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# Research on Generative Design of Chinese Traditional Patterns Combining Random Clustering and Shape Grammar

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**Abstract:**
As the young generation of Chinese consumers pay more and more attention to and identify with traditional culture, the contemporary innovative design of Chinese Traditional Patterns has become a research hot spot in academia and industry. Generative design based on computer code has been widely used in architecture, automobiles, digital media, fashion and other fields, however the application of generative design technology in Chinese Traditional Patterns is still rare. Therefore, this paper tries to explore the generative design method of Chinese Traditional Patterns based on shape grammar theory on the basis of preserving the artistic characteristics of Chinese Traditional Patterns. Firstly, the cluster composition mode is extracted from the Chinese Traditional Pattern composition mode. Second, the concept of random cluster composition is proposed and its visual characteristics are analyzed by applying shape grammar. In the third step, based on the random function and shape operator, the generative design experiment of Chinese Traditional Patterns is carried out by using the visual programming language Grasshopper. Finally, a program code and a special plug-in which can automatically generate patterns are developed to verify the thesis.

**Keyword:** random cluster, shape grammar, Chinese Traditional Patterns, generative design

## INTRODUCTION

In the world, the traditional patterns of each nation contain rich cultural genes [1], Traditional patterns use simple visual symbols to symbolize the unique history and culture of each nation, such as Taiji [2] in China and Ukiyo-E [3] in Japan. In recent years, with the rapid development of globalization and China's economy and society, the young generation of China has a stronger and stronger cultural identity with their own nation, cultural consumption phenomena such as "Hanfu" [4], "cultural creation of the Palace Museum" [5], "National tide" [6] have emerged, Chinese Traditional Patterns have entered the social vision with a new look and become a symbol of the revival of traditional culture. The innovative design of Chinese Traditional Patterns has also become a research hotspot in related academic fields.

In the early 20th century, with the development of national textile industry, the academic and educational circles began to sort out and study Chinese Traditional Patterns. Scholar Pang Xunqin carried out pioneering research on traditional decoration and folk art [7]. After the founding of New China in 1949, Shen Congwen [8], Lei Guiyuan [9], Zhang Daoyi [10] and other scholars wrote monographs, systematically summarizing and sorting out Chinese silk patterns, modeling methods of traditional pattern and the classification and pedigree of traditional patterns. Since then, the study of Chinese Traditional Patterns includes the following aspects, 1. the historical development of traditional patterns [11], 2. Contemporary design of traditional patterns [12], 3. Computer aided design of traditional patterns [13]. Studies by foreign scholars include Owen Jones' Chinese Patterns [14], Minao Hayashi's Patterns of Gods and Beasts [15], Jessica Rosin's Lotus and Dragon: Chinese Patterns [16], etc.

With the continuous development of computer-aided design technology (CAD), generative design technology, which transforms design ideas into computer codes, has gradually emerged in the fields of architecture, automobile, digital animation and so on [17]. For example, Israeli architect Zaha Hadid [18] designed Aliyev Cultural Center, Dubai Museum and other special-shaped buildings. Team Lab [19], founded in Japan in 2001, has continuously developed various large-scale digital media installation art by using generative art software such as Processing and Touch Designer, which has attracted wide attention in touring exhibitions around the world. In 2017, Alibaba launched an artificial intelligence design platform "Luban" [20] to meet the demand of e-commerce during the Singles' Day, which designed posters at a rate of 8,000 posters per second.

American professor George Stini put forward the concept of shape grammar in 1972 [21]. Tashkim used the rule schema of shape grammar to represent the form composition features of historical styles of Turkish houses [22]. Professor McMack extracted the front face shape features of BUICK cars in various stages as the basis for the deduction and design of shape grammar rules [23]. Domestic scholars Chen Wei [24], Lu Zhaolin [25] and Zhao Jing [26] carried out research on the application of shape grammar in the fields of vehicle lineage design and brand gene. To sum up, there are few studies on the combination of generative design and shape grammar in Chinese Traditional Pattern design. This paper summarizes the random cluster composition pattern from the artistic characteristics of Chinese Traditional Patterns, and then explores the generative design technology of Chinese Traditional Patterns through the random number algorithm and the program code of generative design with shape grammar as the medium, and Grasshopper [27] software as the design experiment platform. The corresponding design plug-in is developed to verify the research of the paper.

