Trial of Formulating Affordance Features for Product Design

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Abstract. The aim of this research is to formulate relationships between the geometrical attributes of objects and affordance for operations as affordance features. If affordance features are well formulated, then they will allow designers to strengthen intended affordances for higher usability of products or to systematically examine and achieve product or interface shapes with both high usability and aestheticity or novelty. In this paper we show some affordance features and their relationships with quantitative conditions obtained from an analysis of user tests involving sample objects of various shapes.

Keywords: Affordance, feature, product design, usability, emotional design.

1 Introduction

The concept of "affordance" has been proposed and used in the fields of psychology and human interfaces. Affordance is defined as all possible actions latent in the environment that are objectively measurable and independent of the individual's ability to recognize them but are always in relation to the actor and therefore dependent on their capabilities [1], or those possible actions that are readily perceivable by an actor and are dependent not only on the physical capabilities of the actor, but also their goals, plans, values, beliefs and past experience [2][3]. If affordance is appropriately utilized in product design, people can intuitively understand the usage of the product and can easily use it, whereas inappropriate affordance may lead to incomprehensibility of the product and mistakes in its usage.

On the other hand, the concept of a "feature" has been proposed and used in the fields of machine design and CAD (computer-aided design). A feature is defined as a geometric form or entity that is meaningful to one or more design or manufacturing activities (i.e., function, manufacturability evaluation and serviceability) and is used to denote some aspect of a real-world entity of interest in a process [4]. A feature can be used as a type of heuristic method to formulate a relationship between object properties and human thought and activities.

The purpose of this study is to formulate the relationship between the geometrical attributes of an object and affordance regarding its operations, referred to as "affordance features". The formulation of affordance features may lead to the following merits in a product design process.

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- Designers can systematically verify the effect of affordance intentionally embodied for product usability [5] and detect unintentionally or accidentally existing wrong affordance that reduces product usability based on affordance features.
- Designers can obtain indications of how to reinforce their intended affordance or to weaken unintended or accidental wrong affordance to improve product usability by adding or removing the corresponding affordance features of the product.
- Designers can systematically examine and design a product in which high usability, aestheticity and novelty coexist.

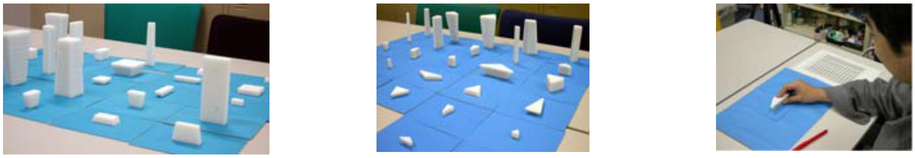
2 Experiments and Shape Samples

2.1 Basic Approach of This Study

There is a related work exploring participant behavior arising from various characteristics (size, texture, color/pattern, weight, sound) of a shape (cube) [6]. In this study, we prepared parametric variations of samples of various shapes made of the same material (ABS plastic) (Fig. 1(a)(b)) by a rapid prototyping system (Stratasys FDM-8000). We showed the shapes oriented horizontally one by one (Fig. 1(c)) to examinees (masters course and undergraduate students in the mechanical engineering department) and asked the question: Suppose this object is an operator of some system. When you see this operator, which operation do you intuitively feel is possible? Choose up to two from the following: "push", "pull", "turn", "tilt", "slide", "other operation (please specify)", "none". Also, we asked the examinees to operate the object in the way they felt it should be operated, and we recorded the operation on a video for additional analyses afterwards. We gave a score of 2 points to their first choice from the above list and 1 point to their second choice, summed the scores for all operations for every sample shape and statistically analyzed the relationships between examinees' answers and the geometrical attributes of the samples used in the experiments [7].

