

CLASSIFICATION AND GUIDLINE OF SELECTION FOR DESIGN MODELING METHODS

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ABSTRACT:

In design, the diverse demands of users and problems of the society have created increasingly complex design problems. Therefore, design modeling methods are necessary for designers and engineers to derivate the exact design solution that responds to the complicated design problems. However, the framework of the methods in design has not been established. Moreover, most of the current studies on the methods only respond to the problems in each aspect of design. Therefore, they have applied the methods in each design process based on their knowledge and experiences. This study shows the classification and the guideline of selection for the methods based on the Integrated Design Model that was showed as the framework of design. As a result, the methods are classified to six types. And this study shows the position of the types in design process and flow charts of the methods as the guideline of selection for the methods.

KEY WORDS: DESIGN METHODOLOGY, DESIGN MODELING METHOD, DESIGN
PROCESS

I. INTRODUCTION

In recent years the demands of users and the social problems have been diverse. In design, the diverse demands of users and problems of the society have created increasingly complex design problems. Therefore, it is important to understand values and images of the design objects and analyze the relation among design objects, human beings and its environment to respond to the complicated design problems. A number of design modeling methods that realize above points have been proposed. Consequently, it is necessary for designers and engineers to derivate the exact design solution that responds to the complicated design problems. However, the framework of design modeling methods in design has not been established. Moreover, most of the current studies on the methods only respond to the problems in each aspect of design. Therefore, designers and engineers apply the methods in each design process based on their knowledge and experiences. The guideline of selection for the application of the methods has not been shown. Consequently, the guideline for selecting the methods is needed for designers and engineers to apply the methods appropriately in design.

This study shows the classification and proposes the guideline for selecting the design modeling methods as the basic research in order to structure the framework of the methods. Firstly, to analyze the methods from the viewpoint of design, this study focuses on the Integrated Design Model that was used as the framework of design in the past study. Secondly, the methods are classified and their feature is clarified based on the Integrated Design Model. Finally, this study analyzes the position of the methods in design and proposes the guideline of selection for the methods.

In this study, the design modeling method is defined as the method that structures a design model. Design model means a structural model or a mathematical model. The model structures or clarifies the relation between a design target and a design solution. The models are applied to the evaluation of candidates of a design solution in the forward problem. On the other hand, the models are applied to the support for derivation of a design solution in the reverse problem. In consideration of the all design process this study focuses the methods from the early process of design to a later process.

2. THE INTEGRATED DESIGN MODEL

The Integrated Design Model, as shown in Figure 1, is a model that has ability to describe all design process in design. This model consists of thinking space where elements

related to the object and reasoning are described, knowledge space where knowledge used for reasoning is described, and relative system surrounding thinking space and knowledge space.

2. 1. DESIGN IN THE INTEGRATED DESIGN MODEL

In the Integrated Design Model, thinking space consists of the value space, the meaning space, the state space, and the attribute space. The value space consists of elements that describe cultural value and functional value, and the relationship between these elements. The meaning space consists of elements that describe function and image, and the relationship between these elements. The state space consists of elements that describe physical quantity

