FLUCTUATING PATTERNS OF ARCHITECTURE FAÇADE AND THEIR AUTOMATIC CREATION

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Abstract. Today, buildings with monotonous façade fill the city. However, many buildings which the elements constituting their façade are changed were seen in work designed by architects. This paper aims at examining the potentiality of automated fluctuating design creation focused on architecture façades, by analysing the design trend of architectural fluctuating designs and creating a fluctuating façade automatically based on the analysis.

Keywords. Automatic creation; fluctuation; façade design

1. Introduction

In the 20th century, buildings with monotonous façade filled the city under the influence of the International Style and advancing industrialisation in architecture, which lead the buildings to be built from the combination of standardised modules. Therefore, the cityscape also became monotonous and boring. In the present age, it is a problem how to realise rich, varied design while still inheriting the method of geometric design.

Meanwhile, it is known that making changes in a simple repetition of modules create richness. The research on relation between "fluctuation" and human sensitivity from around 1970 is one of the early researches on changes of the rhythm (Musha, 1980). If a figure is regarded as a spatial wave, spatial power spectrum can be computed. Here, it is known that we feel something is beautiful if the power spectrum is proportionate to a fraction of frequency because it sympathises with human sensitivity. The products using the "1/f theory", for example lighting design and wallpaper design are manufactured. In architectural design, from the 1990s, recently well-known architects such as MVRDV and Kazuyo Sejima announced architectural works that adopted such "fluctuation" intentionally, and many designs of "fluctuation" can be seen now all over the world.

However, it is necessary to draw quite a number of lines in hand drawing when designing buildings. Therefore it tends to take much time in order to create many designs, and so it is easy to become monotonous. On the other hand by using computer, it is possible to create fluctuating design easily and display many results in a brief time.

In the research using fluctuation, Kamei and Tsukio (1992) presented the potential of streetscape analysis by quantifying the shapes of the skylines and analysing the relations between the fluctuation of skylines and human sensitivity. Kamei (1993) and Onitsuka and Miyake (2006) evaluated the streetscapes by quantifying the images of the streetscape by two dimensions FFT. Hayami and Goto (1997) presented the potential to evaluate the sequential streetscape quantitatively by using Fourier transform to the wave form of the shade of images. Tsunematsu, Hunakoshi and Tsumita (2001, 2005) compared streetscapes by extracting the “fluctuating elements” and defining the fluctuating degree, and analysed the relation between the fluctuating degree and the sensitivity of the streetscape using the SD method. Although the analysis about fluctuation of streetscape are done in many researches as presented, but there are only a few researches about the fluctuation of façade. Also, these researches are analyses of the present situation, and they don’t make models to make new suggestion.

In this paper, from the architectural designs which were announced, the cases which avoid monotonousness and realise new rich façade design by using “fluctuation” are examined. The fluctuating patterns in the architectural designs are extracted and categorised, and then the combinations of categories used are clarified. Furthermore, an attempt is made to create architectural façade using fluctuation automatically by computer programming, taking notice of the typical fluctuating façade pattern chosen from the case study. This attempt aims at examining the potentiality of automated fluctuating design creation focused on fluctuating architecture façade design by computer programming.

2. Classification of fluctuating façade

2.1. COLLECTION OF CASES

Architectural façade is composed of various parts and elements, for example windows, structure members such as pillars and slabs, and equipments such as lattices and signboards. The impression of building will change greatly by changing the sizes, shapes and arrangement of these elements. This paper defines “fluctuating façades” as façades which have changes in the elements, compared to the “normal” façades with elements of same sizes, shapes and intervals.

First, the case study was done in order to clarify what kind of façade designs exist in fluctuating façades.

The architectural design cases with intentionally fluctuated façades were collected from Japanese architectural journals, “Shinkenchiku” and “a+u”. As a result a total of 270 cases, 158 cases from “Shinkenchiku”and 112 cases from “a+u,” were collected.