2.2 Experiment 1 on Frustum-Shaped Samples

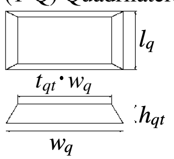
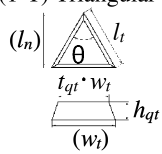
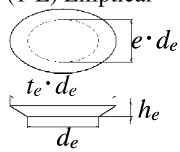
In this study, we made four types of samples based on different shapes for use in the experiments. The first three types were frustum-shaped samples. For each of the quadrilateral, isosceles triangular and elliptical frustums, we made 27 samples with 4 parameters, each taking 3 values (Table 1). We used the data for elliptical samples from our previous laboratory study [8]. The numbers of examinees were 12, 22 and 13 for experiments 1-Q (Jul. 2006), 1-T (Nov. 2006) and 1-E (Dec. 2005), respectively. For isosceles triangular samples, we considered the possibility that the affordance may depend on the orientation of the triangle, i.e., whether or not the triangle is inverted relative to the examinee. Therefore, we divided the 22 examinees into 2 groups and showed one group samples with the upright triangular orientation and one group samples with the inverted triangular orientation.

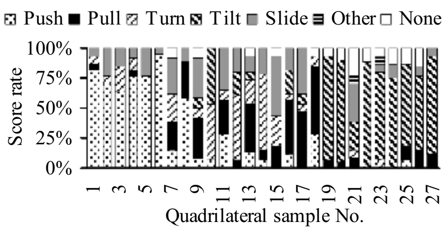


(a) Quadrilateral frustum samples. (b) Triangular frustum samples. (c) Experiment.

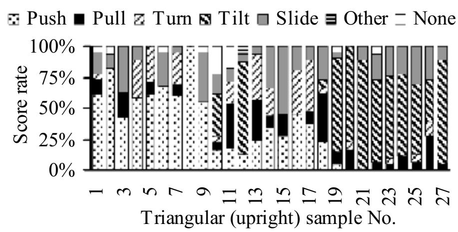
Fig. 1. Appearance of frustum-shaped samples

Table 1. Frustum-shaped samples (experiment 1)

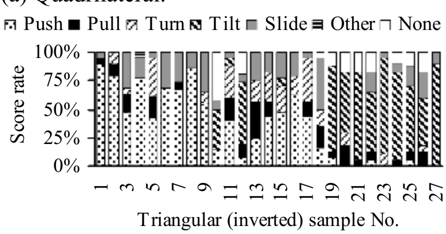
Experiment and sample shape	(1-Q) Quadrilateral 		(1-T) Triangular 	(1-E) Elliptical 
Parameters	l_q = 10, 20, 40mm w_q = 10, 20, 40mm		l_t = 10, 20, 40mm θ = 30, 60, 120°	d_e = 10, 20, 40mm h_e = 5, 10, 30mm
	h_{qt} = 10, 25, 100mm, t_{qt} = 0.8, 1, 1.5			e = 0.3, 0.6, 1 t_e = 0, 1, 2
Square rate	min(l_q,w_q)/max(l_q, w_q)		min(l_n,w_t)/max(l_n,w_t)	e



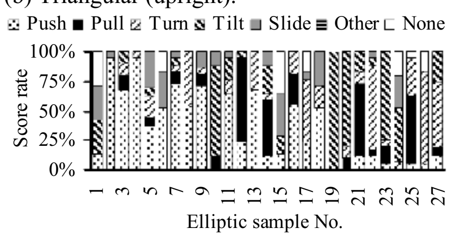
(a) Quadrilateral.



(b) Triangular (upright).



(c) Triangular (inverted).



(d) Elliptical.

Fig. 2. Aggregated answers for experiment 1 (experiments 1-Q, 1-T and 1-E)

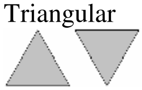
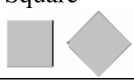
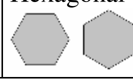
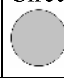
The operation preferences of all examinees were aggregated by the scores obtained for each type of sample as shown in Fig. 2. For example, most examinees tended to push quadrilateral sample 1 whereas they tended to tilt sample 27, which indicates that the geometrical attributes have an effect on the answers.

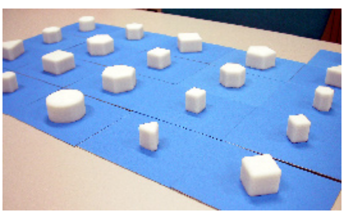
2.3 Experiment 2 on Regular Polygonal and Circular Samples

The fourth type of samples were regular polygonal (triangular, square, pentagonal and hexagonal) and circular (Table 2, Fig. 3(a)). To give the impression of an equal horizontal cross-section area for each regular polygon and circle, we used the mean of the circumscribed and inscribed circle diameters of regular polygons (radius in the case of a circle) as the horizontal size factor. For regular polygonal samples, we considered the possibility that the affordance may depend on the orientation of the polygon, and we made two oppositely oriented samples for every polygon. By assigning one value to the height and three values to the mean diameter for every polygon and circle, we made 27 samples. The number of examinees was 11 for experiment 2 (Jan. 2007).