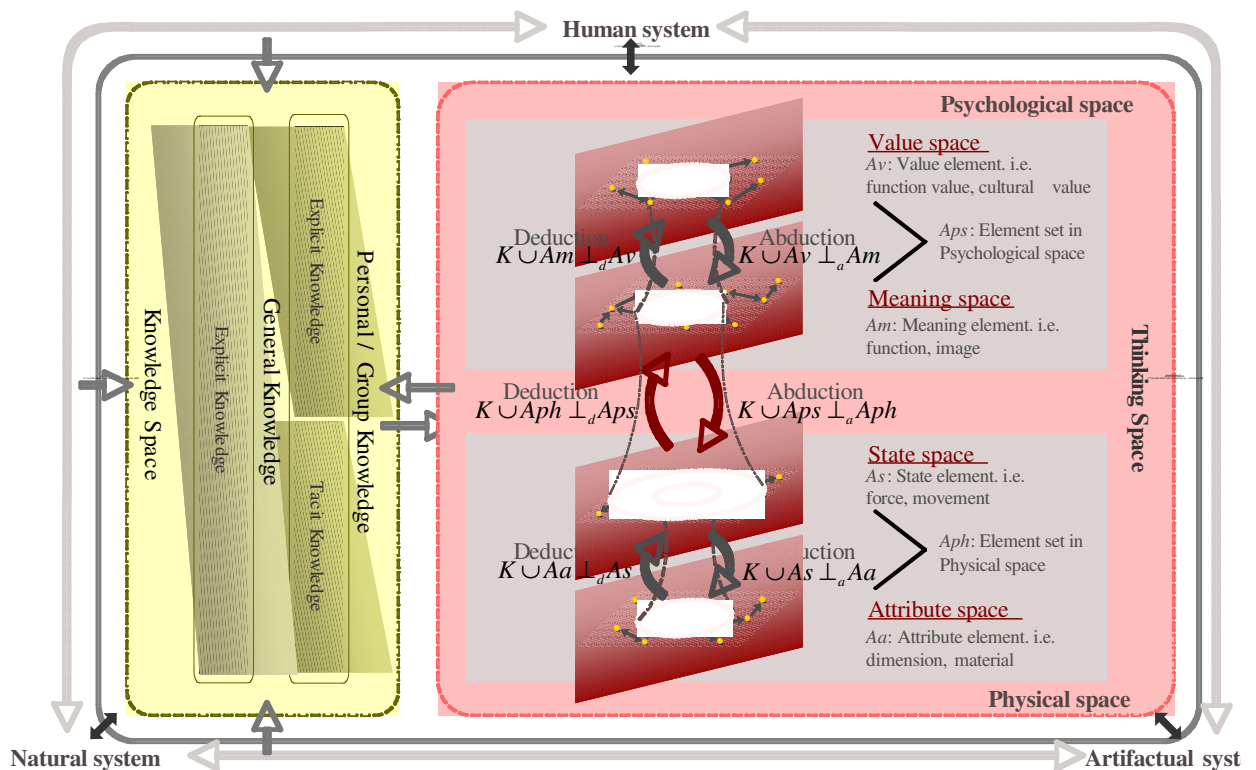


Figure 1: The Integrated Design Model

generated when the objects is in a condition, elements that describe a condition, and the relationship between these elements. Condition is the system that consists of supposed

elements excluding elements consisted of object. Condition consists of time elements, spatial elements including gravitational field and magnetic field, and human elements that describe bodily and physiological property including body height and eye motion. The attribute space consists of elements that describe geometrical and physical property including dimension and material like being shown in the technical drawing. The psychological space that describes psychological elements of the object consists of the value and meaning space. The physical space that describes physical elements of the object consists of the state space and attribute space.

Knowledge space consists of the personal and group knowledge and the general knowledge. The personal and group knowledge describes tacit knowledge and explicit knowledge that are based on personal or group experience and context. The general knowledge describes explicit knowledge that is based on axiom and theory of science.

Modeling in space and modeling between spaces are acts that model elements relation in thinking space. Modeling in space is an act that builds relation models of elements in the same space. Modeling in space consists of grasp of elements relation and boundary setting. The former describes a grasp of supposed elements in the same space and grasp of relation in these elements. The latter describes a setting boundary of objects domain toward the elements that exists innumerably in the same space. In design, to set a boundary shows that supposed elements become clear. On the other hand, modeling between spaces is an act that builds relation models of elements in the different spaces. Models built by modeling between are used for deduction and abduction. The deduction is reasoning used to derive upper space elements from lower space elements. In contract, the abduction is reasoning used to derive upper space elements from lower space elements. For example, the latter is reasoning when someone drives configurations and colors that generates the image.

