CALCULATION OF DESIGN COGNITIVE FEATURES BASED ON COMPLEX LINKOGRAPHY-NETWORK

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Abstract

In view of the complexity of multi－disciplinary team collaborative innovation design process, the quantitative design of cognitive research can be realized by putting forward to deconstruct design complex cognitive space based on the complex linkography-network model. This thesis builds a complex linkography-network model for the complexity of the design of cognitive forms, and describes complex design cognition from the perspective of process and content, and then extracts the characteristics of cognitive process based on the essence of the cognition, and uses a rational analysis to structural decomposition of cognitive complexity. Cognitive instances are used to analysis and verify the validity of the characteristics of expression. This study provides the possibility for manifesting the complex relationship of implicit cognition and the intelligent diagnosis for design cognitive research.

Keywords: Design cognition, Collaborative design, Computational design methods, Industrial design

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1 INTRODUCTION

Design cognitive and computational research has been widely explored in recent years in the field of design theory. The theory of Human Problem Solving proposed by Simon (1979) and Schön's (1983) Reflection-in-action theory are the most representative ones. Following them, Archer (1981) proposed that the systematic method for design is composed of three steps: analysis, creation, and execution. Josephs et al (1992) developed the Analysis-synthesis-evaluation model. Gero (2009) founded the Function-Behaviour-Structure (FBS) model. Experts and scholars have carried out extensive and in-depth research on problem solving and design situated cognition. These studies have focused on several aspects of the cognitive process model, reflective cognitive model and cognitive state description, but cannot answer how to adapt to ill-structured problems, especially how to integrate a multidimensional cognitive model. Based on previous research, this paper attempts to propose a linkography-network model that integrates linkography and networks, for the first time to achieve a comprehensive study of the design and content of cognitive processes, and extracts the cognitive characteristics from these two perspectives so as to promote the team design cognitive computing research.

1.1 Design knowledge and space

Design is a knowledge-intensive activity. Design knowledge refers to the sum of various information and experience that can be applied to product design and decision-making. At the same time, design knowledge needs to be acquired, expressed and reused in the specific mapping space. In the respect of knowledge reasoning modelling, fusing and reusing, Takai et al. (2011) proposed a design knowledge inference method from requirements to parameters (from top to bottom) and from parameter to structure (from bottom to top) to obtain a design solution, which can satisfy both demands and constraints at the same time. Baxter et al. (2007) put forward the design knowledge reuse method based on process model and construct the framework of design knowledge reuse. Dorst and Cross (2001) applied their observations to a co-evolution model of problem/solution spaces. Cash et al. (2009) visualized and analysed the different design contexts through the growth rate of complex networks. The existing design cognitive modelling method lays the foundation for partial knowledge modelling and spatial feature recognition, but it is difficult to express non-structural data, uncertain behaviour and state specification to high-level cognitive space expression. And it is more difficult to provide transparent and scalable operating environment. Therefore, to establish an adequate expression of visual model of dynamic design cognition is a new direction of design cognitive research, which also provides a new idea for expressing complex network structure and showing the essence of design cognition.

1.2 Design cognition

Design cognition usually results from the joint effects of imaginative thinking and abstract thinking. Asimow (1962) proposed that the structure of the design process consists of the vertical structure of the continuous behaviour and the horizontal structure of the decision making cycle. Zeisel (1995) considered that the design process is the helical structure composed of concept, performance, and testing. Mitchell (1992) proposed the concept of "design cognition and computation". These phases and state program models illustrate the characteristics of design activities at the low level of information processing. It is a general understanding of the process that the designer form the design, but it is not clear what is the key factor in the originality of design. Therefore, the research and discussion of the design need to be further developed to the high level of design cognitive activities of the information processing process and design thinking process. Based on the classic design cognitive model, this paper employs the methods of protocol analysis to acquire the abundant linguistic information in the team design process, builds a systematic and multidimensional model based on the linkography and network, and analyses characteristics to achieve a deeper understanding of the cognition process of semantic research and explore the concept evolution law of the team design process.