2.2. CLASSIFICATION OF FLUCTUATING FAÇADE

The patterns of fluctuating architectural façade are extracted by examining what kind of elements of façade are changed from the collected cases, and grouping them by similar types (Figure 1.)

As the elements which are fluctuating, windows, panels, ornaments, sashes, slabs, pillars, blinds, verandas, large terraces, roof shape, prints, colours, structures which walls and slabs are unified, uneven vertical surface and volumes were seen. The elements were further divided into several fluctuating categories. Six categories including interval size and shape were seen in the window element. Six categories including, repetition, size and shape were seen in the panel element. Four categories including interval and size were seen in the ornament element. Three categories including interval were seen in the sash element. Three categories including interval and gap were seen in the slab element. Two categories including interval were seen in the pillar element. 33 categories were seen in all, and the categories of changing windows and the categories of changing panels were seen frequently.

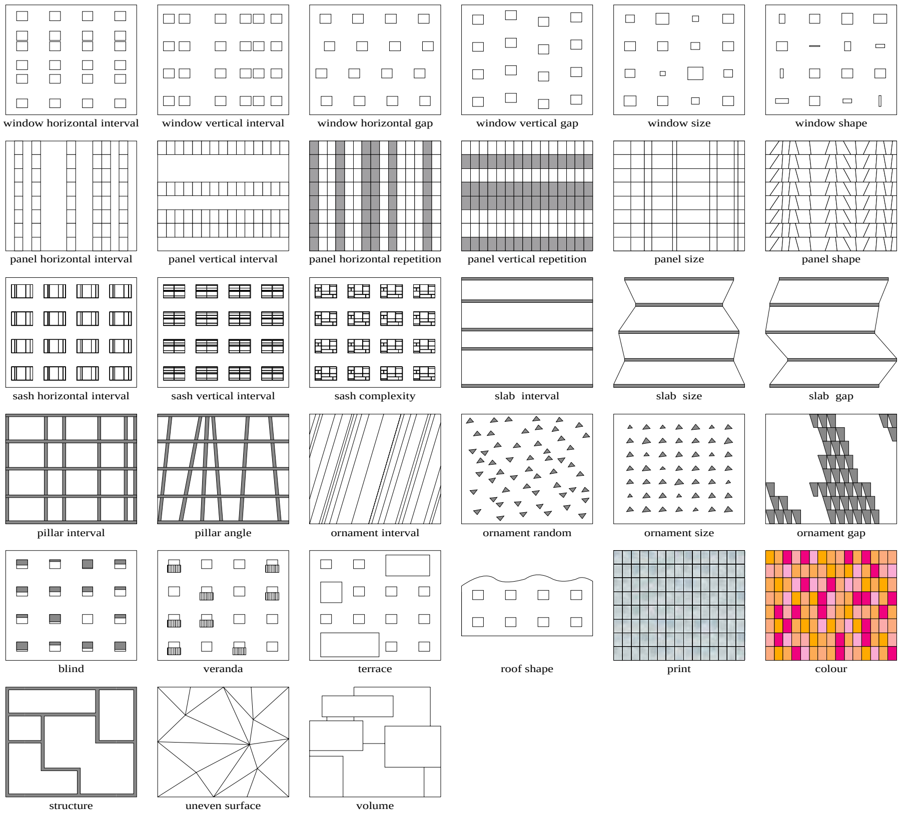

Figure 1. Categories of fluctuating façade

2.3. EXAMINATION OF PATTERNS

The collected 270 cases were classified into previously clarified 33 categories.

The total number of each standard category is shown in TABLE 1.

In total, the categories concerning windows were seen frequently. Therefore, it can be said that window categories is the categories that is used in many buildings. Also, the categories of horizontal changes were seen more frequently than the categories of vertical changes. It is thought that there are fewer restrictions in horizontal direction compared to vertical direction, considering the fact that there are restrictions by floor heights.