2. 3. DESIGN SUBJECTS IN THE INTEGRATED DESIGN MODEL

The Integrated Design Model describes two types of design objects from the early process of design to the late process. First type is External design in the early process of design. In External design, the relation between the design object and environment is important. Therefore the design object is design elements in all spaces in the Integrated Design Model. Second type is Internal design in the later process of design. In Internal design, the detail of design object is important. Therefore design object is design elements mainly in state space and attitude space in the Integrated Design Model. As described above, in design object, the

Integrated Design Model describes External design and Internal design. It is necessary to suit the design modeling methods to both types of design objects for designers and engineers.

2. 4. DESIGN PROCESSES IN THE INTEGRATED DESIGN MODEL

The Integrated Design Model describes three types of design processes from the early process of design to the late process. First process is conceptual design. In this process, a design target in psychology space is determined. Second process is basic design. In this process, basic design elements in psychology space and in physical space are determined. Third process is detailed design. In this process, final design solution in physical space is determined. As described above, in the design process, the Integrated Model describes the conceptual design, the basic design and the detailed design. It is necessary to suit the design modeling methods to all types of design processes for designers and engineers.

2. 5. DESIGN MTEHODS IN INTEGRATED DESIGN MODEL

The Integrated Design Model describes two types the design methods from the early process of design to the late process. First method is emergent design. Emergent design applied in early process of design mainly. In this method, designers and engineers design based on the top down process and the bottom up process in psychology space because the design target is not clarified in early process of design. Emergent design tend to search for the design solution form the wide range of design elements and to derive diverse design solution. Second method is optimum design. Optimum design applied in the later process of design mainly. In this method, designers and engineers design based on the top down process in the physical space because the design target is clarified in the later process of design. Optimum design tend to search for the design solution form the narrow range of design elements and to derive unique design solution. As described above, in design method, Integrated Design Model describes emergent design, and the optimum design. It is necessary to suit the design modeling methods to both types of design methods for designers and engineers.

3. CLASSIFICATION FOR DESIGN MODELING METHODS

This study classifies the design modeling methods based on the Integrated Design Models. Firstly, the methods are sampled from papers related design and engineering. Secondly,

the methods are evaluated based on the Integrated Design Model. Finally, the methods are analyzed using Cluster Analysis in order to classify them.

3. 1. SAMPLING OF DESING MODELING METHODS

The design modeling methods are referred to papers of the Japan society for the science of

Table 1: The list of design modeling methods

No.	Method name	No.	Method name	No.	Method name	No.	Method name
1	Factor analysis	11	Correspondence analysis	21	Canonical correlation analysis	31	Petrinet
2	Response surface method	12	Self-Organizing Map	22	Interconnected Neural Network	32	Partial differential equation
3	Hierarchical Neural Network	13	Multiple Regression Analysis	23	Dual scaling	33	Laddering method
4	Relevance tree method	14	Principal component analysis	24	algebra eduation	34	Rough sets
5	Covariance structure analysis	15	Ordinaly differential equation	25	Multi-dimensional scaling	35	Association diagram method
6	Cluster analysis	16	Affinity diagram method	26	Characteristic diagram	36	Decision making trial and evaluation laboratory
7	Routes chart method	17	Quantification theory type Öü	27	Path analysis	37	Failure mode effect analysis
8	Decision tree	18	Quantification theory type ÖŸ	28	Discriminant Analysis	38	Fault tree analysis
9	Identify mapping model	19	Quantification theory type Ö°	29	Fuzzy inference	39	Interpretive structual modeling
10	Cohort analysis	20	Quantification theory type Ö¸	30	Protocol analysis	40	Quality function deployment

Figure 2: Evaluation items of design modeling methods

View point	item		Evaluation Criteria
Act of Design Modeling	Comparison	The relationships between all elements	Check if you compare the relationships between all elements.
		The relationships between elements for a specific elements	Check if you compare the relationships between elements for a specific element.
	Structuration	Integration	Check if you integrate elements.
		breakdown	Check if you break down a specific element.
Design Modeling Knowledge	Represented Knowledge	Qualitative Data	Check if you deduct qualitative datas by qualitative datas .
		Qualitative and Quantitative Data	Check if you deduct qualitative datas by quantitative datas or quantitative datas by qualitative datas.
		Quantitative Data	Check if you deduct quantitative datas by quantitative datas .
	Operated Knowledge	System of Axiom	Check if you use generally knowledge while modeling act.
		Hypothetical Axiom	Check if you use individual knowledge or part of group knowledge while modeling act.