2 DESIGN COGNITIVE MODEL BASED ON LINKOGRAPHY-NETWORK

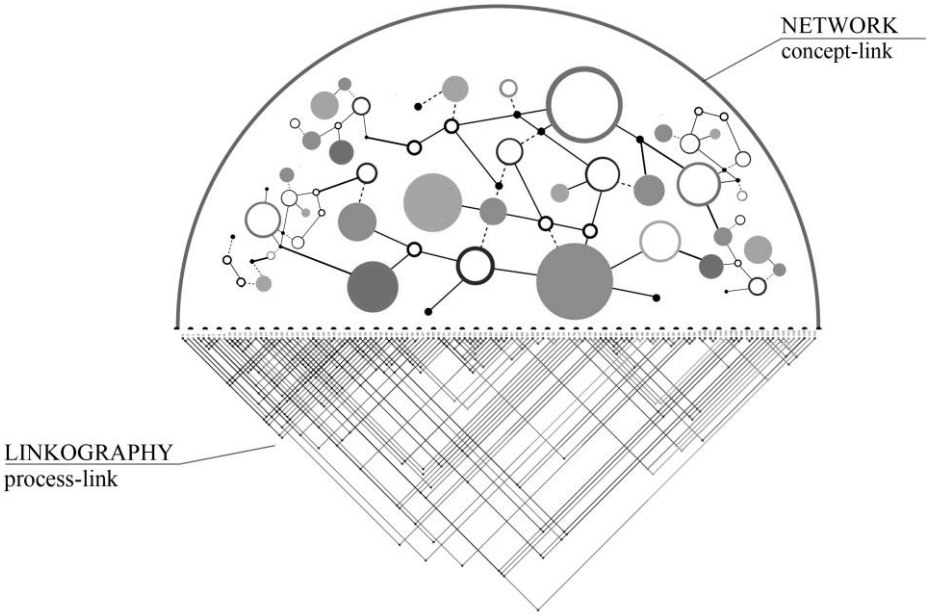

Figure 1. Linkography-network model

The linkography first proposed by Goldschmidt (1994), which is an effective means of assessing the level of designer and team design, and can show the development process of design creativity from the perspective of temporal series. It can be based on the degree of relevance of conceptual evolution of design and the relevance of module-oriented implementation. However, in cognitive space, it is difficult to independently reflect the innovation and problem of the concepts in the non-sequential space. Network, another form of linkography-network model, describes the concept evolution process during the design process in the form of semantic network, referring to the network-link relationship among the conceptions. Compared with the linkography, the network breaks the time sequence.

As there is a correlative mechanism between them, this paper proposes to connect the linkography with the network and establish the linkography-network model, which can be used to describe the originality, path evolution, development reasoning, problem diagnosis and innovation evaluation of the design process with a comprehensive quantitative expression, and can explicit recessive design cognitive process and provide the method for the visual analysis on design process.

The linkography-network model consists of two main parts: process-link and concept-link, as shown in Figure 1. The linkography is the main form of process-link. Under the expression of link information matrix, the process-link can realize the entropy processing and integration analysis of cognitive process for complex time series design, find the key node of concept development according to the volatility effect, and present the migration and transformation status of design concepts. Concept-link is based on the form of network, which can centralize the evolution process of network analysis concept, and explore the subject content of design concept. According to the different modules in the linkography-network model, the characteristics of design process research are divided into two parts: the process-link and the content-link (Figure 1). It lays the foundation to extract cognitive features of design context in the study, which manifests the implicit aspects of innovation.

3 THE CHARACTERISTICS EXTRACTION

3.1 Cognitive characteristics

Design situational cognition characteristic is a result of abstract cognitive features, from the concept evolution, cognitive reasoning, situation change and other dimensions to represent the logical law and essential attribute in complex design situational cognition. Therefore effective identification and extraction of hidden informational characteristic provide an efficient way to analyse, diagnose and

predict the content and relationship of the design situational cognition from the aspects of gradation, structure, relevance and predictability.

