

Application of Fractal Geometry to Architectural Design

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Abstract Contemporary architecture tends to deconstruct modern architecture based on rationalization just like reductionism and functionalism and secedes from it. It means change from mechanical to organic and ecological view of the world. According to these changes, consideration of a compositive relationship presented variety and complexity in architecture. Thus, the modern speculation based on rationalism cannot provide an alternative interpretation about complicated architectural phenomena. At this point in time, the purpose of this study is to investigate the possibilities of the fractal as an alternative tool of analysis and design in contemporary architecture. In this study, two major aspects are discussed. First, the fractal concepts just like 'fractal dimension', 'box-counting dimension' and 'fractal rhythm' can be applied to analysis in architecture. Second, the fractal formative principles just like 'scaling', 'superimposition trace', 'distortion' and 'repetition' can be applied to design in architecture. Fractal geometry similar to nature's patterned order can provide endless possibilities for analysis and design in architecture. Therefore further study of fractal geometry should be conducted synthetically from now on.

Keywords: Fractal, Fractal Dimension, Box-Counting Dimension, Fractal rhythm, Self-Similarity, Non-Linearity, Randomness

1. INTRODUCTION

1.1 Background and purpose of the study

Ruling values and change of thought in an era have transformed thinking diversely also in architecture. Diversion of paradigm in science is coming out as new attempts challenging the existing system in architecture. Nowadays advanced architects are putting their theoretical background on a world view of science, and they are reflecting its flow of change into architecture.

Since the Thoma Kun's paradigm theory, it has been understood that history is not of straight line by passage of time but a process for trend of human thinking to be substituted. Also in architecture it can be said that division of an age such as ancient times, modern times and present age is a change of design consideration trend.

Architectural design in present age attempts to secede from recent architecture based on perfect rationality like reductionism or functionalism and rather to show its dismantling or secession from it. It means a conversion from mechanical world view to organic · ecological world view, and from decisive thinking to

thinking of non-decisive possibility. Conversion of world view and thinking has been reflected as an attempt to build up architecture in a composite relation in which multidimensional variables are intervened, and thereby it makes modern architecture as highly complex and diversified forms emerging from the existing single form.

Table 1. Change of design consideration trend¹

Ancient times	Modern times	Present age
Sort of space and time	Space-time	Space-time-information
Absolute	Relative	Interactional
Fixed	Solidity	Movement
Essence	Material	Information
Individual	Separated	Variety
Analogical	Mechanical	Digital
Entire undivided	Fragment	Fractal
Invariability	Variable	Evolution
Predictable	Measurable	Particular
Formality	Abstract	Mixture
External	Structure	Inner structure
Singular	Entire singular	Hybrid
↓	↓	↓
Control by rule (control)	Order through relation (order)	Cooperation action by combination (synergy)

Therefore it is a difficult situation to interpret complexity and diversification of modern architecture only with the existing theories based on rationalism. Accordingly the purpose of this study is to propose 'fractal', which is one of scientific theories on complexity being raised as a new paradigm of the 21st century, as an alternative appropriate to interpretation of modern architecture, and thereby to review its possibility.

¹ Gausa, Manuel and et al., Recomposed from P. 626 of The Metapolis Dictionary of Advanced Architecture, Distributed Art Pub Inc., 2003, P. 626

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Moreover, the purpose of this study is also to review application cases and extension possibility of fractal formative principle, which is a new theory being pursued by modern architects, and thereby to extend formative language in the aspect of architectural design method and process.

Accordingly in this study, application possibility of fractal geometry in modern architecture is to be closely examined more widely through close examination of fractal's principles applicable not only to architectural design process and logic but also to interpretation.

Development direction of the study is as follows; Firstly, subjective concept and formative feature of fractal geometry will be reviewed through theoretical consideration, and thereby principle applicable as tools for analysis and method of architectural design will be reviewed. Secondly, concept of fractal applicable in the aspect of analysis, and fractal formative principles to be utilized in the aspect of design method will be reviewed focused on the cases respectively. Thirdly, a possibility of fractal geometry as tools for analysis and method of architectural design will be reviewed through application of previously suggested fractal concepts and formative principles into analysis and method of architectural design.

2. THEORETICAL CONSIDERATION OF FRACTAL GEOMETRY

2.1 Chaos and fractal

Chaos which is a paradigm of scientific theory in the 21st century is a theory to deal with moving of system difficult to predict due to its complexity and irregularity. Chaos means confusion and disorder. But it connotes order, and also it has a creative ability to self-organize abundant structures dynamically.²

Fractal called geometry of chaos is geometry able to describe and analyze structural irregularity of nature system. Fractal having started as a simple concept in pure mathematics has occupied an important position in clarifying complex shapes, phenomena and non-linear state in nature, which is difficult to explain only with curves and curved surfaces in the existing Euclid geometry. It has provided a new innovative view in understanding chaos problems.