design, the Japan Society for Design Engineering, the Japan Society of Mechanical Engineers and the dictionary, surveying and handbook of design. As a result, the design modeling methods are shown in Table 1.

3. 2. EVALUATION OF DESIGN MODELING METHODS

The items and the criterion of evaluation for the design modeling methods have been defined based on Integrated Design Model. Firstly, in thinking spaces of Integrated Design Model, the process of the design modeling is analyzed. As a result, it is defined that design modeling consists of the comparison to the relation with design elements and the structure of the relation with design elements. Moreover, the comparison is divided into all design elements and objective design elements. Moreover the structure is divided into synthesis of design elements and analysis of design elements. Secondly, in the knowledge of the Integrated Design Model, the knowledge for design modeling is analyzed. As a result, it is defined that the knowledge consists of the represented knowledge and the control knowledge. Moreover, the represented knowledge is divided into qualitative data, qualitative and quantitative data and quantitative data. The control knowledge is divided into General Knowledge and Personal and Group Knowledge. The items and the criterion of evaluation that are defined are shown in Table 2. Finally the design modeling methods have been evaluated by the criterion.

3. 3. HOW TO CLASSIFY DESIGN MODELING METHODS

The design modeling methods are analyzed using Cluster Analysis in order to classify them. Cluster Analysis is statistical method that defines the distance of the subjects and classifies the subjects based on the distance. This study uses the Ward Method of Cluster Analysis because in this method the chain effect is not caused easily and this method is useful to classify. The Ward Method makes a cluster using the non-similar level data according to the criterion that is the sum of the square of the cluster is minimized in a new cluster. In this method, the Distance of Euclid d_{ij} is used as the non-similar level data by equation (1). For qualitative data the Distance of Euclid is calculated by the Binary data.

$$d_{ij} = \left(\sum_{r=1}^p (x_{ir} - x_{jr})^2 \right)^{1/2} \quad (1)$$

Concretely, it is expressed that the variable number is p , the variable is $x_{i1}, x_{i2}, \dots, x_{ip}$ ($i=1, 2, \dots, n$) and the subject number is m . In the case that the cluster is l, m and the combined

cluster is lm , it is expressed the variable number is k and the variable is x_{mik} , x_{lmk} , and the subject number is nl , nm . According to above case it is provided the equation (2) to (5) . In equation (5) the cluster and the subject are combined to minimize the value of ΔS_{lm} . In the same way, this process repeats until all clusters are combined.

$$S_l = \sum_{i=1}^{n_l} \sum_{k=1}^p (x_{lik} - \bar{x}_{l.k})^2$$

(2)

$$S_m = \sum_{i=1}^{n_m} \sum_{k=1}^p (x_{mik} - \bar{x}_{m.k})^2$$

(3)

$$S_{lm} = \sum_{i=1}^{n_l+n_m} \sum_{k=1}^p (x_{lmik} - \bar{x}_{lm.k})^2$$

(4)

$$\Delta S_{lm} = S_{lm} - S_l - S_m$$

(5)

This study has analyzed the evaluated data using Ward Method of Cluster Analysis. The clustering process is showed in Dendrogram of Figure 2. In the Figure 2, the horizontal axis is the cluster distance and the vertical axis is the design modeling methods. As a result of Figure 2, all clusters are combined in the cluster distance 4.91.