3.2 Process type characteristics

3.2.1 Complexity-Process information entropy

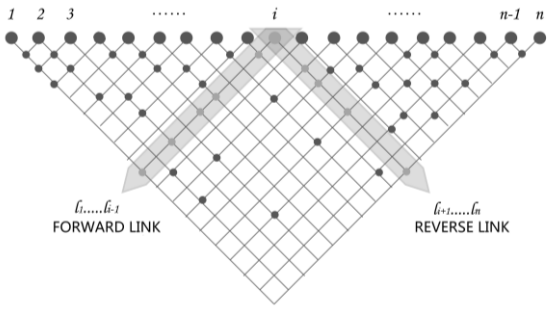

Figure 2. T-code expression linkography

Design cognitive complexity is the result of ill-structure, uncertainty of design problem and fuzzy variability of design solution. The complexity analysis of design cognition combines the T-code method of certainty information theory with a linkography. T-code is to use the before and after link code in linkography to form a T-code string, and then calculate, which contains the forward link and reverse link (Figure 2). The complexity index of design cognition based on T-code analysis mainly includes complexity Tc, information volume Ti and entropy Te. Tc refers to the level of the complexity. The higher the Tc value, the more complex the display of the string structure. Ti is the amount of information. The amount of information was obtained through the calculation processing. Usually, the more irregular the character distribution in the string, the greater the amount of information it contains, indicating that the process of design cognitive reasoning is more complicated. Te is entropy, indicateing the character arrangement mode. The high Te value means that the low repetition character arrangement and more difficulty to predict the new character arrangement mode. Nodes with great entropy are often transitional concepts or mutation concepts. The minimal entropy nodes are concepts that are focused or generated in a certain stage. Therefore, through the complexity calculation, we can locate the extreme points and the fluctuation points of the entropy, which correspond to the concept of transition, new concept and isolated concept in the design cognitive process.

3.2.2 Depth value

The complexity of design cognition reflects the direct complex relationship between design nodes, but the direct relationship between non-directly related design nodes cannot be expressed. For the relationship between the indirect design nodes, this paper introduces the depth value for analysis. The depth value is the minimum number of connections that a space in the system reaches in another space. In the linkography, it represents the shortest distance d_{ij} from one node to all other nodes, the average of which is the depth value average MD_i. Expressed in Equation (1):

$$MD_i = \frac{1}{\text{n-1}} \sum_{j=1}^{\text{n-1}} d_{ij} \qquad (i \neq j) \tag{1}$$

Where: MD_i is average depth of node i, d_{ij} is the shortest distance from node i and node j, and n is total number of nodes. The depth feature quantity can effectively react to the link condition of the indirect nodes. Depth shows the degree of linking of different design nodes, that is, the design node in the design process of the degree of relevance. The depth here is not the physical space distance, but a form of expression of the degree of relationship, is an expression borrowed from spatial distance.

3.2.3 Concentration degree

Concentration degree is the introduction of spatial syntax in the description of a space in the system and other space gathering or discrete degree. It reflects the total number of steps required from the

starting point to the other points in the space. It is generally believed that the clustering of the design is relatively strong for the degree of concentration greater than 1; for the case where the degree of integration is between 0.4 and 0.6, the distribution of design cognition is relatively dispersed; which is below 0.4, design cognition can be regarded as irrelevant. Entropy is concerned about the disorder state; concentration degree is concerned about the orderly state, the formation of complementary. In entropy graph, we are concerned about the cusp, but to some extent, ignore the local turning points. Concentration degree makes up for this problem; the highest change point of integration degree in a certain degree is the gentle section of entropy. The combination of the two can be a good idea to find out the creative turning point, and the trend.