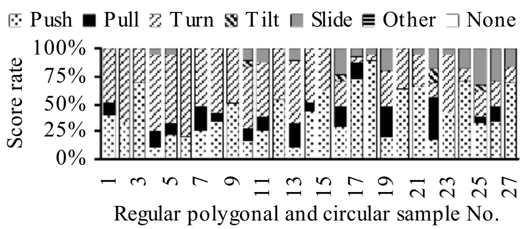
The answers obtained from all examinees were aggregated as shown in Fig. 3(b), which also indicates that the geometrical attributes have an effect on the answers.

Table 2. Regular polygonal and circular samples (experiment 2)

Horizontal section shape	Triangular 	Square 	Pentagonal 	Hexagonal 	Circular 
Parameters	height h_r = 25mm, mean of circumscribed and inscribed circle diameters d_r = 24, 36, 48mm				



(a) Sample appearance.



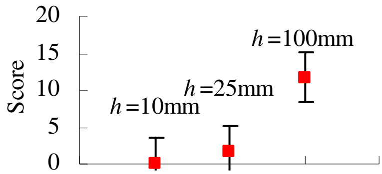
(b) Aggregated answers for experiment 2.

Fig. 3. Regular polygonal and circular samples

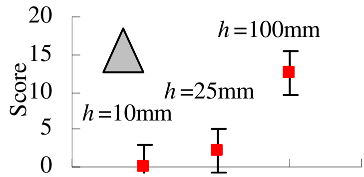
3 Affordance Feature of "Tilt"

3.1 Correlation between Affordance of "Tilt" and Instability of Shape

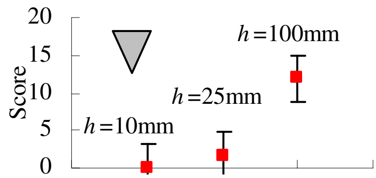
We analyzed the results in Fig. 2 and obtained the results shown in Fig. 4, indicating that samples of greater height obtained higher scores for "tilt". Furthermore, the recorded video indicates that examinees tended to tilt samples in the direction in which the shape was thin. These results indicate that being tall and thin, i.e., physically unstable (easily toppled), is relevant to the affordance of "tilt".



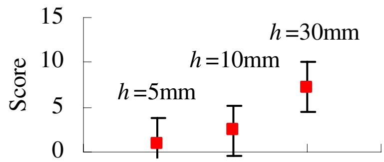
(a) Quadrilateral.



(b) Triangular (upright).



(c) Triangular (inverted).



(d) Elliptical

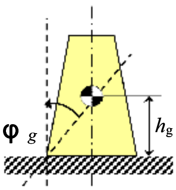
Fig. 4. Effect of sample height on "tilt" score

To confirm this quantitatively, we defined the critical slant angle of a shape (Fig. 5(a)). When we incline a 3D shape by angle ϕ_g so that the center of gravity is moved to a position above the boundary of the base (to be precise, its convex hull), the shape is in an unstable state (a critical state where the shape begins to topple spontaneously). We define this angle ϕ_g as the critical slant angle. A shape with a lower critical slant angle is more unstable. When we plot the relationship between the critical slant angle and the obtained score for "tilt" for the samples in Table 1, we obtain the graph shown in Fig. 5(b). There is an apparent negative correlation between the critical slant angle and the score for "tilt", and it appears that the score starts to increase around the critical slant angle of 30°. Therefore, we assume that the affordance of "tilt" is related to not the actual instability but the perceived instability.