3. 4. RESULT OF CLASSIFICTION FOR DESIGN MODELING METHODS

In this study, the modeling method is classified to six clusters according to Dendrogram of Figure 2. The feature of each cluster of the design modeling methods is analyzed. As a result, the following five were confirmed. Firstly, in the cluster distance 4.91 the design modeling methods are divided in the cluster 1, 2 and 3 and cluster 4, 5 and 6. According to the results in the evaluation of the design modeling methods, it is confirmed that the former is the methods

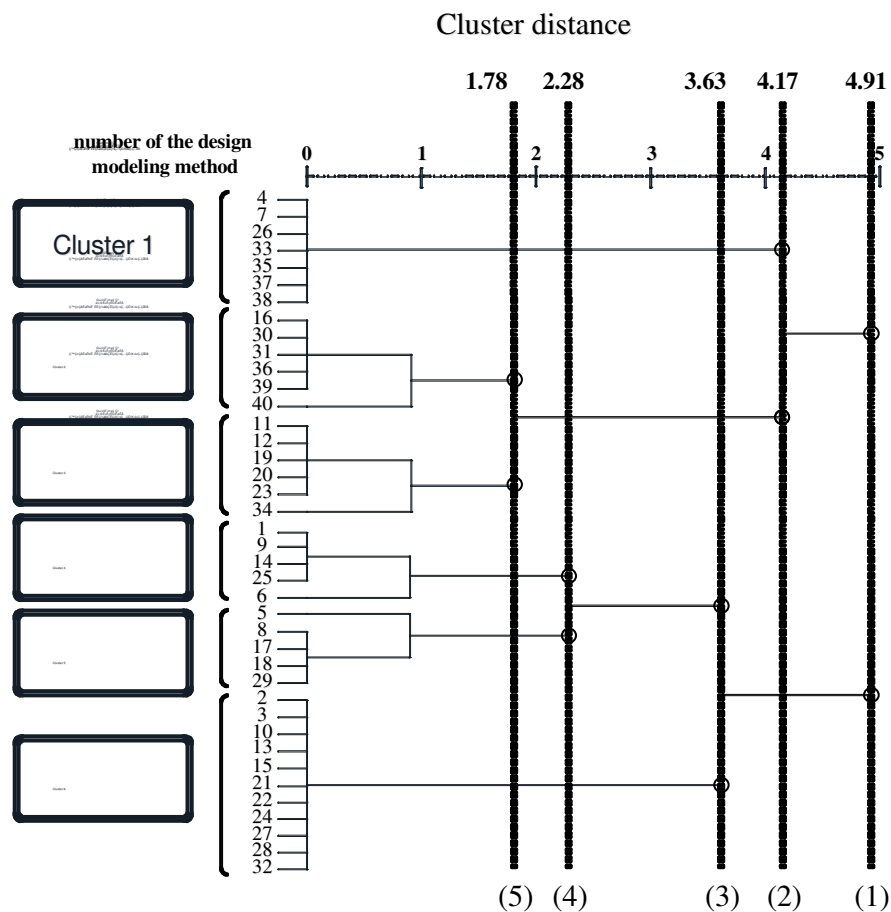


Figure 2: The results of Cluster Analysis

that do not use quantitative data and the latter is the methods that use quantitative data.

Secondly, in the cluster distance 4.17 the design modeling methods are divided in the cluster 1 and cluster 2 and 3. It is confirmed that the former is the methods that analyze design elements and the latter is the methods that synthesis the design elements. Thirdly, in the cluster distance 3.63 the design modeling methods are divided in the cluster 4 and 5 and cluster 6. It is confirmed that the former is the methods that use qualitative data and the latter is the methods that do not use qualitative data. Fourthly, in the cluster distance 2.28 the design modeling methods are divided in the cluster 4 and cluster 5. It is confirmed that the former is the methods that compare to the relation with design elements and the latter is the methods that compare to objective design elements. Fifthly, in the cluster distance 1.78 the design modeling methods are divided in the cluster 2 and cluster 3. It is confirmed that the former is the methods that use Personal and Group Knowledge and the latter is the methods that do not use Personal and Group Knowledge.