Fractal appears in phenomena of nature system of all scales from molecule to astronomical unit. As its examples, there are structures of the coastline and ground surface, loci of lightning, crystal shape of snow, discharge phenomenon of electricity, curves indicating irregular rise and fall of the stock market, turbulence of fluid, and distribution of the cosmic galactic system.

Besides, attention has been paid to fractal in the field of physics, geography, architecture, art, and philosophy from the end of the 1970's. In the 1980's it had been studied as an aesthetic geometric theory. Nowadays fractal is applied in various fields of music, fine arts, and literature, and also in architecture it is applied to design in a new method by progressive architects.

It is because fractal has inherent principles and attributes useful in application into architecture and art. In this chapter, it is to be examined closely through creation principle of fractal, its representative type, and geometric characteristics.

2.2 Creation principle of fractal geometry

Fractal geometry is developed by means of algorithm differently from classical geometry to be developed in numerical formulae. If a certain figure is inputted and then fractal equation computes its result, its next result is obtained from repeated feedback to be substituted again by the equation.

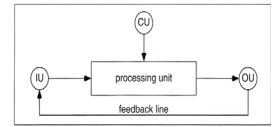


Figure 1. Feedback algorithm

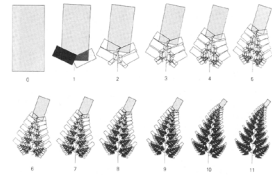


Figure 2. Bracken produces by IFS

Since fractal geometry is created with computer by using a series of equation having a mathematical form of non-linear feedback, Euclid shape is not drawn. It is because minute change can cause dramatic effects due to sudden non-predictive phenomena to appear in repetitive operation process. Namely, fractal has a creative attribute in which small change of information incorporated in creation causes complex structures and consequently brings substantial change of shape.

2.3 Type of fractal geometry

In representative type of fractal geometry, there are Cantor dust, Koch curve, Sierpinski gasket, and Mandelbrot set. Summarizing those shapes and creation process, it is as shown in Table 2;

Table 2. Type of fractal geometry

type	form	morphosis
Cantor dust (1872)		·Infinity repeat of process that removes middle 1/3 portion and leave both 0 ~ 1/3, 2/3 ~ 1 portion in 1 length line
Koch curve (1904)		·Trisect line segment bends and raises line segment of middle, and creates line segment four that is 1/3 length of original line segment ·Infinity repeat of process that change with four line segments that occur newly reducing constructor
Sierpinski gasket (1916)		·Infinity repeat of process that remove middle triangle among four triangle that created by connecting emphasis of each jargon of regular triangle
Mandelbrot set (1975)		·A set of complex number c that do not diffuse $z=z^2+c$ in case calculated repeating when z early value by $z=0+0i$ in complex number formula $z=z^2+c(z=x+yi, c=c1+ c2i)$

2.4 Geometric characteristics of fractal

Fractal of various types has common characteristics different from Euclid geometry due to the above-mentioned creation principle. Enlarging fractal shapes, they are not regular at all differently from Euclid shapes. Enlarging size

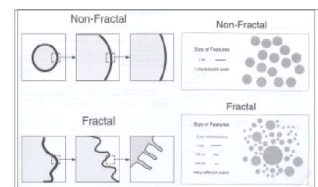


Figure 3. Non-fractal and Fractal

² Yong-un Kim, Yong-guk Kim, The world of fractal and chaos, Book Publishing Useong, , 2000, P. 155-162

of shapes such as triangle, circle, sphere and cylinder in traditional geometry, its structure disappears.

But, even though parts of fractal shapes are enlarged or reduced gradually, they do not become simple, keep non-linearity, and exhibit self-similarity.

Geometric characteristics of fractal are summarized as self-similarity, non-linearity, and randomness contributes in analyzing irregular patterns of nature, and it has functionality as a creative formative principle.