## RESEARCH PATH AND METHOD

### Cluster Composition in Chinese Traditional Patterns

Definition 1: Cluster composition -- cluster composition is a pattern composition pattern summarized from the artistic features of Chinese Traditional Patterns. Cluster composition gathers several basic elements of the same or different patterns (hereinafter referred to as primitives) together to form the visual center of the pattern, Typical patterns in Chinese Traditional Patterns, such as "double fish pattern" [28], " BaoXiang flower pattern " [29], " rice character pattern" [30], and " Chinese knot pattern" [31], all belong to cluster composition, which represents the aesthetic preference of symmetry, introspection and centripetal in Chinese traditional aesthetics.

As shown in Figure 1(a) -- (d) below, it is a common design procedure to construct visual center by cluster composition in Chinese Traditional Patterns. From the perspective of Gestalt psychology [32], the aggregation of primitives forms a meaningful "graph", while the blanks around primitives form a meaningless "bottom".

Figure 1(a). Double fish patter

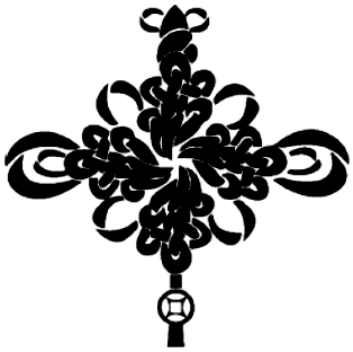

Figure 1(b). Chinese knot pattern

Figure 1(c). Rice character pattern

Figure 1(d). BaoXiang flower pattern

Figure 1. Cluster composition of Chinese Traditional Patterns

As shown in Figure 1(a)-(d), cluster composition mostly pays attention to the metric. For example, the two primitives of the double fish pattern require left-right symmetry, the rice character pattern arranges primitives

radially, the BaoXiang flower pattern requires primitives to be contained in a circle and present radial symmetry. From the contemporary aesthetic point of view, the metrical arrangement in the cluster composition is rigid, not lively and free enough. Therefore, the following will be based on the shape grammar theory cluster composition innovation.

**Shape Grammar and Shape Operator**

According to George Steini's definition, a shape grammar is a tuple of four elements, which can be expressed as:

$$SG=(S,L,R,I) \quad (1)\ [33]$$

Where S -- the finite set of shapes. L -- the finite set of deduced regular symbols (shape operators). R -- the finite set of rules for deducing (ways of applying shape operators). I -- the initial state of the deduction. Specifically, it corresponds to S -- the set of several primitives in this study. L -- the set of shape operators of the primitive, including the four shape operators of moving, scaling, rotating and mirroring. R – the set of rules for the use of shape operators in cluster composition, including how to distribute the primitive on the specified surface, how to move, scale, rotate, mirror and other shape calculation of each primitive. I - the initial blank format.

Based on the shape grammar shown in formula (1), combined with the concept of cluster pattern in Definition 1, aiming at the deficiency of metrical composition in Chinese Traditional Patterns, the concept of random cluster composition is proposed.

**Definition and Characteristics of Random Cluster Pattern**

Definition 2: Random cluster composition -- Random cluster composition distributes a number of cluster centers randomly on the pattern surface and a number of primitives randomly around the cluster center. Each primitive is randomly scaled, rotated, mirrored and other shape calculations to produce a composition pattern that not only retains the artistic characteristics of Chinese Traditional Patterns, but also has the design semantics of contemporary patterns such as lively, free, and spontaneous design. Random cluster composition is also known as random cluster pattern.

Taking pine leaf pattern [34] in Chinese Traditional Patterns as primitive, three pattern composition methods of pine leaf pattern, namely metrical composition, random composition and random cluster composition, are compared to analyze different artistic features, as shown in Figure2 (a) - (c) below.

By comparing Figure 2(a) and Figure 2(b), it can be seen that the random distribution composition in Figure 2(b) is livelier and freer than the metrical distribution composition in Figure 2(a). Compare Figure 2(a), Figure 2(b) and Figure 2(c), It can be seen that the two composition modes in Figure 2(a) and Figure 2(b) only have two visual levels: 1. the blank part as the base of the pattern, 2. pine leaf pattern part as the picture part. The random cluster composition in Figure 2(c) forms three levels of the pattern,1. blank part as the base, 2. three clusters, 3. pine leaf pattern in the cluster. The three clusters form three visual foci respectively, and the flow of sight is formed between the three visual foci. Therefore, the visual level and visual information of the random cluster composition pattern are richer than that of the metrical composition and the random composition.