TABLE 1. Total number of each category

the total number of cases	fluctuating category
73	window horizontal interval
70	window size
69	window horizontal gap
63	window shape
57	window vertical gap
53	panel horizontal repetition
51	panel vertical repetition
49	panel horizontal interval
45	panel size
31	window vertical interval
31	panel vertical interval
22	colour
18	terrace
15	roof shape
14	structure
14	volume
13	blind

the total number of cases	fluctuating category
11	print
8	sash horizontal interval
8	ornament random
7	uneven surface
7	pillar interval
6	sash vertical interval
6	sash complexity
6	veranda
5	slab interval
5	pillar angle
5	ornament size
4	panel shape
4	slab gap
4	slab size
2	ornament interval
1	ornament gap

TABLE 2. Combinations of categories

the number of cases	combination of fluctuating categories					
28	panel horizontal repetition	panel vertical repetition				
18	panel horizontal interval	panel size				
10	window horizontal interval	window vertical interval	window horizontal gap	window vertical gap	window size	window shape
9	panel horizontal interval	panel vertical interval	panel size			
	terrace					
8	panel horizontal repetition	panel vertical repetition	colour			
	panel vertical interval	panel size				
	panel horizontal interval					
7	window horizontal interval	window horizontal gap	window vertical gap	window size	window shape	
	window horizontal interval	window horizontal gap	window size	window shape		
	roof shape					
6	window horizontal interval	window vertical interval	window horizontal gap	window vertical gap	window size	
	panel vertical interval					
	volume					
5	window horizontal interval	window horizontal gap				
	print					
4	window horizontal interval	window size	window shape			
	window horizontal gap	window size	window shape			
	panel horizontal repetition	panel vertical repetition	print			
	panel horizontal repetition	panel vertical repetition	blind			
3	panel horizontal interval	panel size	blind			
	slab interval	slab gap	slab size			
	window horizontal gap	window vertical gap				
	pillar interval	pillar angle				
	ornament random	ornament size				
	blind					
	sash complexity					
	structure					
2	window vertical interval	window horizontal gap	window vertical gap	window size	window shape	
	window horizontal interval	window vertical gap	window size	window shape		
	panel horizontal interval	panel vertical interval	panel size	colour		
	window horizontal interval	window horizontal gap	window vertical gap			
	window horizontal interval	window horizontal gap	terrace			
	window vertical interval	window size	window shape			
	window vertical gap	window size	window shape			
	panel horizontal interval	panel size	terrace			
	window horizontal interval	window vertical gap				
	sash complexity	structure				
	uneven surface	volume				
	window horizontal interval					
	sash horizontal interval					
	sash vertical interval					
	slab interval					
	colour					

Next, of all cases, 109 cases were applied to plural categories. The combinations of plural categories are shown in TABLE 2.

From TABLE 2, the combination of “panel horizontal repetition” and “panel vertical repetition” were seen most frequently, in 28 cases. The combination of “panel horizontal interval” and “panel size” followed by 18 cases. It is thought that the patterns concerning panels were seen a lot because the prefabricated panels were used in order to hold down costs. In the patterns concerning windows, frequently seen combinations is likely to have combined many categories, for example, ten cases had combined six fluctuation categories and thirteen cases had combined five fluctuation categories (two types of combination were seen, seven cases and six cases each.) From this, it can be said that designs using fluctuated window patterns tend to combine multiple types of categories in order to increase complexity.

About the size of façade, from TABLE 3 and 4, it was clarified that fluctuation was used to buildings of various scales from smaller than five metres to over a hundred metres in width and from about three metres to over two hundred metres in height. From TABLE 5, the buildings with wide façade were seen more than the buildings with tall façade. It is thought that there are designers' intentions to reduce monotonousness by adding changes to wide façades which are visible by people for a long time.

