Emergent Design System Using Computer-Human Interactions and Serendipity

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***Abstract*— This paper describes a basic study on an emergent design system in which serendipity occurs from interaction between computer and human. Serendipity is a natural ability to unexpectedly make interesting or valuable discoveries. The possibility of generating new design ideas will increase if we can utilize serendipity. Therefore, we propose an emergent design system that produces serendipity by using form organizing phenomenon seen in nature and three-dimensional modeling like clay-modeling. Then, we perform elementary experiments with designers. Thus, this system prompts the chances of getting inspirations and unexpected discoveries in the process of deriving ideas. As a result, we show the possibility of generating new design ideas by using this system.**

Keywords-emergence; design system; interaction; serendipity

I. INTRODUCTION

The design process can be roughly divided into two categories: the early process which consists of conceptual and basic designs, and the late process which consists of detailed design [1]. In the early process, novel and diverse design ideas must be obtained from a global solution search under unclear design conditions. Thus, in previous study, we propose an emergent design system. This system is based on the concept of emergence, which is a natural phenomenon that creates diverse organism. We demonstrate diverse design proposals are derived using the system [2]. On the other hand, designer's experience and knowledge earned through trial and error are the key elements in designing. When highly-experienced designers generate design ideas using a representation method, such as a sketching or clay modeling, sometimes unexpected values are discovered by chance. This ability to find something interesting or valuable by coincidence is called serendipity [3]. A previous study on serendipity reported that design ideas not originally envisioned by the designer emerge when designers are devoted to sketching [4]. Therefore, design proposals derived by the emergent design system should enable designer's serendipity to occur.

In this research, an emergent design system which uses computer-human interactions is proposed to support idea generation. This system consists of two fundamental functions: a self-organizing function based on the concept of emergence, and a three-dimensional modeling function imitating clay modeling. During the iterations of these functions, designers should be inspired by self-organizing design proposals. Therefore, generating novel and valuable design ideas will become easier. Additionally, we conduct elementary experiments to test the effectiveness of this system. As a result, we confirm the possibility that the proposed system has ability to support the idea generation.

The paper's structure is presented as follows: first, we describe about the concept of emergence, and propose an emergent design system. Then, we describe about the methods and the results of elementary experiments. Finally, the results are examined and our conclusion is presented.

II. EMERGENCE AND EMERGENCE DESIGN

In nature, various organisms exist in the same environment. In the fields of biology and ecology, scientists have hypothesized that various species have been created through the process of emergence. The concept of emergence is as follows: a new function, the character, and the action acquired by an interactive dynamic process where global order appears by local interactions between individuals, which behave autonomously, with the environment. On the other hand, this order restrains the behavior of an individual [5]. Herein, the appearance of global order is a bottom-up process, whereas the process of restraining individual behavior is a top-down process.

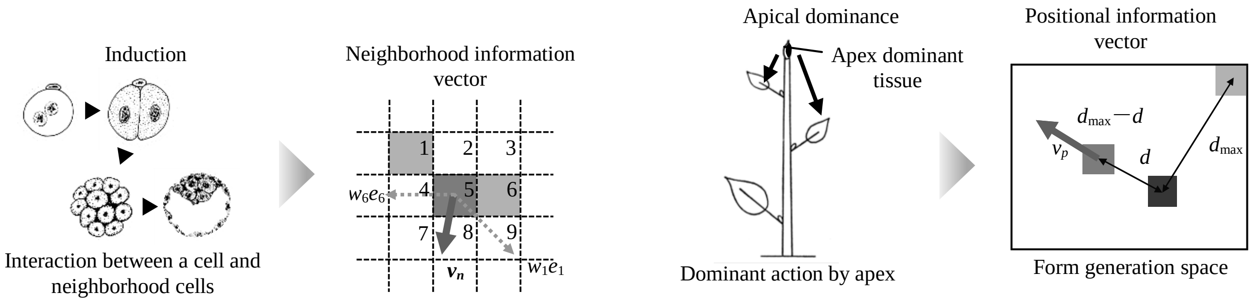
There are two similarities between the early design process and the emergence process. First, the process to generate design ideas through evaluation using certain standards is similar to the bottom-up process which generates the entire feature by the interaction of autonomous components in emergence. Second, the process to optimize detailed parts of the design proposal is similar to the top-down process, which binds the components by entire feature in emergence. Thus, the concept of emergence may be applicable to design, and diverse novel design proposals can be derived by "emergent design" where bottom-up and top-down processes interact.