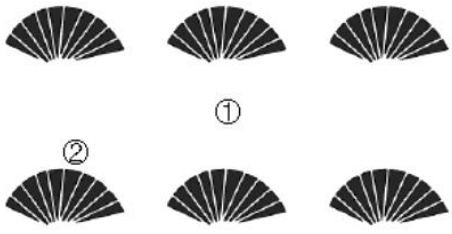


Figure 2(a). Metrical composition of pine leaf pattern

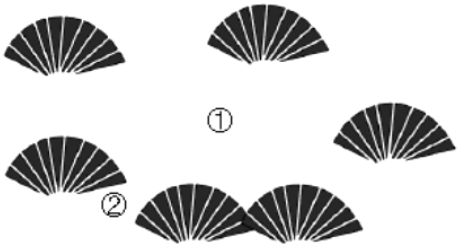


Figure 2(b). Random composition of pine leaf pattern

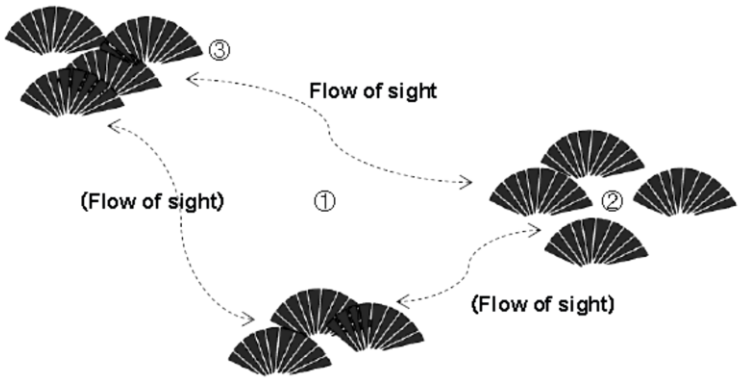


Figure 2(c). Random cluster composition of pine leaf pattern
Figure 2. Characteristics of random cluster pattern of Chinese Traditional Patterns

Figure 2(a) - (c) only adopts the moving operator defined by formula (1), but does not adopt the other three shape operators. Due to the characteristics of human thinking, it is difficult to achieve real random composition, and it will be very redundant and inefficient to design random cluster patterns by hand. The main work of designers should be to formulate the design framework, judge the design quality and adjust the design direction and other decision-making content. Therefore, based on the programming language of generative design Grasshopper, this paper adopts the research idea of "random function" and "shape grammar" to carry out the generative design experiment of random cluster pattern, in order to explore the intelligent and automatic design innovation technology of Chinese Traditional Pattern.

**Generative Design Experiment of Random Cluster Pattern**

Compared with manual design, the significance of using program to generate random cluster patterns is as follows: 1. by adjusting the random number seed and numerical intervals, a large number of patterns can be automatically generated, which can greatly improve the design efficiency, and reduce the designer's heavy and repetitive labor. 2. the task of automatic pattern generation is given to the computer algorithm, and the designers are mainly screened from a large number of patterns generated by the computer, and adjust the relevant design parameters. Through the reasonable division of labor of human-computer interaction, the designers are more focused on the design process of decision; 3. The generative design of random cluster pattern can internalize the designer's design concept and design idea into the program code through the algorithm, such as the composition skeleton of the pattern, the proportion relation, the color matching method, and so on, to form the design framework of the pattern.

***Experimental principle of generative design of random cluster pattern***

*Uniform distribution and random function*

If the density function of random variable X is P (X) [35], its distribution function is F(X), which satisfies the following formula (2).

$$p(x)=\begin{cases}\frac{1}{b-a}, & a<x<b\\ 0, & x\le a \text{ or } x\ge b\end{cases} \qquad F(x)=\begin{cases}0, & x<a\\ \frac{x-a}{b-a}, & a\le x<b\\ 1 & x\ge b\end{cases} \tag{2}$$

Then X is said to follow the uniform distribution on interval (a,b) [36], denoted as X ~ U(a,b), where U(0,1) is called the standard uniform distribution. The distribution of the cluster center of the random cluster pattern on the pattern canvas (two-dimensional rectangle) (where the two-dimensional interval [x, y] can be mapped to the linear interval of the one-dimensional [x]) and the distribution of the primitives around the cluster center (taking the cluster center as the center of the circle and distributing on the circumference of several concentric circles) are uniform. Similarly, the random rotation Angle, random scaling coefficient and the number of primitives is uniformly distributed in a linear interval.