Table 3. Geometric characteristics of fractal

Characteristic	Contents
Self-similarity	<ul style="list-style-type: none"> ·Pattern in pattern to pierce all reduced scales ·Even if cut what portion, structure that included whole of portion that resemble with whole shape ·Repetitive construct that portion reflects whole
Non-linearity	<ul style="list-style-type: none"> ·Structure of own similarity that shows continuously non-linearity, and it is not strict own similarity or monotonous repeatability ·Sensitive relativity about initial condition ·Exceptional, random, nonestimate, irregularity, amplification as compared with linearity
Randomness	<ul style="list-style-type: none"> ·While series of the predictable events converges by the estimate possibility, principle that creative system emanates ·More rich and useful fractal to concept of random

3. FRACTAL GEOMETRY IN THE ANALYSIS OF ARCHITECTURAL DESIGN

3.1 Recognition of architectural design by fractal dimension

Fig. 4 is a graph showing a distribution of conical cell and rod cell from the center of retina in the eye of a human. It can be seen that more details can be perceived only within the range of 2° at the center of retina, and major shapes can be perceived within the range of about 20°.³

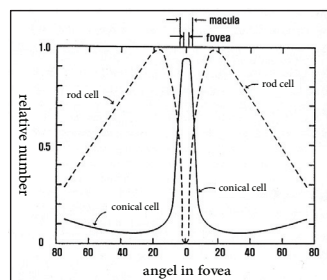
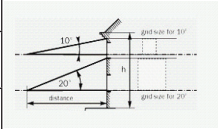


Figure 4. Distribution of cell of conical cell and rod cell

Depending upon observation distance and observation angle by means of such principle of visual perception, size of recognizable unit is determined (Table 4). When analyzing the front face of a building with the box-counting dimension, size of lattice is determined according to this angle and the distance from a building.⁴

Table 4. Size of recognizable unit by means of observation and observation angle

Observation distance \ Observation angle	1.5 m	3 m	6 m	12 m	24 m	Size of unit that is available observation = distance x tan (angle)
02°	5.2 cm	10.5 cm	21.0 cm	41.9 cm	83.8 cm	0.8 m
05°	13.1 cm	26.3 cm	52.5 cm	105.0 cm	210.0 cm	2.1 m
10°	26.5 cm	52.9 cm	105.8 cm	211.6 cm	423.2 cm	4.2 m
15°	40.2 cm	80.4 cm	160.8 cm	321.6 cm	643.2 cm	6.4 m
20°	54.6 cm	109.2 cm	218.4 cm	436.8 cm	873.6 cm	8.7 m



Therefore movement of observer in the building is accompanied by visual change. Sequence refers to phenomenon that continuous changes occur in perception and experience by movement of observer accompanying such visual change. Observer recognizes spatial continuity in that process, and definitely observer has accumulative spatial experiences for infinitely divided scenes. In the course of recognizing several scenes⁵ created and divided in this process, observer experiences changes in fractal imension.

For example, observing the Great Wall of China from the sky, it looks like a long curve of one-dimension without width and height.

Approaching it gradually, it looks like a plate of two-dimension with height and length even though there is no width. Approaching more closely up to the distance that it can be perceived as a wall, it is seen as a body of three-dimension for the first time. When observing small stone of wall component at the distance several meters away from the front, this stone looks like a point of zero-dimension. Approaching it very closely, this stone is seen as a body of three-dimension once again. Such change of dimension can be repeated up to the scale of atom that indicates boundaries of material.⁶

Robie House of Frank Lloyd Wright can be analyzed in the same way. Observer can observe an overall outline of the building at a certain distance. Approaching it closely, pattern of the window and the wall can be recognized. Approaching it more closely, the knob of the door and details of the window are recognized. Such process is repeated likewise also in the inside of the building.



Figure 5. Robie House

If observer approaches closely the building gradually from a certain distance, it can be seen that Robie House has details of gradual self-similarity from a large scale to a small scale. Self-similarity of the building is understood gradually as one approaches the building, comes in and out it, and uses it.

³ Carl Bovill, Fractal Geometry in Architecture and Design, Carpenter Center for the Visual Arts, Harvard University, 1996, P. 118

⁴ Wolfgang E. Lorenz, Fractals and Fractal Architecture <http://www.iemar.tuwien.ac.at/modul23/Fractals/>

⁵ Yeong-geol Gweon, Space Design Lecture No. 16, Book Publishing Kukje, 2003, P. 73

⁶ Wolfgang E. Lorenz, Fractals and Fractal Architecture <http://www.iemar.tuwien.ac.at/modul23/Fractals/>

3.2 Analysis of architectural design by the box-counting dimension

In the course of observing architectural design by the sequence reviewed previously, a numerical calculation method for an image of the building's front side perceived at a certain point is a method by the box-counting dimension. It is proceeded with a method to compute a ratio between the number of rectangles incorporating lines within that rectangle, and total number of rectangles while overlapping lattices over the front face of observation target and then reducing the size of rectangles.

