,6)
Rule 2	Triangular prism	(a,b,h)	(6,6,5)

Fig.15 Primitive shape.

When we manufacture a cantilever, the pillar which we usually call support to the part of the beam must be added to the design shape in the Stereolithography. However, manufacture without support is sometimes required. For example, it is required when we want to avoid a surface being made rough by the removal work of the support. Otherwise, it is required when the part of the beam is minute and the removal of the support is difficult.

The shape for fundamental experiment to accumulate knowledge is shown in the Fig. 14. The experiment which made a dimension change is done to three kinds of beam shapes, and identifies the dimension of the part of the beam when support isn't required at the time of the manufacture.

The length of "b" wasn't needed for the support about the result of the fundamental experiment with a shape 1 by less than 3mm. Then, the dimensions that the part of the beam was manufactured increased 1mm without requiring support after the length of "a" exceeded 20mm. As for the length of "b", it was less than 6mm with a shape 2, and it was less than 8mm with a shape 3 that support wasn't required. The above knowledge was stored in the knowledge database of this system.

6.2 The example of the inference

We presumed the design of the probe which has a beam shape, and the application of the system was done. The primitive shape which we registered is shown in the Fig. 15. The result of the fundamental experiment is stored in the knowledge of the manufacture as the Table 3.

The application of the system was done with three kinds of different probe which perform the same function for the purpose of the shape selection of the probe and the sizing.

A design shape and that element shape and a combination element, the result of the knowledge that it is applied to that combination element are shown in the Fig. 14.

If a shape 2 and a shape 3 are manufactured in the x-axis direction, a designer can understand that we don't need to add support from a result of execution of the system. The manufacture knowledge that grasping was difficult could be provided for the designer with an executive example of this system without manufacturing it. The function which narrowed the shape design of the part of the beam was realized by the system. It was shown that this system could become the effective tool in the design for taking a production method into account.

7. CONCLUSIONS

Manufacture evaluation with every partial shape was enabled because a design shape was divided into the element shape and a combination element was built.

It was shown by this system that it could become the effective tool which took a production method into account in case of design.

Table 3 Manufacture Knowledge database

	Judgment conditions	Shape *	Knowledge of manufacture
Shape 1	if (a<20){ b>3};	Pma(1、1)+Pmb(1、1)	Support is required for Pmb
Shape 1	if (20<a){ b>4};	Pma(1、1)+Pmb(1、1)	Support is required for Pmb
Shape 2	b>6;	Pma(1、1)+Pmb(2、1)	Support is required for Pmb
Shape 3	b>8;	Pma(1、1)+Pmb(2、-3)	Support is required for Pmb

* Pma(Prim. shape, manu. dir.): Parent primitive shape
Pmb(Prim. shape, manu. dir.): Child primitive shape
Manufacture direction(1: Z direction, 2:X direction, 3:Y direction)
Primitive shape(1:hexahedron, 2: Triangular prism)

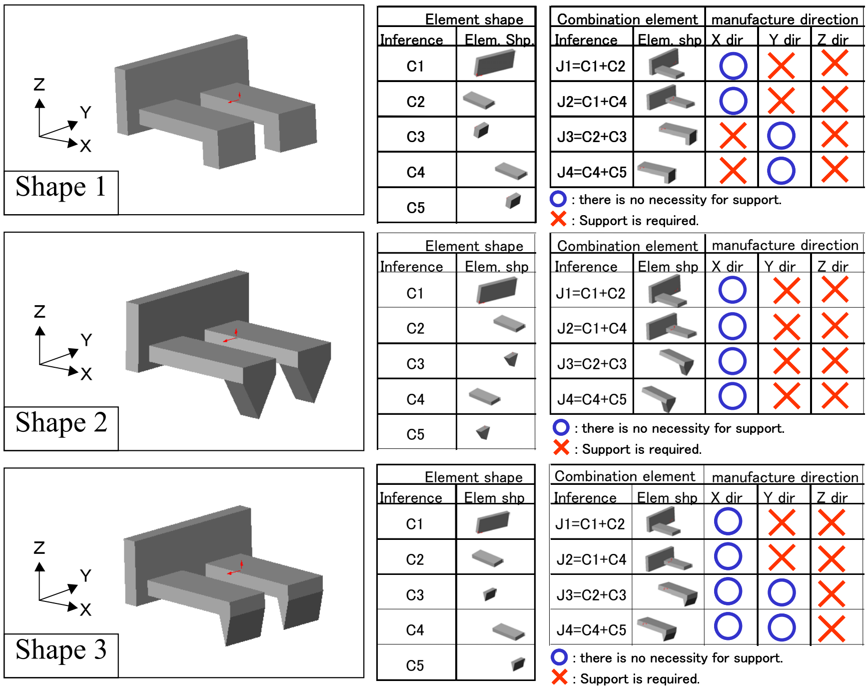


Figure14 System execution results

REFERENCE

[1] For example, Tsai-C. Kuo, Samuel H. Huang, Hong-C. Zhang, "Design for manufacture and design for 'X': concepts, application and perspectives", Computers & Industrial Engineering, 41 (2001), pp.241-260.

[2] H. NARAHARA, "Accuracy Improvement Procedures for Stereolithography Parts", International Journal of the Japan Society for Precision Engineering, 28(4), (1994), pp.301-304.

[3] D. Frank and G. Fadel, "Preferred Direction of Build for Rapid Prototyping Processes", Proc. of The Fifth International Conference on Rapid Prototyping, University of Dayton-RPDL Dayton, (1994),pp.191-200.