형상 문법이 건축 조형에 미치는 영향 연구

형상 문법으로 생성된 건축 조형의 미적 가치를 중심으로

A Study of the Influence of Shape Grammar on Architectural Form

focusing on the aesthetic value of architectural form created by shape grammar

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Abstract

Although shape grammar has been researched for nearly 50 years, its potential in architectural design remains far from being exploited. Shape grammar can be used to describe and understand the architectural design language of certain buildings and generate new architectural forms through regular combinations of shapes. The object of this study is the shape-generating properties of shape grammar. Shape grammar, as a design language of shape generation, has the influence and value on architectural form and is the focus of this study. In this paper, shape grammar is explored from two aspects of form value and aesthetic value. Its influence on architecture's form generation and aesthetics is analyzed based on the theoretical knowledge of cognitive science and neuroaesthetics. The results demonstrate that shape grammar can help generate architectural forms while positively inducing the occurrence of aesthetic preferences. The shape-generating properties of shape grammar can be applied to architectural forms, addressing the limitations of traditional design methods relying on inspiration or experience. Moreover, shape grammar, as a beautiful design language, can more actively stimulate the occurrence of aesthetic preference by emphasizing the visual features contributing to aesthetic preference (grouping, symmetry, and processing fluency). It can be concluded that shape grammar not only addresses the limitations of traditional architectural design methods but also makes forms more attractive. The purpose of this study is to recognize the shape-generating value and aesthetic value of shape grammar, give full play to its value in the field of architecture, and guide the design of architectural forms.

Keyword

Shape grammar, Architectural form, Shape generation, Aesthetic preference, Supernormal stimulus

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요약

형상 문법에 대한 연구는 50년 가까이 됐지만, 건축 조형으로서 디자인의 잠재력이 아직 활용되지 않고 있다. 형상 문법은 건축물의 디자인 언어를 묘사하고 이해하는 데 쓰일 수 있으며, 모양의 공간 연결 규칙을 통해 건축 조형을 생산할 수 있다. 본 연구는 형상 문법의 생성 특성을 대상으로 한다. 형상을 생성하는 디자인 언어로써 형상 문법이 건축 조형에 미치는 영향 및 가치를 중점으로 탐구한다. 본 연구는 형상 가치와 심미 가치 두 측면으로 형상 문법을 연구 및 분석한다. 인지 과학 및 신경 미학적 이론 지식을 이용하여 형상 문법이 건축의 형상 생성과 심미적 측면에 미치는 영향을 분석하다. 형상 문법은 건축 조형의 생성을 돕고 미적 선호를 적극적으로 유발함을 보여준다. 형상 문법이 가진 형상을 생성하는 속성은 건축 조형 디자인에 적용될 수 있으며, 전통 디자인 방법은 영감과 경험에 의존하는 한계를 해결한다. 또한 형상 문법은 아름다운 디자인 언어로서 미적 선호를 유발하는 시각적 특징(패킷, 대칭, 처리의 용이성)을 강조하거나 과장함으로써 심미적 호감을 더욱 적극적으로 자극할 수 있다.따라서 형상 문법은 건축 조형의 전통적 디자인 기법의 한계를 해소할 수 있을 뿐만 아니라, 조형을 더욱 매력적으로 만들 수 있다는 결론을 내릴 수 있다. 본 연구는 형상 문법이 가진 형상 생성 가치와 심미적 가치를 인식하고 건축 분야에서 그 가치를 활용하기 위한 것이다. 형상 문법은 건축 조형 디자인에 활용될 수 있는 새로운 아이디어와 방법을 제공한다.