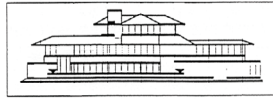


Figure 6. Front elevation of Robie House

Computing the box-counting dimension at the front face of Robie House of Frank Lloyd Wright, it is as follows;

Table 5. Box-counting dimension at the front of Robie House

Grid	Grid 1: 16x4	Grid 2: 32x8	Grid 3: 64x16
Image			
Number of box	64	256	1024
N(s)	50	140	380

Computing the box-counting dimension at the front elevation of Villa Savoye of Le Corbusier in the same way, it is as follows;



Figure 7. Front elevation of Villa Savoye

Table 6. Box-counting dimension at the front elevation of Villa Savoye

Grid	Grid 1: 14x8	Grid 2: 28x16	Grid 3: 56x32
Image			
Number of box	112	448	1792
N(s)	88	268	675

Two sets of fractal dimension can be obtained with this value.

Table 7. Fractal dimension by box-counting dimension

Classification	Grid 1 and grid 2	Grid 2 and grid 3
Robie House	$D = \frac{[\log(140) - \log(50)]}{[\log(32) - \log(16)]}$ $\div \frac{0.447}{0.301} \div 1.485$	$D = \frac{[\log(380) - \log(140)]}{[\log(64) - \log(32)]}$ $\div \frac{0.434}{0.301} \div 1.441$
Villa Savoye	$D = \frac{[\log(268) - \log(88)]}{[\log(28) - \log(14)]}$ $\div \frac{0.484}{0.301} \div 1.607$	$D = \frac{[\log(675) - \log(268)]}{[\log(56) - \log(28)]}$ $\div \frac{0.401}{0.301} \div 1.333$

As the size of grid becomes minute, fractal dimension is reduced. It means that complexity of details is lowered as it approaches a small scale. As a result of analyzing fractal dimension for the front faces of two buildings, phenomenon of lowered complexity in details was coincided, but the difference of its extent was large. In the Robie House, fractal dimension showed a minute change

from 1.485 to 1.441. But in Villa Savoye, a degree of its change was comparatively large from 1.607 to 1.333 .

It shows that the Robie House has more complex details comparing with Villa Savoye. Such difference might be an extremely natural result accompanied from mutually different design concepts of Frank Lloyd Wright's organic architecture and Le Corbusier's purism design. But such method has its meaning in the point of having analyzed and shown quantitatively architectural design.

3.3 Analysis of architectural design by fractal rhythm

Fractal rhythm is created while varying fractal dimension of 1/f noise similar to a change pattern of nature. By means of comparing architectural grid with patterns of fractal rhythm, a degree of mixing with order and change can be analyzed quantitatively.

Table 7 is a table analyzed by means of overlapping grid based on major components (column and wall) in the plane of 'Villa Rotunda' of Palladio and 'Wiltz House' of Frank Lloyd Wright and then comparing them with grid having a fractal dimension of 1.7.

Planned grid of Villa Rotunda makes a form of geometric symmetry of a square, whereas planned grid of Wiltz House shows fairly autonomous rhythm and it is similar to fractal rhythm of 1.7. Preparing a bar graph with rhythm of the horizontal axis plane, it becomes a shape of step function. Height of the bar indicates a horizontal grid interval to be divided by a vertical grid line at the plane.

Rhythm full of order and rule appears in the graph of Villa Rotunda, whereas irregular rise and fall in Wiltz House is similar to rhythm of fractal dimension of 1.7. It can be seen that rhythm in the plane of Wiltz House is much more autonomous than rhythm of Villa Rotunda, and it is close to rhythm appearing in the 1/f noise of fractal.

Table 8. Example of fractal rhythm

Classification	Villa Rotunda	Willits House	1.7 Fractal dimension
Plan			
Fractal rhythm			

Fig. 8 is a figure of concrete soundproofing wall erected in the expressway No. 50 in the west side of Anapolis, Maryland. It can be seen that the soundproofing wall designed using Euclid geometry causes a collision with rhythm similar to fractal in the top of trees protruded behind the wall.

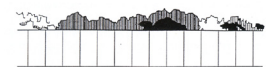


Figure 8. Concrete soundproofing wall

Rhythm of the trees seen behind the soundproofing wall is similar to a fractal dimension of 1.3. Height and width of the soundproofing wall can be varied with a dimension of 1.3 which is the same

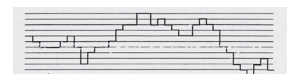


Figure 9. Fractal rhythm

dimension as the trees.

Wall formed newly with fractal rhythm has rhythm similar to one of the trees, and accordingly it can make more natural and harmonic order than the existing one.