III. EMERGENT DESIGN SYSTEM

In this section, first the previous emergent design system is described. After that, an emergent design system which uses computer-human interactions is proposed.

A. Previous Study in Emergent Design System

The emergent design system consists of bottom-up process and top-down process. In the bottom-up process,



(a) Induction (b) Apical dominance

Figure 1. Model of the input vectors

diverse design proposals meeting the low standard set by the designer are derived by self-organizing, while the top-down process satisfies the constraint conditions, and optimizes proposals that satisfy the constraints. This system derives diverse designs by going through these two processes.

1) Bottom-up process: In the bottom-up process, forms are generated self-organizationally using Cellular Automata (CA) [6]. In the incidental method, the states of cells in the lattice are updated following a local rule. More specifically, at time *t*, the state of an element is S_t and the state of the neighborhood (mostly Von Neumann neighborhood or Moore neigborhood) is N_t. The state of the element at time *t*+1 describes as

$$S_{t+1} = f\,(S_t, N_t) \tag{1}$$

where, *f* is the transition function which influences the behaviors of the elements.

In the emergent design system, the diversity of an organism is noted, and rules refering to two propoerties for diverse organism morphogenesis, "induction" and "apical dominance", are the input vectors for the CA [7].

An organism is formed by interactions between neighborhood cells. These neighborhood cells affect each other, causing a cell to change and exhibit different features (Figure 1(a)). This property is called 'induction'. The first input is defined as the neighborhood information vector $\boldsymbol{v_n}$, which is expressed as

$$\boldsymbol{v_n} = \sum_{i=1}^{26} b_i w_i \boldsymbol{e_n} \tag{2}$$

where, *i* is the surrounding element number, b_i indicates the existence or non-existence of an element (1 or 0), w_i is the coefficient of the vector direction, and e_i is the unit vector of the direction to the object element.

In the developmental process, a certain tissue dominates, such as the bud of a plant or the head of an animal. Such tissues are called the apex, and the dominant action by the apex is called 'apical dominance' (Figure 1(b)). The second input is defined as the positional information vector $\boldsymbol{v_p}$, which is expressed as

$$\boldsymbol{v_p} = (\,d_{\max} - d\,)\boldsymbol{e_d} \tag{3}$$

where, d_{max} is the distance between the apex and the most distant cell from the apex, *d* is the distance between the apex and the object element, and $\boldsymbol{e_d}$ is the unit vector of the direction to the object element. Moreover, the form operating parameter *k* is set and input vector $\boldsymbol{v_{in}}$ is defined as expressed in Eq. (4).

$$\boldsymbol{v_{in}} = k\boldsymbol{v_n} + (1-k\,)\boldsymbol{v_p} \tag{4}$$

Diverse forms can be generated by changing the form operating parameter *k*. If the value of *k* is near unity, then induction tends to strongly influence *k*. In contrast, if *k* is near 0, then *k* is strongly influenced by apical dominance, and a rhomboid or board form tends to be generated. The input parameters in the bottom-up process are the position of apex, form operating parameter *k*, form generation space, element size, initial element, and evaluation item. The apex position becomes the center of action for apical dominance, and the form generation space is a space that allows CA to be generated. The element size is a voxel and is composed of form. Thus, reducing the element size causes the output to be in a detailed form. The initial element position is where the form generation of CA begins. Thus, diverse design proposals are generated self-organizationally in the bottom-up process.

2) Top-down process: In the top-down process, diverse design proposals generated by the bottom-up process are optimized or modified to satisfy design constraints such as strength or stiffness. For example, the modification method by increasing and decreasing elements, which is inspired by an adaptive function of bone remodeling, is applicable [8].

B. Emergent Design System Using Computer-Human Interactions

We propose an improved emergent design system to support idea generation. Figure 2 shows the flow of the proposed emergent design system. This emergent design system consists of incidental form generation and representation methods. Induction and apical dominance, which are concepts from the previous design system, are

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used in self-organizing form generation because these self-organizational concepts enable serendipity.