Contents

1. Introduction

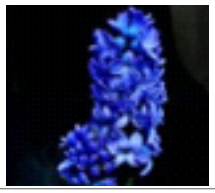
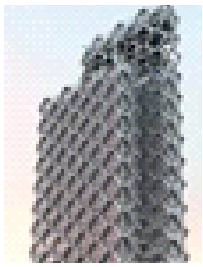
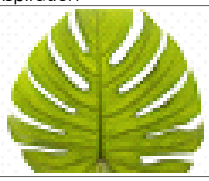
Evidence from cognitive science suggests that the separation of cognitive ability and expression ability driven by the existence of isolation in the brain limits people's ability to create shapes (Lyu Xin & Cho Taigyou, 2019). The process of perceiving architectural forms is easy while the process of creating forms is relatively difficult (Wei Ranran & Cho Taigyoun, 2021). As a result, traditional architectural forms are frequently designed by imitating natural shapes or using experiences or associations as inspiration. However, it is difficult to make good designs without inspiration or experience. Two thousand years ago, the Roman architect Vitruvius emphasized beauty as one of the three central aspects of architectural design. The beauty of architecture belongs to the realm of the artificial, and many architectural designs are inspired by the human body or body parts (Semir Zeki, 2019). One of the most famous definitions of beauty by Edmund Burke is that beauty is a certain characteristic of the body that mechanically acts on the human brain through sensory intervention to a large extent (Edmund Burke, 1767). Aesthetics involves the essence and expression of beauty (Gourav Nandkishor Vinchu et al., 2017). It is a set of principles that architects follow to design pleasant architectural forms. Gourav Nandkishor Vinchu et al. emphasized that anyone can master the philosophy of aesthetics by following some key aesthetic principles (such as Symmetry, Balance, and Pattern).

Shape grammar is a set of shape rules created by George Stiny and James Gips in 1971. Shape grammar was initially proposed for painting and sculpture and was later applied to other fields such as architecture. The shape grammar spans nearly 50 years while its potential for artistic, architectural, and engineering practice and education remains untapped (Buthayna Eilouti, 2019). Shape grammar can be used to describe and understand the design language of certain buildings and generate new architectural forms through regular combinations between shapes. Nonetheless, shape grammar has been used to describe and understand some architectural design languages in the past, and its shape-generating properties are still a relatively unexplored field in the research of architectural forms.

In this study, the shape-generating properties of shape grammar and their influence on architectural forms are investigated from two aspects: the generation of architectural forms and aesthetic preference. First, the literature

related to architectural forms and shape grammar is reviewed. Besides, the aesthetic preferences for shapes are analyzed from a neuroaesthetic perspective, and the general visual characteristics promoting the occurrence of aesthetic preference are summarized. Finally, the value of the generation characteristics of the shape grammar to the architectural forms from the results of the students' works is analyzed. The results suggest that shape-generating properties of shape grammar can produce surprisingly complex shapes through simple rules. Moreover, shape grammar, as a design language based on shape operations, can be adopted to summarize the morphological rules of buildings and generate new architectural forms by combining relationships between shapes or spaces. Shape grammar can be regarded as a design language to support the generation of architectural forms. Additionally, shape grammar can apply visual features that stimulate the occurrence of aesthetic preferences in a supernormal stimulus in the process of generating architectural forms. It can activate its neural mechanisms more powerfully and evoke direct emotional responses. Therefore, shape

[Table 1] Inspiration of Architectural Forms

Inspiration of Architectural Forms			
Hotel and Residences for Lusail City		Milwaukee Art Museum	
Architectural Shape	Inspiration	Architectural Shape	Inspiration
	 Cistanche		 Seabird
Image source: www. googel.com(2021.03.17)			
Hex Towers		Burj Al Arab	
Architectural Shape	Inspiration	Architectural Shape	Inspiration
	 Honeycomb		 Sailboat
Image source: www. googel.com(2021.03.17)			
The Palm Jumeirah		Pyramide du Louvre	
Architectural Shape	Inspiration	Architectural Shape	Inspiration
	 Palm		 Pyramid
Image source: www. googel.com(2021.03.17)			

grammar has a positive impact on architectural forms. Hopefully, this study can provide a minor contribution to the application value of cognitive shape grammar in architecture and guide the design of architectural forms.