Figure 10. Wall formed newly with fractal rhythm

Also at the time of designing continuous buildings such as tenement houses and buildings in the shopping area, patterns similar to nature can be created through application of fractal rhythm likewise. Fig. 11 shows the arrangement of building groups created through application of this method. It is an example showing that pattern similar to rhythm exhibited by nature can be formed through application of fractal rhythm when height and width of a building is determined.⁷

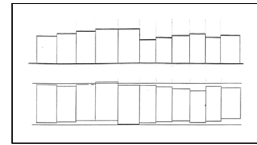


Figure 11. Building arrangement formed with fractal rhythm

3.4 Summary and analysis

Summarizing principles of fractal geometry applicable to the analysis of architectural design, it can be summarized as follows;

Table 9. Summary and analysis

Fractal element	Application in architectural design analysis
Fractal dimension	Cognition process about architectural design by sequence
	Observer do not look at building at fixed visual point, but sense change of Fractal dimension on eye through uninterrupted experience that feel on whole body and through motion in actuality environment
Box-counting dimension	Elevation analysis by using box-counting dimension in architectural design
	It can compare with the complexity of detail as quantitative counting by analysing result of Villa Savoye of Le Corbusier and Robie House of Frank Lloyd Wright
Fractal rhythm	Analysis of fractal rhythm in grid pattern of architecture and city
	By analysing fractal rhythm in grid pattern of architecture and city, it can analyze degree that order and change are mixed as quantitative. Although it is complicated if it apply this, it can create pattern similar to order of nature.

4. FRACTAL FORMATIVE PRINCIPLE APPLIED TO ARCHITECTURALL DESIGN

4.1 Scaling

Scaling in architectural design is utilized as a method to move selected shapes to another place by separating and isolating them from original context, and then to transform this basic form by means of reduction or enlargement.

‘Canaregio Region Compartment’ was created by undergoing a transformation process of scaling and of complex point

⁷ Carl Bovill, *Fractal Geometry in Architecture and Design*, Carpenter Center for the Visual Arts, Harvard University, 1996

symmetry. line symmetry after creation of L-lettered cube through transformation of a square and then overlapping transformed L-lettered shapes mutually. By means of this overlapping, respective elements become shapes different from original shapes, and then they are reconstituted into new meanings.

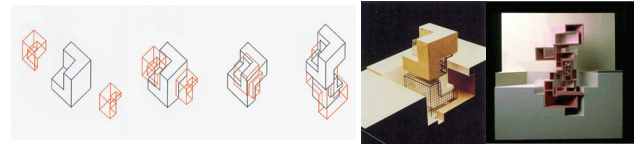


Figure 12. House 11A of Peter Eisenman (1978)

L is a shape in which a square is divided into four pieces and then a quarter of them is eliminated. Peter Eisenman said that L-lettered shape of neither a rectangle nor a square was determined as a shape symbolizing ‘an unstable thing’ or ‘a thing indicating a relation’. According to Eisenman, each L is an unstable geometry oscillating between perfect shape and geometric shape, and also it is a shape symbolizing imperfection of man and an era of imperfect individual. L-lettered masses not limited in scale and adjusted to various sizes collide mutually and build up one shape⁸

Thereafter, Eisenman conducted a work to incorporate another house within a house by putting in parallel the same ‘House 11A’ of various sizes scaling-transformed through ‘Canaregio Region Compartment’. The smallest object is corresponding to the body height of man, and the largest object is too large to call it a house. It was an act that denied function itself of the existing traditional house.

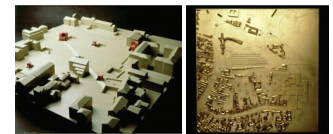


Figure 13. Canaregio Region Compartment of Peter Eisenman

Object to be arranged through scaling-transformation is continued vastly and it fills the ground. Existence of an object within an object is in commemorative of original shape. But it surpasses original shape, and then it becomes a component of architecture having self-similarity.

This project is the one and only indicating a scale. It has sublated the existing imperative idea against the human body, and also it has suggested an ‘analogic’ model with mutually different scales within the same project. Consequently it is a work having received an appraisal that a design strategy was suggested, which intends to make value of things itself, and privilege being possessed by object in a particular scale be deprived.⁹

4.2 Superimposition Trace

Superimposition represents a dynamic state of time and space by visualizing a process of transforming from one shape to a certain another shape, and trace of similar concept represents its track by analogizing invisible movement by shift and rotation.