At present, Linear Congruence Generator [37] (LCG) is used to generate pseudorandom numbers in various computer programming languages [38]. Linear Congruence Generator, proposed by Lehmer in 1951, uses the principle of congruence operation in number theory to generate random numbers, as shown in Formula (3).

$$x_{i+1} = (ax_i + c)MOD(m) \quad (3)$$

Where a is the multiplier (constant), c is the increment (constant), X0 is the random number seed, and M is the modulus. Using the linear congruence method to generate random numbers, if the random number seed is the same, the random number sequence will be the same. In computer programming, the random number seed is generally from the system clock (timing/counter value), and electrical noise, CPU temperature, mouse path and so on are used as the random number seed. However, in the generative design program of random cluster pattern in this paper, in order to facilitate the designer to control and adjust the shape of the pattern, the random seed comes from the user through the keyboard and mouse input value.

*Combination of random function and shape operator*

Based on the random function in formula (3), the random function is combined with the four shape operators in formula (1), as shown in Figure 3(a) -- (d) below. Figure 3. (a) Generate 6 positions on the canvas by random function, and then move the primitive (Deer pattern [39]) to these 6 positions. On the basis of Figure 3(a), each primitive is randomly rotated in Figure 3(b), and the rotation Angle of each primitive is generated by a random function. On the basis of Figure 3(a), each primitive is randomly scaled in Figure 3(c), and the scaling ratio of each primitive is also generated by random function. On the basis of Figure 3(a), three of the primitives among six primitives are randomly selected to be mirrored in Figure 4(d), and the remaining three remain unchanged.

Figure 3(a). Combination of random function and moving operator

Figure 3(b). Combination of random function and rotating operator

Figure 3(c). Combination of random function and scaling operator

Figure 3(d). Combination of random function and mirroring operator

Figure 3. Combination of random function and shape operator

***Generative design experiment process of random cluster pattern***

On the basis of Formula (1) - Formula (3) and Figures. 2(c) and 3(a) - (d), the random function is combined with the shape algorithm, The generative design experiment of random cluster pattern includes the following steps: 1. Find the right development tools according to the program flow, and write the program. 2. Using the random function algorithm to find the shape and adjust the pattern shape. 3. Code integration, developing special plug-in for random cluster modeling of Chinese Traditional Pattern design.

*Development tool of generative design of random cluster pattern*

Grasshopper, the mainstream generative design programming language in the current design field, is used for program development. Grasshopper is a functional plug-in in Rhino, a 3D design software, which is widely used in the fields of architecture, clothing and household. Grasshopper is also a visual programming language, which can establish data processing logic through the connection between various predefined "batteries" (data processing modules), form data flow and generate defined graphics.

*Algorithm shape finding for generative design of random cluster pattern*

In the generative design of random cluster pattern, the program code can automatically generate a large number of patterns. But do computer-generated patterns work? In this regard, designers need to make manual intervention, judgment and decision, and carry out scheme adjustment to achieve man-machine collaboration in generation design of random cluster pattern [40]. By adjusting the interval of the random function and the seed of the random function, the improvement and optimization of design scheme was achieved, this process is called "algorithmic shape finding".

*Design plug-in for generative design of random cluster pattern*

In the generative design process of random cluster patterns, designers need to constantly interact with computer to timely adjust the pattern automatically generated by the computer. However, most pattern designers do not have the background knowledge of Grasshopper programming language, so it is necessary to package various modules and batteries as a whole. To shield users from the complex logic connections inside the program, a design plug-in of generative design of random cluster pattern for designer is developed. For the designer, the visible parts of this plug-in need to include: 1. input of primitives, 2. input of canvas size input, 3. the various random number intervals and random number seeds of the algorithm for shape finding, 4. the output of random cluster pattern.

## RESEARCH RESULTS

The experimental results of the program development for generative design of random cluster pattern include two parts: 1. the Design plug-in of generative design of random cluster pattern, 2. Modeling steps and design results of the program for generative design of random cluster pattern.

### Design Plug-in of Generative Design of Random Cluster Pattern

The generative design program of random cluster pattern starts with a design plug-in, as shown in Figure 4 below. The left side of the plug-in contains 38 input options, except for the input of three primitives and two canvas dimensions. The remaining 33 input options are various adjustable design parameters (such as the number of clusters, the random distribution location of clusters, etc.), random number intervals, and random number seeds. On the right side of the plug-in is the output, including the pattern canvas and 3 set of primitives processed. By coloring the canvas and primitives, the final random cluster pattern can be obtained.