TABLE 3. Width of façade of cases

width of façade	the numberof cases
200 - metres	3
150 - 200 metres	7
100 - 150 metres	31
90 - 100 metres	9
80 - 90 metres	10
70 - 80 metres	12
60 - 70 metres	11
50 - 60 metres	21
40 - 50 metres	23
30 - 40 metres	25
20 - 30 metres	37
10 - 20 metres	61
- 10 metres	19

TABLE 4. Height of façade of cases

height of façade	the numberof cases
61 - metres	10
31 - 61 metres	42
10 - 31 metres	134
- 10 metres	69

TABLE 5. Aspect of façade of cases

aspect of façade	the numberof cases
wide façade	196
square façade	4
tall façade	52

3. Creation of fluctuated window patterns

3.1. CREATION OF FLUCTUATIMG FAÇADE IMAGES BY PROGRAM

It is clarified that there are many fluctuating façade designs from the case study. As the sizes, shapes, arrangements and so on of elements composing the building façade change in fluctuating façade design, it takes a long time to create a fluctuating design by hand drawing. Upon this, a computer program is made to automatically create a fluctuating façade design, in order to create numerous designs in a short period of time. Although many combinations of categories are expected in fluctuating façade, the fluctuating patterns concerning windows are selected here because these patterns were seen most frequently in the case study.

From the analysis done in the previous chapter, it became clear that window categories are composed of changes in intervals and gaps between windows, and changes in sizes and shapes of the windows itself. In order to create these patterns automatically, these categories were rearranged into six categories: "x direction window size," "y direction window size," "x direction window interval," "y direction window interval," "x direction axial change" and "y direction axial change" (Figure 2.)

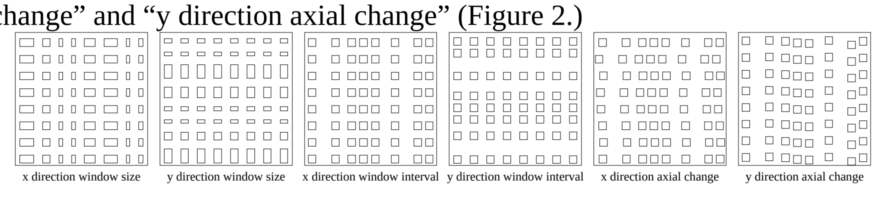

Figure 2. Fluctuated window categories.

3.2. ALGORITHMS

The following is the process to create façade images.

1. The width and the height of the building, and the number of windows are inputted and the standard façade which the window are placed regularly is created.
2. The phase θ is decided from the random number between 1 and 360°.
3. 1/f wave is created from function (1) and A_n is sampled from this formula with the number of window. The frequency f is chosen properly.

$$g(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty} \frac{2}{\sqrt{f}} \sin\left(2\pi f n x + \theta_n\right) \tag{1}$$

4. First, width of windows and intervals between windows are determined. The minimum value in A_n is identified. B_n are calculated by adding a constant to all of A_n in order to make all of the numbers into a positive number.

$$B_n = A_n + const \tag{2}$$

5. For the width of the windows, C_n are calculated so that the sum of B_n becomes the sum of the widths of the windows Sw. *Win_x* and *win_y* are calculated individually from C_n for the "x direction window size" and the "y direction window size."

$$C_n = \frac{B_n}{\sum_i B_i} Sw \tag{3}$$

6. For intervals between windows, D_n are calculated so that the sum of B_n becomes sum of interval of window Si. *Wall_x* and *wall_y* are calculated from D_n for the "x direction window interval" and the "y direction window interval."

$$D_n = \frac{B_n}{\sum_i B_i} Si \tag{4}$$

7. Next, the values of axial changes are determined. The absolute values are calculated from the sampled A_n. The maximum value Max are identified in the absolute values.
8. The upper limit value Sg is determined in the range that does not protrude from the building. E_n are calculated in order to make Max into Sg. *Axis_x* and *axis_y* are calculated individually from E_n in for the "x direction axial change" and the "y direction axial change."