3.2.4 Link evolution path

The information of the nodes in the linked table is divided by the forward link and the reverse link. The link information for different directions reflects the different design states and evolution forms of the nodes. The directional evolution of the nodes is proposed. Link evolution combined with linked table data provides an effective reference for potential design information mining, and also makes concept evolution path search possible. For any of the concepts i and j, the path P (i, j) between the two is described in Equation (2):

$$P(i,j)=\lfloor C_i, C_{i1}, C_{i2}\cdots C_{k\text{-}1j}, C_j \rfloor \tag{2}$$

Where, Cij is design node i to the design node j between the transfer node. The minimum number of links Cij in the linkography, reflecting the degree of influence of the creative evolution, can express the shortest path between the two concepts. The maximum path in all the shortest paths on the forward link can reflect the impact of the span. The shortest evolution path feature in the design concept of search and retrospective concept evolution path, can locate the concept of evolution of the key nodes, is conducive to the design process concept of grasp and creative concept of capture. For the entire network contains complex content information, which through the decomposition of the structure, can effectively distinguish between different information content.

The number of paths through the overall design of the nodes can reflect the robustness of design cognition, that is, the convergence and divergence characteristics. In view of the early stage of the conceptual design, the evolution path between the design nodes is less, and the divergent state of the design thinking is presented. For the later stage of design, the design nodes are closely connected with each other, and the corresponding evolution path can be more selective, showing the convergence state of the design.

3.3 Content type characteristics

3.3.1 Latent Semantic content

Latent Semantic Analysis (LSA) (Landauer ,2006) uses the method of statistical calculation to analyze a large number of text sets, so as to extract the potential semantic structure of the text, to express the design of internal relations, and to achieve quantitative expression of the way. It uses statistical methods to analyze a large number of text sets, and then extract the potential semantic structure of the text, to express the design of internal relations, to achieve quantitative expression of the way. In team design discussions, there is a high degree of consistency between documents that are generally adjacent to each other. The semantic coherence tends to decrease as the distance between documents increases. When the distance between the two documents is small, the semantic consistency is distributed in the vicinity of the fitting curve. When the document distance is large to a certain extent, the semantic consistency tends to be discrete and the regularity is worse.

3.3.2 Content (CONNOR) clustering

CONNOR clustering is mainly used in the classification model analysis method, the design of the design process related characteristics, and then cluster analysis and processing. Multidimensional model of the content network on the concept of clustering operations, breaking the chronological order of the same theme of the concept of clustering, analysis of the design process of the concept of internal relations and conceptual topics between the cross. The concept of the same category will form a conceptual theme. Each concept cluster represents the discussion content of a topic. The time span

between the concepts also indicates that the theme is in the whole design process. Discussion of the span; clustering does not change the concept itself and the concept of the link between the relationship, but with the concept of cluster formation, will indicate the creative concept.

3.3.3 Topic impact-controlling value

The degree of association of the content network can be reflected by the degree of connection. In the design content topic study, the connection value represents the number of nodes connected to the i-th semantic node. In the design cognitive semantic network, the higher the connection value of the design node, the better the permeability and the key in the cognitive network. The connection value reflects the association between the single points of the content network, and the degree of influence on the content subject needs to be expressed by the control value. The control values represent the degree of interrelationship between clustering topics and reflect the degree of influence of a design on a design process. The control value is the degree of freedom of the design theme to the impact and is affected by the number of other design themes.

4 EXPERIMENT

4.1 Experiment and data processing

It is necessary to carry out the team design experiment, complete the design data acquisition to the data processing, and the calculation analysis for the application and validity verification of the multidimensional model in this paper. Experiment with the design of the bicycle lock as the theme, with two rich experienced designers and design three students to attend, the experiment of time set for 120 minutes, the experiment of the main process is: 1. Set the initial and the target state, clear design task, subject, time requirements and steps; 2. Designers discuss their point of view for solving problem, and explore the possibility of a variety of design scheme; 3. The team focus on the scheme, discuss specific solutions; 4. Constantly reflect and summarize until the final design is obtained.
Experiments in graphic and text form to express design ideas and processes, through the recording language to communicate data. And the spoken information is collated and converted into text data, the dialogue data related to the design task are extracted, and the experimental data cleaning, punctuation and coding work are carried out by using the oral analysis method, and 91 design texts are obtained as 91 design nodes, link relationship coding data as shown in Table 1. The role of each node in the table represents the corresponding designer, the link bar indicates the node link, if the link is marked node number, bold part of the text reflects the main concepts and design points.