1) Generate self-organized form in real time: We reconstruct an emergent design system with the Processing programing language, which is benefical to create images, animations, and interactions. In this system, we can see the form generating in real time by increasing elements autonomously. There are two ways to generate forms autonomously. First, selecting a element, and increase elements (Figure 3(a)). Second, elements which increased at last step become the trigger of self-organization. These functions should enable designer's serendipity to occur by revealing diverse and incidentally derived forms.

2) 3D-modeling like clay modeling: In this section, we describe the representation method, which designers can use to generate design ideas. Representation methods are used not only to visualize specific design concepts, but also to convey designers intentions and to adjust design concepts. Our research focuses on a three-dimensional modeling, e.g., clay-modeling, to establish a public image of an idea. In this system, forms can be modified by adding or deleting elements (Figure 3(b)). In order to add elements, you should select an element, subsequently elements at Von Neumann neighborhood or Moore nighberhood will increase. By selecting elements, you can delete the elements.

Three-dimensional models provide information such as depth, which is not intuitive in two-dimensional models. Additionally, through trial and error with representation methods, the likelihood of new ideas from chance or serendipity increases. Hence, three-dimensional representation methods can create new design ideas as well as improve visuospatial cognition.

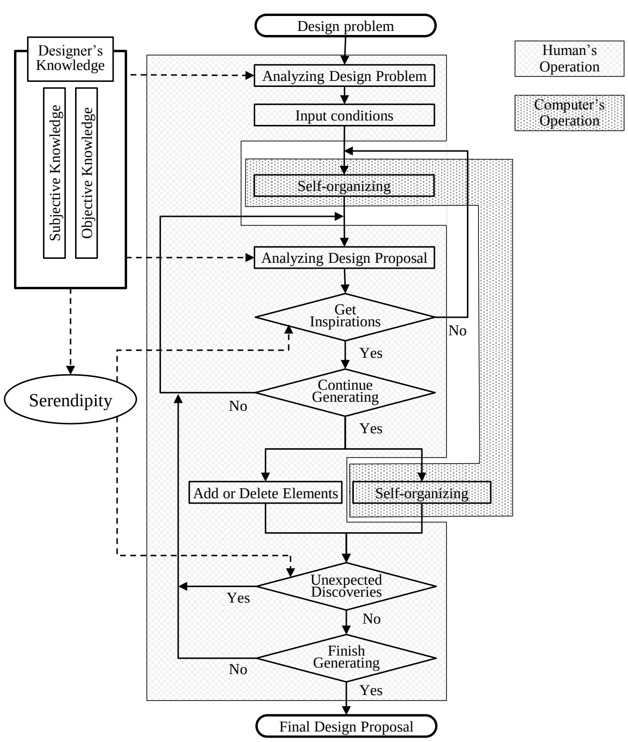


Figure 2. Flow of the emergent design system

IV. Elementary Experiments

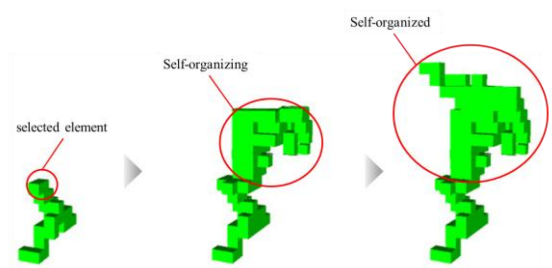
In this section, we describe elementary experiments to test the effectiveness of the system.

A. *Experimental Condition and Methodology*

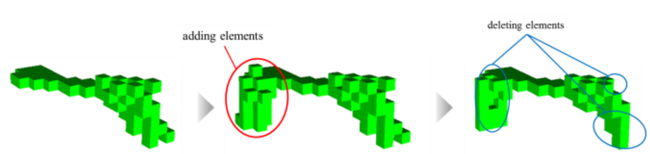
We conduct form generation experiments to clarify the features and effectiveness of the proposed system, including the occurrence of serendipity. In this experiment, we use a chair as a design object. Because a chair design must consider structural features of material mechanics or mechanical dynamics as well as industrial design, a chair is an appropriate application for a basic study to evaluate design idea generation. Four subjects, who are professional designers, participated in the study.

Design proposals are derived using introduced functions via two different patterns. In pattern 1, an initial form, which means the basic form of idea generation, is generated autonomously, and a design proposal is derived using three-dimensional modeling. In pattern 2, an initial form is generated autonomously same as well. Then a design proposal is derived using a three-dimensional modeling and self-organizing form generation. Finally, in both patterns, each subjects draw design ideas within their mind induced by using the system.