2. Shape Grammar and Architectural Form

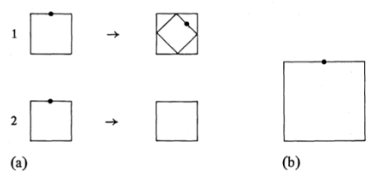
2-1. Methods of Generating Architectural Form

The Bauhaus education method, which occupies an essential position in design education, is based on the premise of feeling and experience. Depending on the practice in the design studio, the design method can be optimized by exploring more possibilities through enough experience and feeling. In this system, students can explore correct answers or processes to solve problems (G. James Daichendt, 2010). Zhong Feifeng generated architectural forms by adding, subtracting, and deforming basic geometric shapes (Zhong Feifeng, 2018). In this process, the designer has gone through constant trial and error. This infinite decision-making process eventually evolved into an exercise in choosing interests and concessions (Eduardo Souza, 2005).

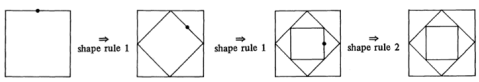
The architectural bionics proposed in the middle of the 20th century is to draw inspiration from nature, imitate and replicate the shape of biological organisms as the inspiration for architectural design (Chiu Wangting & Chiou Shangchia, 2010). Table 1 lists some architectural forms imitating natural shapes, such as Hotel and Residences for Lusail City (Cistanche), Milwaukee Art Museum (Seabird), and The Palm Jumeirah. Natural shapes inspired these architectural forms. Lyu Xin and Cho Taigyoun (2019) classified the methods of generating architectural forms from cognitive science into three categories: directly or indirectly imitating natural shapes, designing using geometric shapes (mathematical structure), and designing through experience and cognitive awareness (symbolization) (Lyu Xin & Cho Taigyoun, 2019). The ability to perceive shapes is formed automatically, but not for the ability to generate shapes (Wei Ranran & Cho Taigyou, 2021). This is in that isolation in the brain leads to the separation of cognitive ability and expressive ability and thus limits people's ability to create shapes (Lyu Xin & Cho Taigyoun, 2019). Therefore, traditional methods of architectural form generally rely on inspiration or feeling to imitate design.

2-2. Introduction of Shape Grammar

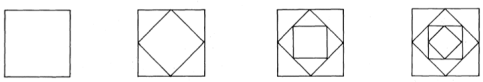
George Stiny, an American designer and computer theorist who is teaching the Department of Architecture at MIT, first introduced the concept of shape grammars in 1971 in an article with James Gips, a professor of computer science at Boston College (George Stiny & James Gips, 1972). Shape grammar is a method of generating forms with specific shape rules and using shapes as primitive.



[Figure 1] (a) Shape rules, (b) initial shape (George Stiny, 1980)



[Figure 2] Generation of a shape using the shape grammar of figure 1 (George Stiny, 1980)

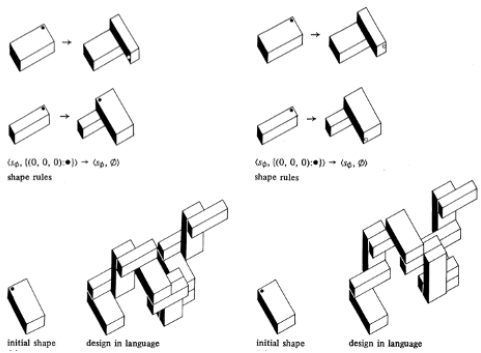


[Figure 3] Some shapes in the language defined by the shape grammar of figure 1 (George Stiny, 1980)

The primitive shape is first applied, followed by the shape rules. The result of applying a shape rule to a given shape is another shape consisting of the given shape with the right side of the rule substituted in the shape for an occurrence of the left side of the rule. The primitive shape b in Figure 1 is embedded in a square by rule 1. The shape generated after three iterations is illustrated in Figure 2. The shape combination rules in Figure 1 are continuously repeated, and the final generated shape is exhibited in Figure 3. The rules are based on geometric transformations (namely, translation, scaling, rotation, reflection), allowing one shape to become part of another shape. It can be used as an analysis tool to decompose complex shapes or as a shape-generating tool to generate complex shapes starting from simple ones (Eleftheria Fasoulaki, 2008).