Table 1. Experimental data encoding results

No	Text data	Role	Link number			
1	Wish a **one-handed operation** bicycle lock. Existing lock cannot be operated by single hand. They need to be operated by two hands.	C				
2	Single hand operation. Not necessary to squat down to lock bikes	Z	1			
3	Separated from the existing bicycle and bicycle lock, after people unlocking, they need to find place to hang lock. Hope there will be a **integrated design can combine** lock part and bike.	W				
…	…	…	…	…	…	
31	Or combination with the **pedal**, use pedal to unlock bike, but everyone can kick bike pedal, so we need a more safety way.	J	5	17	26	
…	…	…	…	…	…	
91	Final solution: the **pedal locks the bike and handlebar unlocks it**.	Z	82	83	85	86

4.2 Analysis of results

4.2.1 Process type characteristics

On the basis of uncertainty theory of information coding, the design of cognitive complexity mainly through entropy index calculation to be analysed. The complexity of node parameter values and the entropy change of adjacent nodes result as shown in Figure 3 (b).

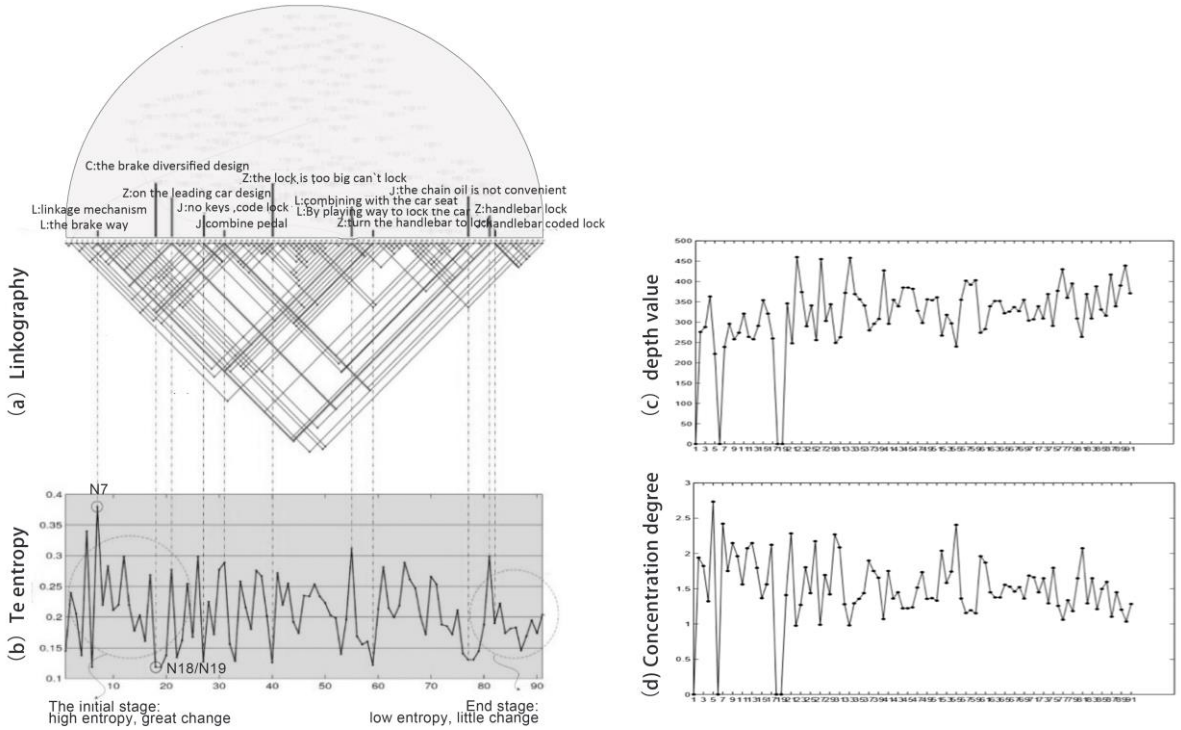

Figure 3. Experiment process type characteristics analysis diagram

Along with the advancement of the design process, each node of the entropy in the fluctuating, because of the large initial stage of new concept. The beginning is relatively severe. Design cognition shows the characteristics of disordered state. The maximum value of the entropy is node N7, and the maximum value is 0.379; the minimum point is node N18 \ N19, and the minimum value is 0.119. Figure 3 can be learned from difference change interval narrowing, where consistency is higher and the overall design process does not appear the main concept of mutations. N7 reflects its inspiration and associated effects on subsequent concept, as summary to the foregoing discussion about lock the car behaviour, and guide from perspective of the way of car lock, giving two possible ways to lock the car. N18 presents the diversification of lock design but failed to develop follow-up to deepen, department without link-isolated concept, the entropy value is minimum.