3. 5. FEATURE OF THE TYPE OF DESIGN MODELING METHODS

This study clarifies the feature of the cluster of design modeling in design object, design process and design method based on the Integrated Design Model. Firstly, we will discuss the position of the design modeling methods in design object based on the classification of them. It is confirmed that the cluster 1, 2 and 3 are the methods that use qualitative data. From this finding it can be stated that these clusters are used in psychology space. It is confirmed that the cluster 4 and 5 are the methods that use qualitative and quantitative data. From this finding it can be stated that these clusters are used in psychology space and physical space. These findings suggest that the cluster 1, 2, 3, 4 and 5 are applied to External design that targets the interaction between a design object and environment in all space in Integrated Design Model. It is confirmed that the cluster 6 is the methods that use quantitative data. From this finding it can be stated that the cluster is used in physical space. This finding suggests that the cluster 6 is applied to Internal design that targets the detail of design object in attitude space in Integrated Design Model. Secondly, we will discuss the position of the design modeling methods in design process based on the classification of them. It is confirmed that the cluster 1, 2 and 3 are the methods that use quantitative data. From this finding it can be stated that these cluster is used in psychology space. This finding suggests that the cluster 1, 2 and 3 are applied to conceptual design in that designers and engineers clarify the relation of design elements in psychology space. It is confirmed that the cluster 4 and 5 are the methods that use qualitative and quantitative data. From this finding it can be stated that the cluster is used in psychology space and physical space. This finding suggests that the 4 and 5 are applied to basic design in that designers and engineers

clarify the relation of design elements in psychology space and physical space. It is confirmed that the cluster 6 is the methods that use quantitative data. From this finding it can be stated that this cluster is used in physical space. This finding suggests that the cluster 6 is applied to detail design in that designers and engineers clarify the relation of design elements in physical space. From the above findings it is suggested that the design process arrives from the cluster 1, 2 and 3 at the cluster 6 through the cluster 4 and 5 from in conceptual design to detail design through basic design. Thirdly, we will discuss the position of the design modeling methods in design method based on the classification of them. It is confirmed that the cluster 1, 2 and 3 are the methods that use qualitative data. And the clusters are the methods that compare and structure the relation of design elements. From this finding it can be stated that the clusters are used in psychology space to derivate diverse design solution. These findings suggest that the cluster 1, 2 and 3 are applied to the emergent design in that designers and engineers need the diversion of divers design solution. It is confirmed that the cluster 6 are the methods that use quantitative data. And the cluster is the methods that compare and structure the relation of design elements. From this finding it can be stated that the cluster is used in physical space to derivate unique design solution. These findings suggest that the cluster 6 is applied to the optimum design in that designers and engineers need the diversion of unique design solution. From the above findings it is suggested that in emergent design the cluster 1, 2 and 3 are important methods and in optimum design the cluster 6 is important method.

4. GUIDELINE OF SELECTION FOR DESING MODELING METHODS

From the above discussion this study clarifies the position of the design modeling methods in design to use the guideline of selection for the methods. Firstly, the cluster 1, 2 and 3 are applied in conceptual design to derivate diverse design solution. Secondly, the cluster 4 and 5 are applied in basic design to derivate design solution that fills constant standard. Finally, the cluster 6 is applied in detail design to derivate unique design solution. In an actual design, firstly, designers and engineers clarify the design problems using the methods in the cluster 1 or 2. For example, they are Characteristic Diagram, Laddering, QFD (Quality and Function Deployment) and ISM (Interpretive Structural Modeling). Secondly, they clarify the design targets using the methods in the cluster 3. For example, they are Quantification Theory Cluster 3 or Cluster Analysis. Thirdly they clarify the relation between the design targets and design solution using the methods in the cluster 4 or 5. ||

For example they are Principal Component Analysis, Factor Analysis, Quantification Theory Cluster 1, Quantification Theory Cluster 2. Finally, they derivate design solution using the methods in the cluster 6. For example, they are Multiple Regression Analysis or Ordinary Differential Equation. From the above findings, in design the position of the design modeling methods are described in the Figure 3.