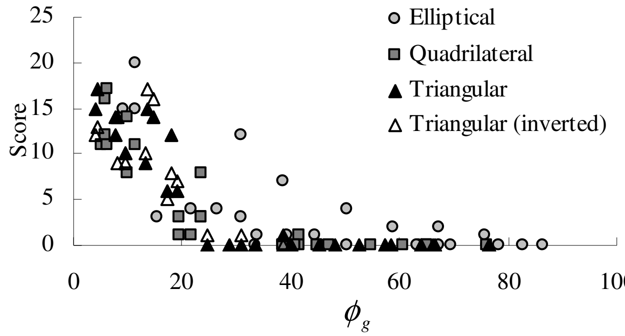
To verify this assumption, we prepared figures of nine shapes whose critical slant angles were distributed almost uniformly from 15° to 60°. We showed the figures pairwise to examinees, based on a paired comparison method, and asked them to evaluate the relative stability of the two shapes on a five-point scale. By analyzing the result (Fig. 6), we found that the correlation coefficient between critical slant angle and perceived instability was R = -0.93 and that the border between perceived stability/instability was at about 30°, which supports our assumption.

Here is a summary of this section.

- The affordance feature of "tilt" is often attributed to shapes with a critical slant angle of less than about 30°.
- The reason for this is thought to be that a critical slant angle of about 30° may be the border at which a shape is perceived as stable or unstable. This result may be used for not only providing affordance but also in the perceptual and psychological design of shapes.



(a) Definition of critical slant angle ϕ_g .



(b) Relationship between "tilt" score and critical slant angle.

Fig. 5. Relationship between geometrical attribute and "tilt"

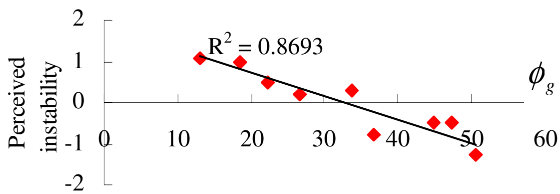


Fig. 6. Relationship between perceived instability and critical slant angle

3.2 Effect of Triangle Orientation

The recorded video of the experiment using triangular frustum samples indicates that the examinees tended to tilt the sample differently depending on the angle θ of the isosceles triangle (Table 1). Here we define the direction parallel to the shorter of l_n and w_t of the isosceles triangle in Table 1 as the "short direction" and the direction parallel to the longer of l_n and w_t as the "long direction". By classifying the scores based on the direction in which examinees tilted triangular frustum samples, we obtain Fig. 7. Here we observed the following tendency regardless of whether the shapes were presented to the examinees as an upright triangle or inverted triangle

- For samples of θ =120° (obtuse triangle), most examinees tilted the samples in the short direction.
- For samples of θ =30° (acute triangle), some examinees tilted the samples in the short direction and others tilted them in the long direction.

Triangular frustum samples are toppled more easily in the short direction than in the long direction. An isosceles triangle can also be represented by the direction from the center of its base to its vertex, identical to the direction indicated by a triangular arrow symbol. We define this direction as the "arrow direction" of the triangle. The above observations may be explained as follows.

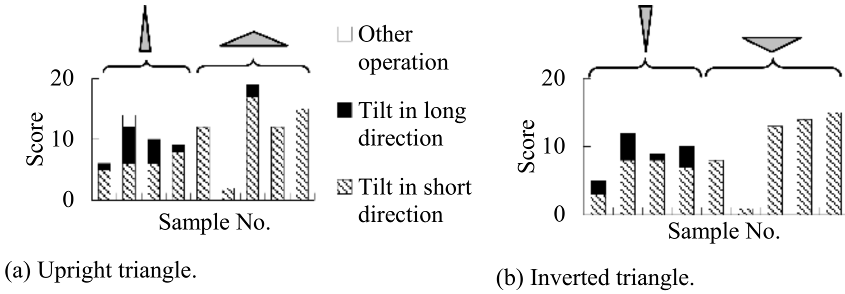


Fig. 7. Relationship between geometrical attribute and "tilt" (triangular frustum)

- For samples of θ =120°, the toppling direction and the arrow direction defined above coincide.
- For samples of θ =30°, the toppling direction and the arrow direction are orthogonal; thus, there were two possible directions of tilting.

This observation suggests that both the toppling direction and the arrow direction may affect the affordance of tilt.