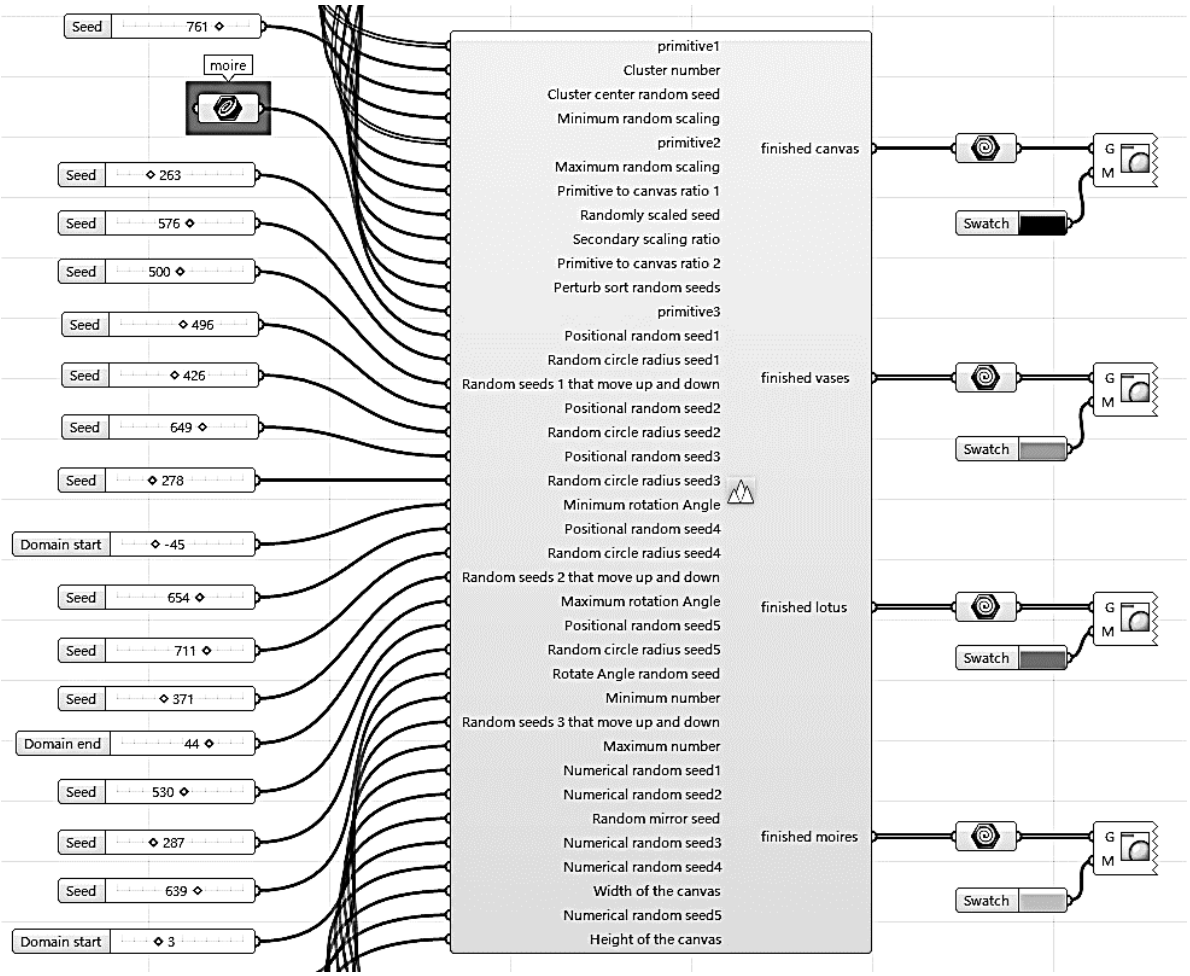


Figure 4. Design plug-in for generative design of random cluster pattern

**Modeling Steps of Generative Design of Random Cluster Pattern**

In order to show the operation mode of the generative design program of random cluster pattern more intuitively, the modeling steps and design results of generative design of random cluster pattern are presented as shown in Figure 5(a)-(d) below.