2-3. Shape Grammar in Architectural Form

Shape grammars were initially proposed for painting and sculpture (Stiny & Gips, 1972; Stiny & Gips, 1978). Early examples focused on two-dimensional works. Shape grammar began to shift from two-dimensional works to three-dimensional spatial grammar since it provided formalism for innovative design (Stiny, 1980). Moreover, it exerted a significant impact on architectural design. In the early days, shape grammar was widely used as a design language to describe and understand the diversity of architectural forms rather than to create new buildings (Terry W. Knight, 1991). In the early 1990s, shape grammar was adopted in the teaching of architectural composition. Architecture students at MIT, Harvard, UCLA, and Yale adopted shape grammar to understand the architectural design language of certain buildings and made various modifications to generate their new language (Bojan Tepavčević & Vesna Stojaković, 2012). Frederick Froebel's kindergarten approach was well-known to architects and designers (Mac Cormac, 1974). Children utilized blocks in free play to design new forms through repeated experimentation (Stiny, 1980). Later, shape grammar was brought into the design studio and architectural practice to reach its full potential. Stiny analyzed the kindergarten education method and proposed a new method that can add blocks to the architectural design. Meanwhile, this method provides some guidance that the combination of blocks should be adopted where that is to develop a grammar for the original design language. Stiny's proposal "develops the idea that a language of designs can be defined from scratch by rules applying to a vocabulary of building elements" (Stiny & Mitchell, 1980).



[Figure 4] Shapes with Shape Grammars (George Stiny, 1980)

Koning and Eisenberg (1981) used shape grammar to make their program generate all the prairie houses designed by Frank Lloyd Wright and other houses that are different but look like architects' works (Koning & Eisenberg, 1981). The specified shape grammar can also generate houses in the Queen Anne style (Flemming, 1987). Shape grammar has a powerful ability to analyze forms and generate shapes. In addition to being used to interpret architectural forms, it can also be employed to produce new architectural forms through shapes. Moreover, original or novel designs can be generated using shape grammar to combine elements through different rules. Figure 4 illustrates four simple rules in the shape grammar that lead to the

generation of extremely different shape rules by changing the position of the labels on the shapes. The combination rules between shapes determine the formation of spatial relationships, and different spatial combination rules drive different final forms. It is the value of shape grammar in shape-generating.

3. Visual Aesthetic Preference

3-1. Visual Aesthetic Preference of Architectural Form

Visual perception is the primary source of information. According to research, more than 80% of human information is obtained through the visual system. Therefore, shapes conforming to the brain's visual cognitive habits would be aesthetically pleasing and recognized as beautiful (Lyu Xin & Cho Taigyoun, 2019; Wei Ranran & Cho Taigyoun, 2021). The visual system is sensitive to features such as contrast, grouping, and symmetry (Ramachandran & Hirstein, 1999). The visual factors (perceptual fluency, symmetry, and grouping) that can promote aesthetic preferences and the conditions that can promote the generation of aesthetic preferences are summarized in Table 2. A prominent idea in visual aesthetics is the notion of fluency (Reber et al., 2004). People prefer shapes that have some complexities yet are orderly and easy to handle. A higher perceptual fluency also leads to a higher evaluation of beauty (Rolf Reber et al., 1998). Recent studies have also demonstrated that the relationship between complexity and aesthetic preference is an inverted U-shaped curve (Nadal et al., 2010). There is a connection between aesthetic preference and the complexity of visual organization (Alexandros A. Lavdas, 2020). Besides, people generally prefer architectural forms with moderate visual complexity (Frith & Nias, 1974; Leder et al., 2004; Dosen & Ostwald, 2016).

Symmetry also contributes to fluency and aesthetic preferences (Wilson & Chatterjee, 2005). Symmetry is considered the key to natural and artistic perfection (Harold Osborne, 1986). The aesthetic preference for symmetry evolved into reproductive adaptability for human survival (Alexander V. Voloshinov, 1996). Symmetry majorly includes translational symmetry, rotation symmetry, and scaling symmetry (Hermann Weyl, 1952). Compared with simple geometric symmetry, relative diversity symmetry can promote the occurrence of aesthetic preference. Grouping is the basic principle of Gestalt, describing the process by which the visual system sorts repetitive and related information (Alexander, 2002). Grouping features (such as color or form) trigger synchronous action