4 Affordance Feature of "Turn"

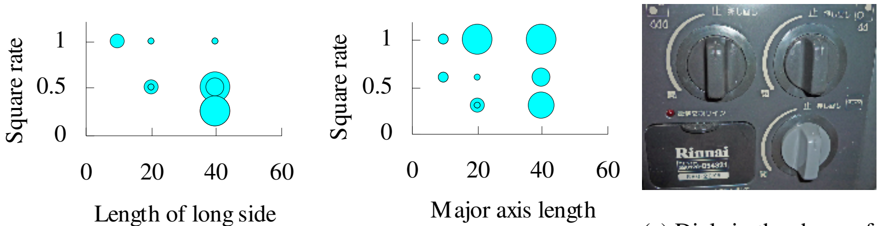
4.1 Quadrilateral and Elliptical Frustum Shapes

In Table 1 we define the square rate of the horizontal cross section of the samples. The square rate has a maximum value of 1 when the cross section is a square or circle, and takes a smaller value when the cross section is longer and narrower.

Here we define a space with length max(l_q, w_q) for the horizontal cross section of quadrilateral samples plotted on the x-axis and the square rate of the cross section plotted on the y-axis. When we represent the scores for "turn" for all quadrilateral samples by the area of a circle and plot them in the space, we obtain the result in Fig. 8(a). Similarly, we define a space where the x-axis is the major axis d_e of elliptical samples and the y-axis is the square rate. When we represent the scores for "turn" for all elliptical samples by the area of a circle and plot them in the space, we obtain the result in Fig. 8(b). These results indicate that the examinees tended to turn the quadrilateral samples when they were longer and narrower, whereas they tended to turn the elliptical samples when they were more circular. Although this result may be supported by the existence of dials in the shape of a quadrilateral frustum as shown in Fig. 8(c), it is possible that either such dials are designed on the basis of human behavior, exemplified by the answers of the examinees, or the examinees' answers are based on their knowledge and experience of such existing dials.

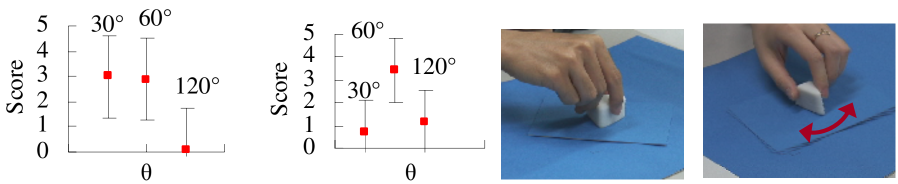
4.2 Triangular Frustum Shape

We analyzed the scores for "turn" obtained for the triangular samples. The result indicates that the orientation of the triangle affects the affordance of "turn" as follows.



(a) Quadrilateral frustum. (b) Elliptical frustum. (c) Dials in the shape of a quadrilateral frustum.

Fig. 8. Relationship between geometrical attributes and "turn" (quadrilateral and elliptical frustum)



(a) Upright triangle. (b) Inverted triangle. (c) Operation on equilateral triangle. (d) Operation on acute triangle.

Fig. 9. Relationship between geometrical attribute and "turn" (isosceles triangular frustum)

- When upright triangular samples are presented, the examinees turned acute (θ = 30°) and equilateral (θ = 60°) samples but did not turn obtuse (θ = 120°) samples (Fig. 9(a)).
- When inverted triangular samples are presented, the examinees turned equilateral (θ = 60°) samples but did not turn acute (θ = 30°) or obtuse (θ = 120°) samples (Fig. 9(b)).

To find the reason for this difference, we observed the recorded video and noticed that many examinees held equilateral triangular samples in a "surrounding" manner as shown in Fig. 9(c), whereas they held acute triangular samples in a pinching manner as in Fig. 9(d). It appears that the orientation of the triangle does not have a significant difference when holding it in a surrounding manner. However, it is more natural to hold acute upright triangular samples in a pinching manner than inverted triangular samples because the former looks like the direction indicator of a rotating dial. Also, it may be easier to grip an upright triangle than an inverted triangle by pinching without slipping.