Figure 5(a) is the beginning of the program. On the left side of the plug-in as shown in Figure 6, three pattern primitives (Bogu bottle pattern, lotus pattern and auspicious cloud pattern) and the size of the pattern canvas are input, and then the three primitives are pre-scaled according to the size of the canvas. In Figure 5(b) 5 cluster centers were first randomly generated on the canvas. In the second step, a concentric circle group with 3 layers of random radius was generated around the center of each cluster. In the third step, the distribution points were randomly generated on the concentric circle group.

In Figure 5(c) the points with too small spacing among random points are firstly removed. In the second step, the random point sorting is scrambled and divided into 3 groups evenly. In the third step, the three groups of primitives are moved to the random distribution point. In Figure 5(d) firstly the primitive of Bogu bottle is randomly scaled. In the second step, the primitive of lotus pattern is randomly rotated. In the third step, the primitive of auspicious cloud pattern is randomly mirrored. In the fourth step, all primitive processed is scaled again into the canvas. In the fifth step, the three groups of primitives are randomly move along the height direction. Finally, the three groups of primitives and canvas were colored respectively.

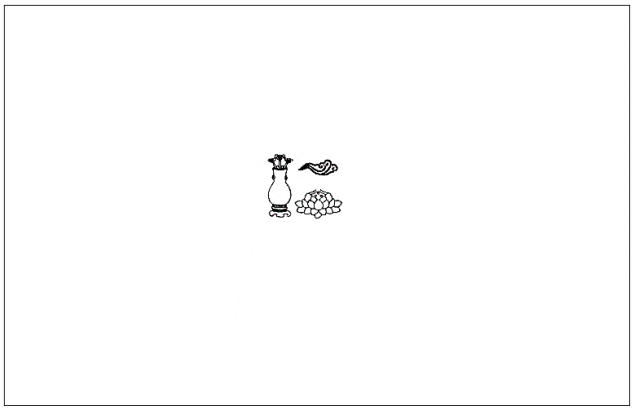

Figure 5(a). Operation results of three functional modules, input primitives, input canvas and primitives pre-scaling

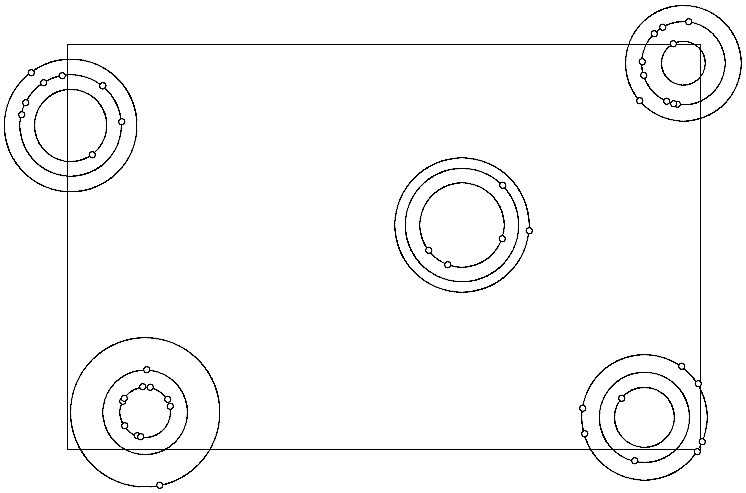

Figure 5(b). Operation results of six functional modules (including other auxiliary modules), the center of random cluster, the radius of random circle, seed of random circle radius, random points on concentric circles, random value of the position on the circle and number of random points in each group.

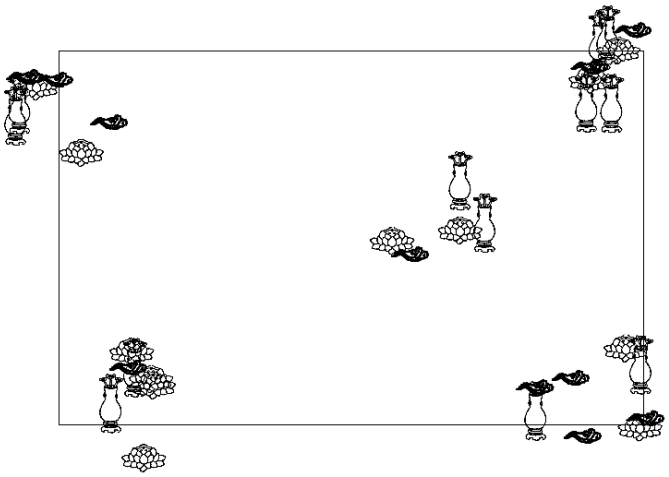

Figure 5(c). Operation results of three functional modules (including other auxiliary modules), removing too small spacing points, Central point of primitives' distribution, and movement distribution of primitives.