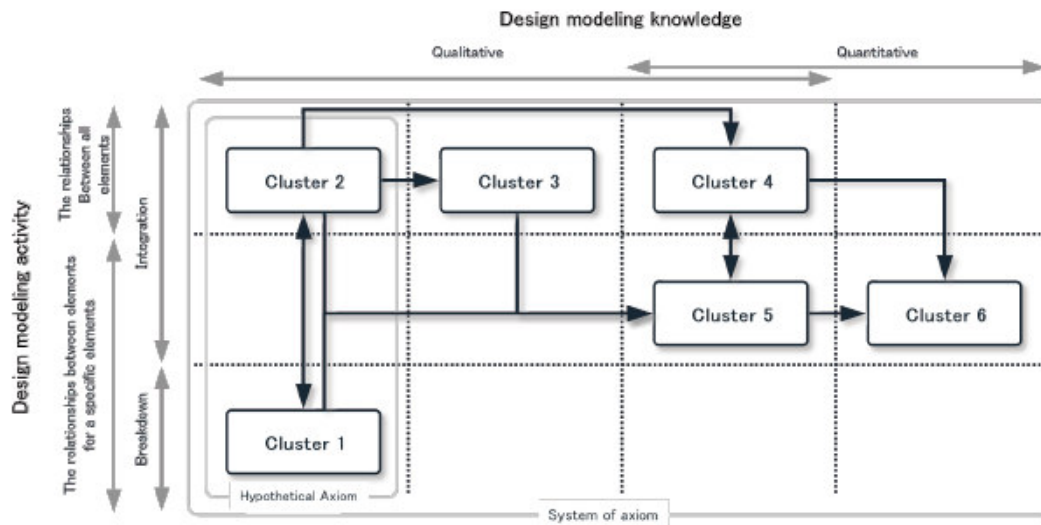


Figure 3: Position of design modeling methods in design

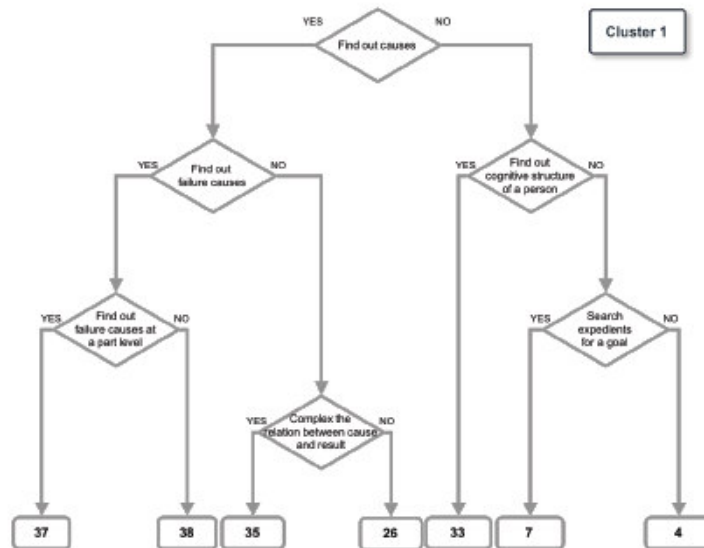


Figure 4: Flow chart of cluster 1

This study proposes the guideline of selection for the design modeling methods in the each cluster of the methods. Selective flow chart is structured by the view of the object and the property of the design modeling in the each cluster of the methods. The result is showed in Figure 4. From the above description of the position of the methods and Selective flow chart in the clusters of the methods, the guideline of selection has shown for designers and engineers.

5. CONCLUSION

This study showed the classification and the guideline of selection for the design modeling methods based on the Integrated Design Model. Firstly, the methods were classified to six clusters using Cluster Analysis. Secondly, the position of the methods in design process was showed by discussing the feature of the clusters in design.

Finally, the flow charts of the methods were proposed as the guideline of selection for the methods.

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