Herein the form operating parameter k is set at three levels; 0.1, 0.5, and 0.9. For each ratio, two design proposals are derived by each subject. Then, overall 48 design proposals are derived. To analyze the process of deriving design proposals and characteristic forms, the number of times serendipity occurs is counted: the number of times subjects change his design concept influenced by inspirations and unexpected discoveries. For the same reason, we write



(a) Self-organization from selected element



(b) Add and delete elements

Figure 3. Examples of form generation

down the remarks of subjects while they are generating design proposals. Additionally, we asked the subjects about the usability of this system after the experiments.

B. Evaluation of the Proposed System

Figure 4 shows the examples of the final design proposals derived by the proposed system, and Table 1 shows the number of times serendipity occurs. To clarify the characteristics of the proposed system, we analyze the results from three different perspectives: influence of form operating parameters, influence of form generating pattern, and differences between proposed system and previous system. Analysis from these three perspectives can determine whether the proposed system efficiently supports design idea generation.

1) Difference of form characteristics related to input parameter: To analyze the difference of the form characteristics related to the form operating parameter *k*, design proposals are derived for three different form operating parameters; 0.1, 0.5, and 0.9. Figure 5 shows examples of derived design proposals for each form operating parameter. When parameter is set to 0.1, rod shaped design proposals are derived. In addition to rod shape proposals, aggregated forms are derived when it is set to 0.5. When it’s set to 0.9, aggregated forms with numerous elements are derived. Consequently, most design proposals depend on the initial form when form operating parameter is set to 0.9. Similar to the previous system, the value of the form operating parameter controls the form characteristics of the derived design proposals. Thus, the parameter affects the form characteristics of the derived design proposals in proposed system.

When we asked the subjects which form operating parameter provides more inspiration and discoveries, most indicated that it is difficult to judge. However, one subject indicated the process depends on the form operating parameter, confirming the initial form affects the form generation process: increasing elements, or decreasing elements. When form operating parameter is set to 0.9, the system produces aggregated forms, and they are the most geometrically similar forms. Hence, the value of the form operating parameter affects the chance of finding inspiration and discoveries. One method to improve control using the form operating parameter is to restrict the surplus increase in the number of elements. Additionally, one subject suggested changing the form operating parameter while deriving design proposals, indicating that the proposed system needs a new function to change the value of the form operating parameter.

2) Difference of form characteristics related to the form generation pattern: In the experiments, two patterns are used to generate forms. Pattern 1 employs a three-dimensional modeling as a representation method, while pattern 2 uses both three-dimensional modeling and self-organizing.

Figure 6(a) shows the process and final design proposals derived by designer B in pattern 2. Table 2(a) contains the remarks of designer B. Although the proposals are as designer B intended, he does not comment on inspiration or unexpected discovery during the experiment. Similar to Figure 6(a) and Table 2(a), Figure 6(b) and Table 2(b) show the process and proposals and comments of designer B in pattern 2,