The depth values change as shown in Figure 3 (c). The overall depth value is in the first increase after the twists and turns trend, for the design phase I, the concept of divergence between the points, the degree of indirect correlation is relatively difficult, with the design process to promote the design of the refinement of the design process so that each other design node to achieve cross-connectivity, the depth value also increases. And in the process of deepening the development of new concepts, making the design concept out of the limits, into the new dimension, resulting in reduced design depth. This shows that this design process is more reasonable. Bicycle lock design node depth value is larger, deepening the level of more specific, not messy, reflecting the design with specific and systematic.

Although the complexity and depth value can be combined to analyze the direct and indirect association of design cognition, but lacks of analysis of the concentration and divergence trend in the design process. As shown in Figure 3(d), the overall concentration concentrated in the vicinity of 1.6, indicating that the design is relatively concentrated, the details of the design to consider more detailed, with a strong design and analysis process.

The next will be based on the network search algorithm to analyse the evolution of the concept of path, as shown in Figure 4. Are searching the shortest path between any two nodes, this paper selected

in the first node to the last node to search. The shortest path length is 6. Figure 4 shows the three kinds of shortest path, as you can see node 5 is three solutions are must go through the nodes, the nodes in the analysis of the totem of centricity also have the highest centricity value, you can see the importance of the concept in the whole process. Three schemes of difference between nodes 21 and 31, node 21 centricity has a great distance and high degree of centricity, and is the biggest span in path. So it can be seen that centricity higher nodes and the long link in the process of the overall design have played an important role well series, also improve the integrity of the design process.