⁸ Ostwald, *Fractal architecture: Late twentieth century connections between architecture and fractal geometry*, <http://www.emis.de/journals/NNJ/Ostwald-Fractal.html>

⁹ Neung-hyeon Kim, *Study on the reanalysis trend of programming as an element of concept in modern architectural design*, Collection of learned papers by the Korean Society of Interior Design, Vol. 25, Dec. 2000, P. 277

'Max Reinhad Haus' of Peter Eisenman's work(1992) is a plan of multi-storied composite building located in Berlin, and it starts from the type of Mobius band¹⁰. As it is represented in the diagram of Fig. 14, shape of the building is created by moving, rotating, and superimposing a square of the plane at the Mobius band of three-dimensional space.

Eisenman expressed a dynamic state of time and space formatively by analogizing invisible movement with the three-dimensional modeling program called 'Form-Z' and then by visualizing its superimposition process.

Folded mass introduced with a non-linear element represents a meaning of concentration possessed by metropolitan city with a tense dynamism.¹¹ Non-linear shape emphasizes recognition for organic real character of nature, not mechanical organization. It emphasizes innovation, change, and creation that is a spiritual nature of shape creation, and it is fundamentally related to self-organization, creativity and jump, and cosmos creation theory.

After Eisenman took out two elements of formality and context of architecture from this work, he created a building type and space created autonomously through application of various digital modeling techniques to it.¹² Max Reinhard Haus created by the effort of architect, who had tried to secede from the existing type, emphasizes a dramatic and decentralized meaning through dismantling.

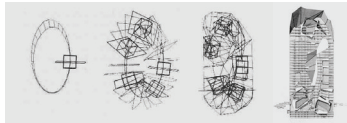


Figure 14. Form development process



Figure 15. Max Reinhad Haus of Peter Eisenman (1992)

4.3 Distortion

Distortion refers to distorting of shape by deforming partially specific elements such as size or interior angle of target. In architecture, distortion is applied in the manner that shape separated from structure mainly by adding directivity or deformation to axis line is operated decoratively, and it reflects architect's intention for seceding from a basic work method in construction by column, beam, wall, and slab.

Fractal formative principle appearing distinguishedly in 'Victoria Albert Museum' of Daniel Libeskind (1996) can be summarized as a shape of the building having quoted a shape of distorted helical curve, and as ceramic wall in the exterior wall formed self-similarly.

Daniel Libeskind invested a helical curve with a meaning that it is a process of engraving present into past and future as well as a

¹⁰ Mobius band is a form without either start or end, and it is interpreted as a representative domain of topology like 'Klein Bottle'.



◀ Mobius band and Klein bottle

¹¹ Hun Kang, Study on 'Fold' as digital architectural design, Collection of learned papers by the Korean Society of Architecture, Gyehoikgy, Vol. 20, No. 11 (Serial Number 193), Nov. 2004, P. 79-80

¹² In-ha Jeong, Study on non-symbolic architecture through the comparison of method of perspective view and digital expression style, Study on Architectural History, Vol. 12, No. 2 (Serial Number 34), June 2003, P. 34

process of dynamic continuance and progress. It was originated from architect's intention to make a progress dialectically for the relation of artistry and popularity, old and new one, outside and inside, and engineering and art.

Initiator of helical curve becomes geometric helical curve while undergoing a process of scaling, distortion, and overlapping. It is overlapped each other and supports a load through a process of slanting-shadow deformation in which it is twisted and angle is deformed. Therefore the museum is consisted of structures without a limitation of column if the center core in the middle is excluded.

This helical curve is not a traditional helical curve having a single center and axis but a modern helical curve that provides various routes, space and environment through various directions suggested along various tracks. Fluid space of distorted helical shape becomes a space that provides diversified activities in museum by means of various attributes, features, and scales. Expanded building can be used flexibly and independently differently from the existing museum galleries due to simple and open structure of helical curve shape. It also creates public entrances of a large scale between densely crowded building forest of city, and thereby it induces natural approach to exhibition hall.¹³

Moreover, ceramic tile used as exterior material for the wall has a shape of fractal geometry having self-similarity. Distorted shape in which a trapezoidal section is twisted in one direction is repeated in the same pattern while undergoing a process of scaling.

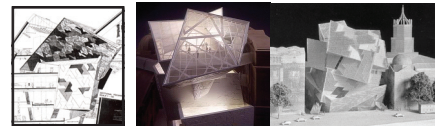


Figure 17. Fractal geometry composition of ceramic tile

This building is evaluated as a building having exhibited continuity and ubiquity of a building having timeliness, historicity and evolutionary situation in the medium of self-similarity of fractal.