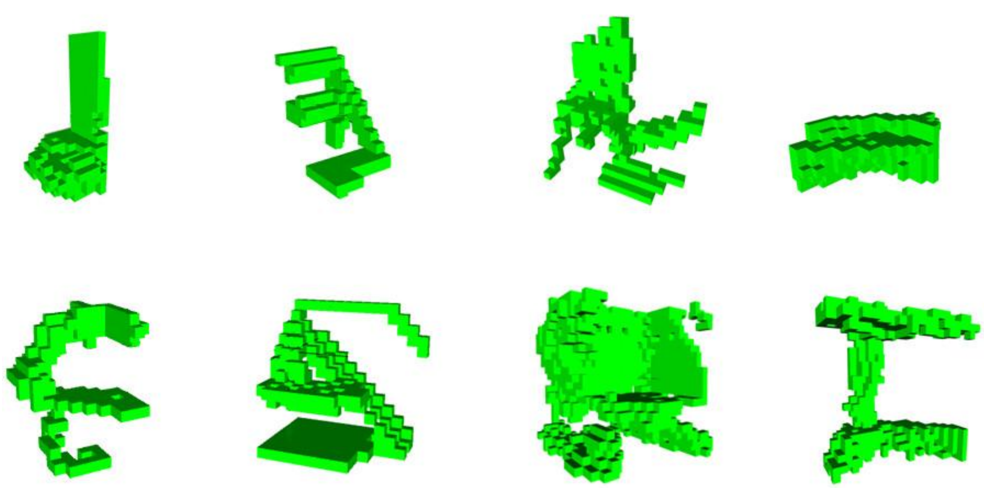


Figure 4. Examples of the derived design proposals

TABLE I. THE NUMBER OF TMES SERENDIPITY OCCURS

		Subject A				Subject B				Subject C				Subject D			
		Pattern 1		Pattern 2		Pattern 1		Pattern 2		Pattern 1		Pattern 2		Pattern 1		Pattern 2	
k	0.1	2	1	1	1	0	0	0	0	2	1	2	2	3	1	5	1
	0.5	0	0	0	0	0	0	1	0	0	0	2	1	0	3	0	0
	0.9	1	1	0	1	0	1	0	0	0	1	0	0	1	1	1	0

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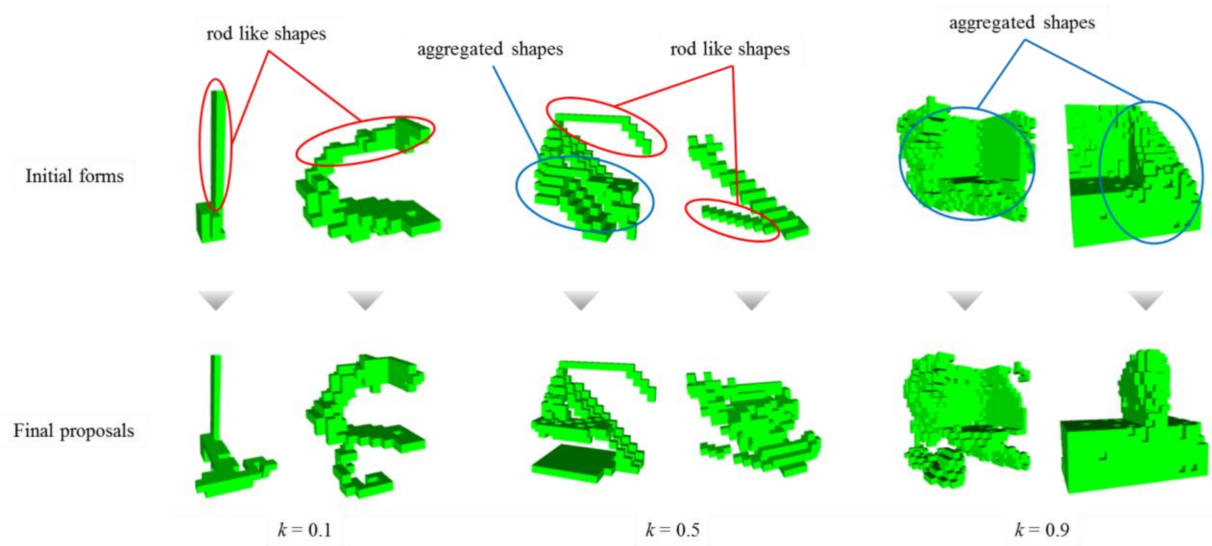

Figure 5. Differences in form operating parameter

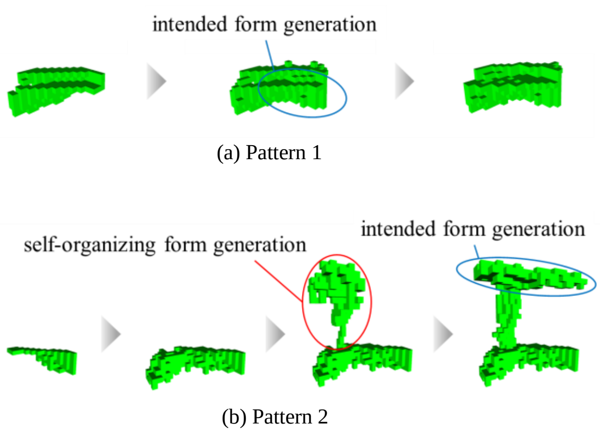

Figure 6. Differences in form generation pattern

TABLE II. REMARKS DURING THE EXPERIMENT

(a) Pattern 1

Process	Remarks
Initial Form	"It's like a bench."
Process	"Need legs for stability."
Final proposal	"Bench at park."