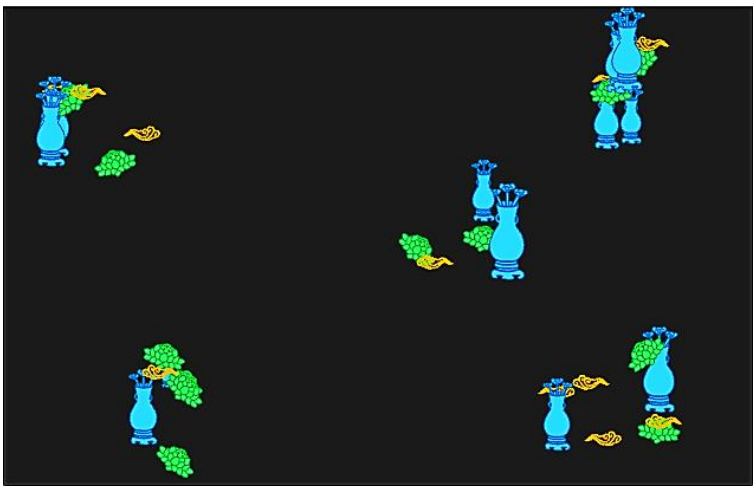

Figure 5(d). Operation results of six functional modules (including other auxiliary modules), random scaling of primitive, random rotating of primitive, random mirroring of primitive, re-scaling of primitive inside canvas, grouping of primitives, and Random occlusion between primitives.

Figure 5. Modeling steps of generative design of random cluster pattern

## CONCLUSION AND DISCUSSION

The thesis mainly completes the following research, 1. summarizes the composition patterns of Chinese Traditional Patterns, puts forward the concept of cluster composition, and puts forward the definition of random cluster pattern based on the theory of shape grammar. 2. The uniform distribution of random variables, random functions and shape operators are combined as the experimental principle of generative design of random cluster patterns. 3. Based on Grasshopper visual programming language, a special design plug-in of random cluster pattern is developed through the steps of program flow analysis, function module design and algorithm shape finding.

The paper finds that the pattern of cluster composition in traditional patterns adopts a rigid metrical arrangement and not suitable for contemporary cultural and aesthetic preferences, therefore, based on the theory of shape grammar, this paper puts forward the concept of random cluster composition by taking the modeling methods such as moving, scaling, rotating and mirroring commonly used in contemporary pattern design as shape operators. Comparing random cluster composition with metrical composition and random composition, the visual characteristics and design advantages of random cluster pattern are analyzed.

Taking random cluster pattern as the entry point, this paper introduces generative design technology into the contemporary design of Chinese Traditional Pattern. Taking bogu bottle pattern, lotus pattern and auspicious cloud pattern as primitives, Grasshopper programming language as tool, the generative design experiment of random cluster pattern is carried out. Design plug-in for random cluster pattern design is developed. The whole code of the plug-in and the code of functional modules in the plug-in can be transplanted to other pattern design programs to achieve design reuse.

With the development of computer-aided design technology, the current pattern design has been carried out in Illustrator, AutoCAD, Photoshop and other computer software, but this design software is still the essence of drawing tools, but the traditional brush has been replaced by the mouse and keyboard. Based on the design plug-in of random cluster pattern, the generative design program developed in this paper can assign the task of drawing pattern to the computer automatically, while designers focus on the formulation of design framework, Screening design scheme, adjusting design parameters and other decision-making work, which can improve the efficiency of pattern design, to achieve a reasonable man-machine division of labor.

Due to the limitations of the author's research level, the variety of Chinese Traditional Patterns is very rich and diversified, and the artistic characteristics are also very complex and diverse, so there are some shortcomings in the research of this paper. Firstly, the concept of cluster composition and random cluster pattern proposed in this

paper comes from the author's research and induction, which lacks the definition of authoritative scholars. 2. There are too many adjustable design parameters for the design plug-in of random cluster pattern, and too many options will lead to combination explosion. 3. In the generative design program of random cluster pattern, the lack of design rules to intervene in the generative algorithm leads to the difficulty of internalizing the design concept of some designers in the program. These questions will be improved in the subsequent study.

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