4.4 Repetition

In architecture, technique of repetition by fractal geometry can obtain an effect of visually unlimited extension by means of lasting repetition of similar shapes.

'Cadiff Bay Opera House' of Greg Lynn (1994) regarded an external factor to determine a feature of place as a scale change and directivity of the coastline around the ground connected with 'Atlantic-Cadif Bay-Target Site'. The coastline facing the Atlantic is expanded to the yacht anchorage of elliptical shape via the port, and the same similar form is repeated continuously even after reaching the opera



Figure 18. Expansion of Cadif bay cost line

¹³ Daniel Libeskind, The Spiral, Space, 2003.04, P. 131

theater. It was intended to interpret that the veins possessed by the ground is not regarded as a thing being fixed simply but 'a character of place' having a continuous topographic change in the mutual relation of wide-area character and proximity.

Lynn explains regularity and diversification based on the theory of symmetry and discontinuous diversification developed by Gregory Bateson, a biologist as well as an anthropologist.



Figure 19. Examples of symmetry destruction

He emphasized, with the example of mutation in the hand of man and the leg of beetle, that symmetry does not emphasize a basic composition principle of a certain organism, but absence of minimum information is expressed.¹⁴

Differentiated growth of another concept means that product should not be determined by internal and external factors from the beginning. It is verified to be a process of evolution by the introduction of timeliness in shape creation. Shape of a building is created as unit space of elliptical shape multiplies continuously through repeated mutation and evolution similar to fractal rule. Elliptical initiator similar to the elliptical yacht anchorage is scaled and rotated in the size of 2/3 and 1/3, and then it is arranged unsymmetrically. They are multiplied by repeating a process of combining streets and surrounding buildings several times while being arranged and rotated from the information of surrounding environment. Multiplication used in a design process is similar to fractal-like character appearing in the process of cell division.



Figure 20. Multiplication process of elliptical shape

Finally volume is deformed again by internal factors of individual programs of the opera hall organizing an internal space, and of structure system used upon shipbuilding. It is a shape that independence of individual shapes is maintained among the whole. This process can be understood as an attempt to deform the existing information into new context.¹⁵

4.5 Summary and analysis

In the cases where fractal formative principle has been applied to modern architectural design, analyzing comprehensively the aspects that three kinds of features such as self-similarity, non-linearity and randomness of fractal geometry are exhibited in architectural design, it is as follows;



Figure 21. Application process of fractal concept

¹⁴ According to Bateson, organism is a result appearing through dynamic non-linear repetition of internal symmetric structure together with a change of unstable context. Therefore destruction of symmetry is an active act for extending internal diversification hiding within a system.

¹⁵ Wolfgang E. Lorenz , Fractals and Fractal Architecture [http:// www.iemar.tuwien.ac.at/modul23/Fractals/](http://www.iemar.tuwien.ac.at/modul23/Fractals/)

Table 10. Summary and analysis

Architecture work	Self-similarity	Non-linearity	Randomness
Peter Eisenman, Cannaregio Region Compartment & House 11A	-Combination of self-similarity to various size by scaling of house 11A : L shape -Cannaregio Region Compartment : house 11A of various size is arranged in Cannaregio region	-L shape : borrowing as form that 1/4 shows lacking unstable action in an exact square -Create form of house as overlapping atypically each other	-Transformation of Scale of house 11A into big or small excessively -Make privilege of object lose in specification scale by exuviating from existent house
Shuhei Endo, Springecture H Public Lavatory	-Self-similarity structure of flowing curved surface that is created by tabula metal skin -It seeks organic with nature by consecutiveness with scenery that appear through physical construction	-Change on outer skin that cotinous line is awry and is wrenched from three-dimensional space	-Progress of form creation of metal skin that is uncompleted and uncertainty
Peter Eisenman, Max Reinhardt Haus	-Meaning of prism including big city by expressing meaning of congestion of big city to tensed retroaction -Non-linear form is not organization mechanism, but emphasize organic originality of nature	-After circumsolve plates in Mobius band of third dimension space, create non-linear form, seemed to fold by polymerizing -Express dynamic state between time and space by materializing traces that move of plates that is not visualized	-Creation of non-linear form is meaning change, own organization -Emphasis about decentering meaning through taking to pieces
Zvi Hecker, Heinz-Galinski School	-Composition of individual masses which is spread by spiral structure of self-similarity -Pursuit for organic with nature (organic composition of city context and extensive metaphor of nature such as snake, fish, mountain and so on)	-Pursuit of universal order by dynamic of sunflower -By own similarity unfolding of three system of spiral style action, grid, concentric circle, strong induction to center	-By detaining the existent tree and arranging mass, promenade is narrow and hoof, that is created episodically
Daniel Libeskind, Victoria & Albert Museum	-Self-similarity composition of ceramic tile that is used for material of outer wall -Express possibility of various and infinite transformation in self-similarity form of distorted spiral	-Trajectory of dialectical action of contorted spiral -System of the line of flow and whole form of spiral style of chaos -Various exhibition system that are involved in difference and similarity through maze structure	-Boundary destruction of wall, floor and ceiling by reiteration that is random repetition of distorted spiral
Frank O. Gehry, Guggenheim Museum, Bilbao	-Self-similarity metaphor of retroaction shape that is growing petals -Organic consecutiveness of nature and city by shape that seem to rise on water surface	-Distortion of liner elements of wall, the floor, roof etc. by status conversion -Express highly, intricately and freely of fluid shape like flowing petal through the way of folding	-Deduction to fluid shape like flowing liquid as size and topology of 26 petal are decided by random