$$E_n = \frac{Sg}{Max} A_n \tag{5}$$

9. The coordinates of the upper left of the windows are calculated from *win_x*, *win_y*, *wall_x*, *wall_y*, *axis_x* and *axis_y*. The followings are the formulas to calculate coordinates.

$$lt\_x(i,j) = \sum_{k=1}^{i-1} win\_x(k,j) + \sum_{k=1}^{i-1} wall\_x(k,j) + axis\_x(j) + const\_x \tag{6}$$

$$lt\_y(i,j) = \sum_{l=1}^{j-1} win\_y(i,l) + \sum_{l=1}^{j-1} wall\_y(i,l) + axis\_y(i) + const\_y \tag{7}$$

Here, $win\_x(0,j) = 0,\ wall\_x(0,j) = 0,\ win\_y(i,0) = 0,\ wall\_y(i,0) = 0$

$const\_x$ and $const\_y$ is the value of $lt\_x(1,1)$ and $lt\_y(1,1)$ at all times.

10. As shown in Figure 3 if the upper left point of the window B is with in area of window A or in the area inside of dotted line, window A and window B are overlapped. To be more precise window A and window B are overlapped when the formula below is satisfied.

$$lt\_y(A) - win\_y(B) < lt\_y(B) < lt\_y(A) + win\_y(A) \qquad (8)$$

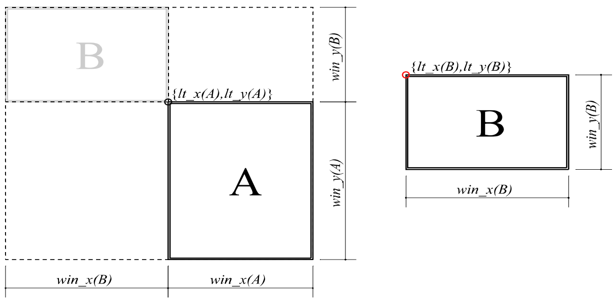

Figure 3. Decision of lap of windows.

If the windows are overlapped, it becomes error and the process from "2." is performed again.

11. The PNG image which the background image is over laid with the images of the windows arranged at the appointed coordinates is outputted. The windows are arranged by cutting them off from a large image in order not to create sense of incongruity (Figure 4.) The sashes are arranged on four sides, top side, bottom side, right side and left side separately because the width of sashes will change irregularly if sashes are arranged collectively. Also, the images of top side sashes are arranged higher for the windows arranged on the upper part of the building.

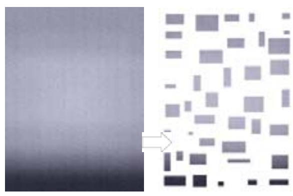

Figure 4. Arrangement of image of window.

12. As a result of the series of process, the image which is shown in Figure 5 is outputted.

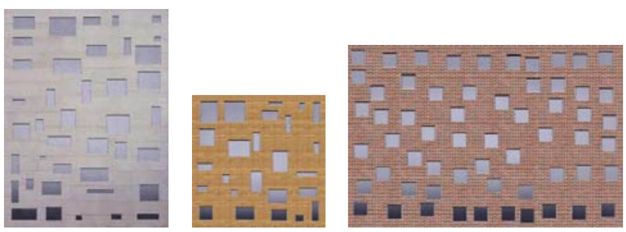

Figure 5. Examples of completed image.

4. Conclusion

In this paper, 33 fluctuating façade categories are extracted from the analysis of 270 cases. Also fluctuating façade with window changes are created automatically from the combination of six categories. The program could display many fluctuated designs in a brief time. This enables the architects to choose good design essence from the presented alternatives and develop a better design. Therefore, it can be said that it becomes possible to realise rich design in many buildings with this program.

This paper showed that various architectural designs could be created automatically by softwarising and liberalising, though only one example of automatic creation is shown in this paper.

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