(b) Pattern 2

Process	Remarks
Initial Form	"It's like a bench."
Process 1	"Need more space for several people."
Process 2	"Use this form for the roof."
Final proposal	"Bench with a big roof."

respectively. The inclusion of the self-organized form generation function inspired a new idea, which designer B used to derive a novel design proposal.

We asked which pattern provides more inspiration and discoveries during the experiments. All four subjects answered that pattern 2 provokes inspiration and discoveries. Although there are no significant difference between pattern1 and pattern 2 as Table 1 shows, there is the potential that generating forms self-organizationally yields unexpected novel forms, inspiring new design ideas. Thus, the subjects uses serendipity in pattern 2 because serendipity more likely occurs when using two form generation functions (representation and self-organizing). Hence, results of the experiment and interviews demonstrate that increasing of chance leads to unexpected discoveries.

3) Use of serendipity: Figure 7 shows design proposals of chair derived by the previous system and the sketches of design ideas generated from the proposals. Although designer can generate a design idea by watching the derived proposal, serendipity happens once, if it occurs at all. Figure 8 shows the process of deriving a design proposal by proposed system and the sketch of design idea generated from the proposal. Table 3 shows the remarks during the experiment. The subject used serendipity several times, and various inspiration and discoveries helped generating ideas, confirming that the proposed system allows forms to be generated as designers intended and serendipity emerges during the process.

We asked the subjects which system is easy to generate new design ideas. Half of the subjects answered that the proposed system is easier, but the other half stated that they

Figure 7. Design ideas generated from the previous system

TABLE III. REMARKS DURING THE EXPERIMENT

Process	Remarks
Initial form	"Use self-organization."
Process 1	"Delete elements to make sitting position."
Process 2	"Use self-organization to make a leg."
Final proposal	"An artistic chair."

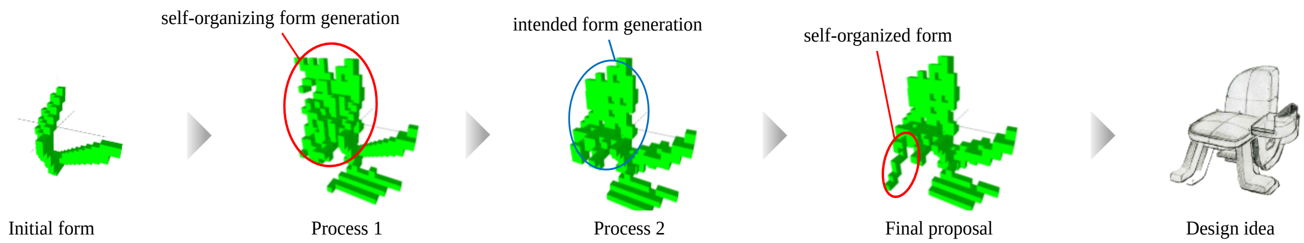

Figure 8. Design idea generated from the proposed system

could not judge. According to designer D, "The proposed system provides chances of finding inspirations and discoveries, generating new design ideas. However, the design idea depends on the final design proposals, which is why it is difficult to say which system is easier to generate new design ideas." Compared to the previous system, the proposed system provides more serendipitous opportunities for inspiration and discovery, but the unfinished design proposals are rejected. Consequently, it is concluded that new design ideas are easier to generate using the proposed system.

V. CONCLUSION AND FUTURE WORK

Herein an emergent design system which uses computer-human interactions is proposed. Additionally, generation experiments to analyze the effectiveness of the system were performed. Compared to the previous system, novel and valuable design ideas are easier to generate in the proposed system. The achievements of this research are described below.

- By enabling interactions in the emergent designs system, designer can generate intended forms via representation method.
- Indicating that both self-organization and representation method help designers to generate novel and valuable design ideas by inspiring designer's serendipity.
- Confirming the possibility that the proposed emergent design system has ability to support the idea generation through iterations of self-organization and representation.

For future researches, we should clarify the mechanisms of how serendipity occurs by studying representation methods which can inspire designer's serendipity. Then, further experiments with larger quantity of subjects to derive statistical consequence should be conducted.

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