<p>Greg Lynn, Cardiff Bay Opera House</p>	<p>·Seek organic with surrounding context by extending coastline to yacht anchorage around earth</p>	<p>·Oval that was modeled on Oval Basin is repeat non-linear and asymmetry along direction of topography</p>	<p>·Whole shape is not decided from whole shape in the beginning ·By differentiation between growth and change by symmetry destruction, evolution of form by time</p>
<p>Bernard Tschumi, Glass Video Gallery</p>	<p>·Transparency of glass scatters city boundary and infinitely extends space visually ·Seek consecutiveness with city environment by pulling down the border of building interior and exterior</p>	<p>·By becoming objet of city space and intermediate that show city space at the same time, formation of ring of circulation Mobius strip</p>	<p>·Surface that keep phenomenon that is indeterminacy and temporary by immaterial and material of glass</p>

5. CONCLUSION

This study was conducted for the purpose of reviewing its possibility by suggesting 'fractal', which is one of scientific theories on complexity in the transition period from a mechanical world view to an organic and ecological world view, and from decisive thinking to thinking of non-decisive possibility, as one alternative appropriate in analyzing complexity architecture of modern. And this study was also conducted for the purpose of reviewing its possibility as an organization principle of organic design of nature's patterned order and similar fractal formative principle in the process of architectural design.

In the analysis of architectural design, method of analyzing through the introduction of elements of fractal geometry can be summarized as follows;

1. In the recognition process of architectural design by sequence based on the theory of ecological perception, observer does not see buildings at a fixed time point, but have continuous experiences to be felt by the whole body through movement in actual environment. At this time changes of fractal dimension are perceived with the eye.
2. Degree of complexity in details can be analyzed and compared quantitatively with the analysis of the front face by utilizing the box-counting dimension.
3. By means of analyzing fractal rhythm in the grid pattern of architecture and then analyzing a degree of mixing with order and change, thing that is complicated but has order, namely, a plane and front face similar to order of nature can be created.

In modern architectural design applied with four kinds of fractal formative principles such as 'scaling', 'superimposition and trace', 'repetition', and 'distortion', position to be possessed by 'self-similarity', 'non-linearity', and 'randomness', which are characters of fractal, is as follows;

1. In architectural design, self-similarity of fractal discovered order existing in flow of nature and then showed a possibility of organic architectural design through its relation with architecture.

2. In architectural design, non-linearity of fractal emphasized a new meaning of architecture as an evolutionary body of time having a vital force by means of showing a process of mutating structures and increasing complexity.

3. In architectural design, randomness of fractal showed that non-predictive creative results can be obtained by sudden emergence and instability brought by repeated non-linear feedback.

Fractal geometry similar to patterned order of nature is an organizing principle of organic design in architecture, and it was reviewed that it has not only an eternal formative possibility but also it can be applied variously also in the aspect of design analysis.

Fractal geometry is a theory that can be applied in design much more variously and abundantly than contents handled in this study. In future, study should be conducted in the aspect that it can be reflected more comprehensively in architectural design by means of deeper studies regarding this matter. Furthermore it will be possible for this study to be continued to grafting of modern architecture with more diversified modern science. For this study method, its position will be evaluated as a part of groping for interdisciplinary research activities and new design methods in architectural design

New paradigm provides new creative formative language. Of course, their aesthetic value and feasibility is not guaranteed because they were used as themes or basic principles of art or design, but obviously it is valuable as one suggestion in architectural design to deny traditional approaches and to pursue new order. Alternative shall be suggested, which confronts new culture and environment more aggressively by utilizing various theories rather than adhering to the existing method blindly.

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