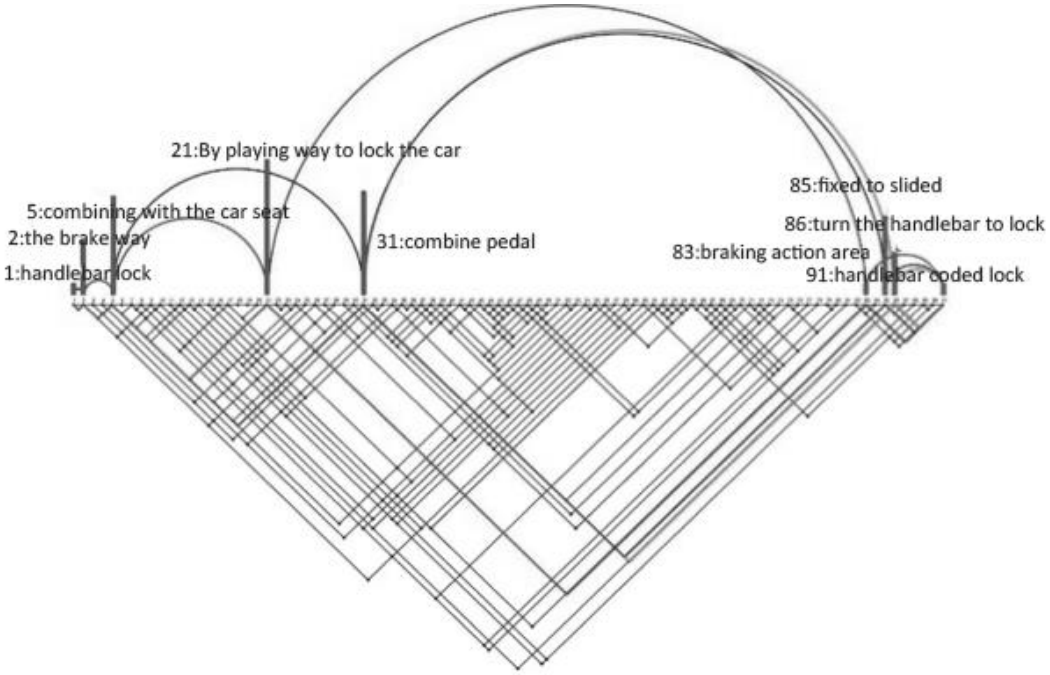

Figure 4. Path search diagram

4.2.2 Content type characteristics

Clustering analysis across the time interval to the design of the whole process is split into different categories, to explore the concept development process. Cognitive concept design in using clustering algorithm for matrix l network processing, realize the concept of clustering, the result is shown in Figure 6, 91 nodes can be clustered into eight categories. Each category concept will have different sketches show the detail, which is composed of 91 nodes, the concept of network, concept in between Undirected connected with arc, according to different colour area representative different categories, the node label with node number and relevant keywords. Cluster 1 has 11 nodes, including: single hand operation, integrated design, remote control locks, parking space, lock and fender, public electronic lock, one hand lock, lock, u-shaped integration. But don't want to the key problems, approached the lock has a feedback. This topic concept is mainly discussing how to make the lock more convenient, considering human aspects of the design of the lock. As you can see the follow-up of N1, N3 and N12 concept is the concept of extension. But cluster 2 concepts focused on discussion of the realization of the concrete of the lock mode. Concept of category 1 and category 2 theme for 3,5,6,7,8 cluster specific lock and details in the form of structure, pointed out the direction of sketch in the figure correspond to the concept of clustering theme, rendering the conversion between different concept sketches and the transfer between the similar concept sketches. Although there are some isolated design points in the cluster, but the overall algorithm accuracy, the realization of the overall design of the classification, and in line with the actual design process. Highlighting the effectiveness of design clustering.