4.3 Regular Polygonal and Circular Shapes

By plotting the scores for "turn" for regular polygonal and circular samples in Table 2, we obtain Fig. 10. Basically, regular polygons with more edges obtain higher scores for "turn". This tendency is applicable to a square when it is oriented as a diamond (so that its one of its vertices is toward the examinees), but not applicable when

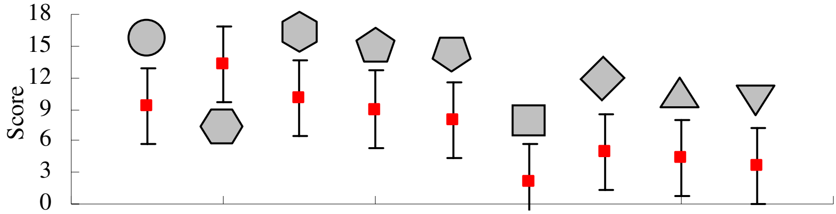


Fig. 10. Relationship between geometrical attribute and "turn" (regular polygonal and circular samples)

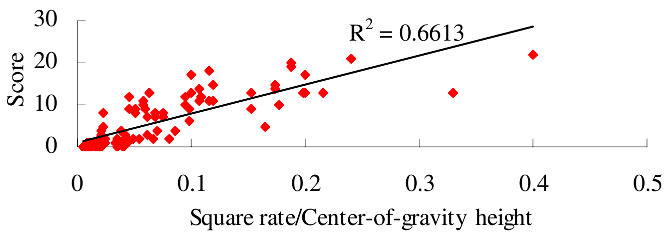


Fig. 11. Relationship between square rate/center-of-gravity height and "push"

it is placed as a square (oriented so that one of its edges is toward the examinees). A possible reason for this difference is that the horizontal and vertical edges of a square may give a stronger impression of stability than the slanted edges of a diamond. Similarly, the circle obtains rather small scores, in contrast to the overall tendency. A possible reason for this difference is that a circle has the affordance of not only "turn" but also other operations such as "push" (as explained later in Fig. 11), and thus the scores are divided between various affordances, reducing their values.

5 Affordance Feature of "Push"

By analyzing the scores for "push" for quadrilateral, triangular and elliptical samples, we obtained the result that the height and horizontal cross section shape affect the score for "push". Samples of lower height obtain higher scores for "push". Regarding the horizontal cross section shape, squares, regular triangles and circles, which have high square rates, obtain higher scores than other quadrilateral, triangular and elliptical shapes. Therefore, we plot the results for quadrilateral, triangular and elliptical samples on a plane where the x-axis is square rate / center-of-gravity height and the y-axis is the score for "push" (Fig. 11). The correlation coefficient between square rate / center-of-gravity height and the score for "push" was R = 0.81, indicating a reasonably strong positive correlation. Thus, shapes with a lower center of gravity and a horizontal cross section with a higher square rate may have the affordability of "push".

6 Conclusions

In this study, we proposed and investigated the concept of affordance features, which are the affordances for specific operations, on the basis of the geometrical attributes of objects.

Through experiments using quadrilateral, triangular and elliptical frustum-shaped samples and regular polygonal and circular samples and analyses based on the experimental results, we demonstrated the possibility of formulating the affordance features of "tilt", "turn" and "push" both qualitatively and quantitatively.

This paper is our first trial of formulating affordance features, and our future direction of research will include the following issues.

- Consideration of not only the geometrical attributes of shapes but also the context of operations (e.g., goals, plans and past experience).
- More systematic experiments and analyses with a larger number of examinees.
- Verification of our formulation by applying formulated affordance features to some design problems.

References

1. Gibson, J.J.: The Ecological Approach to Visual Perception. Houghton Mifflin, Boston (1979) (Japanese Translation)
2. Norman, D.A.: The Psychology of Everyday Things. Basic Books, New York (1988) (Japanese Translation)
3. Norman, D.A.: Affordances, Conventions, and Design. Interactions, pp. 38–42 (May/June 1999)
4. Dixon, J.R., Cunningham, J.J., Simmons, M.K.: Research in Designing with Features. In: Yoshikawa, H., Gossard, D. (eds.) Intelligent CAD, I, pp. 137–148. North-Holland, Amsterdam (1989)
5. ISO 9241-11: Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs) - Guidance on Usability (1998)
6. Sheridan, J.G., Short, B.W., Van Laerhoven, K., Villar, N., Kortuem, G.: Exploring Cube Affordance: Towards a Classification of Non-verbal Dynamics of Physical Interfaces for Wearable Computing. In: IEE Eurowearable 2003, pp. 113–118 (2003)
7. Washio, Y.: Introduction to Design of Experiments. Japanese Standards Association, Tokyo (1997) (in Japanese)
8. Liu, M.C.: Research on Formulization of Affordance Features for Design. Graduation Thesis, Department of Engineering Synthesis, The University of Tokyo (2006)