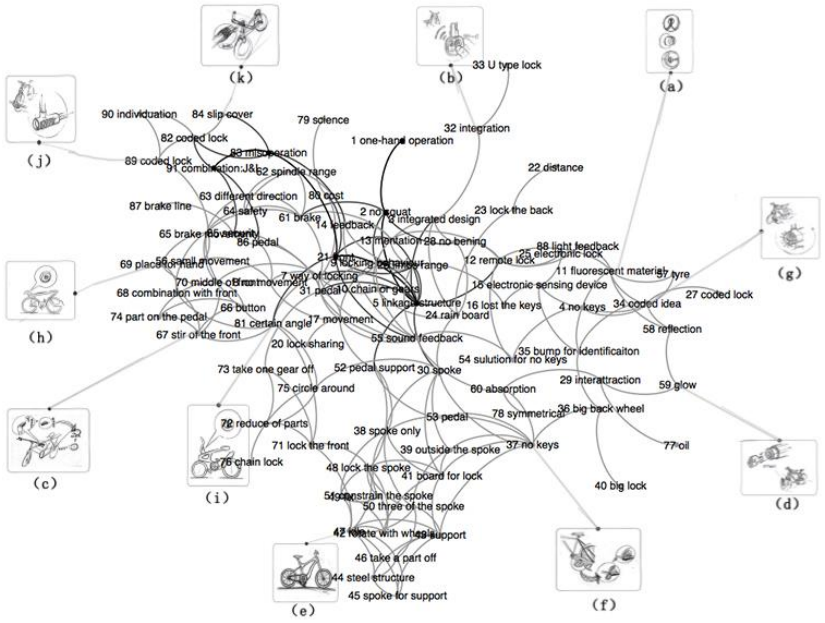

Figure 5. Concept network diagram

Table 2. Clustering results of bike lock experiments

Cluster	Node list
1	[1 3 12 23 24 25 28 32 33 54 88]
2	[2 5 7 8 9 10 13 14 16 17 20 21 26 31 55 79 80 85 86 87]
3	[56 61 62 63 64 65 66 67 68 69 70 74 81]
4	[82 83 84 89 90 91]
5	[4 11 15 27 34 35 40 57 58]
6	[6 18 19 22 29 36 59 60 76 77 78]
7	[30 37 38 39 41 51 52 53 75]
8	[42 43 44 45 46 47 48 49 50 71 72 73]

The subject cluster realizes the centralized classification of different design aspects in the design process. Although the analysis of the design development between each subject can be basically satisfied, the design analysis between the themes is difficult to meet, and the clustering results for the design topic The correlation analysis can be carried out by means of visual analysis of control values. For the eight results of CONCOR (Schwartz, 1977) clustering, the quantitative calculation of the control values is carried out. The results are shown in Table 2 and Figure 6. It can be seen from the figure, the second cluster of the highest degree of influence is 0.064, and the fourth cluster of the lowest impact value of 0.02.

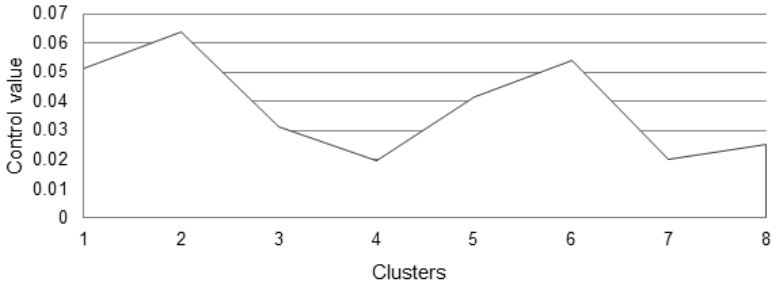

Figure 6. The degree of influence between topics

On the basis of the previous theoretical model guidance, the design of bicycle lock experiment, through the design process of cognitive data acquisition and pre-processing, the cognitive analysis of the original data. The data quantified by cognitive characteristics are presented by means of different forms of expression, which are presented in the form of cognitive information. They provide an

effective way for the analysis of cognitive connotations in design experiments, and realize the comprehensive analysis of cognition and more comprehensive and in-depth analysis. The validity of the theoretical model is validated.

5 CONCLUSION

Complex design problem solving is based on knowledge, including information stimulation, mental response and conceptual expression and other information processing. Based on the complex conceptual design process of fuzzy front end and the research on previous models, this paper puts forward the complex linkography-network model to analyse the complex structural characteristics of the design cognitive process, constructs the multidimensional design cognitive model to support for the obtaining of key concepts and intentions and the analysis of the path backtracking. According to this model, this paper proposes design cognitive method to quantify the design cognition with characteristics from the process and content aspects, with an innovative way to achieve deterministic processing of unstructured information language data, analysis and tacit knowledge acquisition, so as to realize the design cognitive characteristics calculation based on complex linkography-network model, and to provide the diagnosis and analysis method for the realization of conceptual evolution, state transition and knowledge acquisition from the perspective of natural oral reasoning. And through the bike lock design experiment, this paper analyses the design cognitive content in more comprehensive and in-depth way, and tests the validity of the theoretical model. The follow-up study will also further study the core in ill-structured problem-solving mechanism, expand the design thinking theory and method with design cognitive mechanism enrich and develop the existing complex design cognition and calculation methods and theories.

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