[Table 2] Visual Features that Promote the Occurrence of Aesthetic Preferences

Visual Features that Promote the Occurrence of Aesthetic Preferences		
Visual Features	Conditions	Researchers
Fluency	Both complex and orderly; moderately complex	Reber et al., 2004; Rolf Reber et al., 1998; Nadal et al., 2010; Alexandros A. Lavdas, 2020; Frith & Nias, 1974; Leder et al., 2004; Dosen & Ostwald, 2016
Symmetry	Translational symmetry, rotation symmetry, scaling symmetry, etc.	Alexander V. Voloshinov, 1996; Harold Osborne, 1986; Hermann Weyl, 1952; Wilson & Chatterjee, 2005; Ramachandran & Hirstein, 1999
Grouping	Repetitive and relevant arrangement of visual information	Alexander, 2002; Ramachandran & Hirstein; Singer & Gray, 1995; Ramachandran & Hirstein, 1999

potentials between interconnected neurons responsible for processing these features (Ramachandran & Hirstein, 1999; Singer & Gray, 1995). These visual mechanisms may modulate the pleasurable responses associated with viewing the ordered patterns of forms and colors in buildings (Alexander, 2002). The above-mentioned visual features can actively contribute to the occurrence of aesthetic preferences. The universal visual features inducing the occurrence of aesthetic preferences may even more actively promote the occurrence of aesthetic preferences for architecture when being applied to the design of architectural forms.

3-2. Aesthetic Preference as Supernormal Stimulus

In the expanding field of cognitive science, there is a strong interest in neuroaesthetics. In the book "European Art: A Neuroarthistory," Jhon Onians outlines how art reflects cognitive patterns and evolves neural networks in people of different cultures and environments from Paleolithic to modern times. In the monumental four-volume treatise "The Nature of Order", Alexander relates some of the latest discoveries in evolutionary biology to architecture to discuss the need for bio-spheric beauty. Evolutionary development has enabled us to survive and thrive by adopting certain specific preferences for beautiful natural things. The supernormal stimulus was proposed by biologist Niko Tinbergen in 1970 based on the courtship behavior of animals. Biologist Niko Tinbergen discovered that animals exhibit courtship behavior following certain traits in their courtship partners. If these characteristics are amplified, courtship behavior becomes more intense. These features are called supernormal stimuli. For example, oystercatchers prefer artificial eggs that are larger and more distinctly spotted instead of their own normal-sized eggs (Niko Tinbergen, 1951).

Organisms would exhibit a preference for the stimulating properties of natural evolution, such as size and color. Animals exhibit behaviors that favor artificial stimuli over naturally occurring ones when artificially exaggerated stimuli are present (Dave McFarland, 2014). Harvard psychologist Deirdre Barrett believes that supernormal stimuli have a powerful effect on human behavior. Make-up is also a direct example. Make-up can change facial symmetry, skin texture, color, and perception of feature contrast (Etcoff et al., 2011). This can be explained that symmetrical faces appear to be healthier, and people prefer symmetrical faces (Little et al., 2011; Rhodes, 2006; Thornhill & Gangestad, 1999). Moreover, women are considered more attractive when wearing high heels than without high heels (Paul H. Morris et al., 2013). This is because high heels act as a supranormal stimulus exaggerating some gender-specific elements of female gait (Paul H. Morris et al., 2013). Supernormal stimulation can best stimulate the brain's visual area. This effect can be applied to human pattern recognition and aesthetic preferences. Designers can grasp the essence or characteristics of something to evoke a direct emotional response. This process mimics what brain regions have evolved and more powerfully activates the neural mechanisms initially activated by primitive objects (Ramachandran & William Hirstein, 1999).

4. The Value of Shape Grammar to Architectural Form

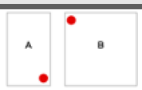
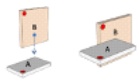
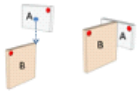
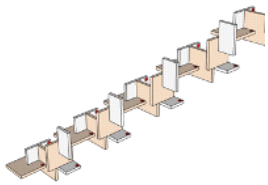
4-1. Generative Value of Architectural Form

Generally, traditional modeling design methods rely on inspiration or experience. However, inspiration is a sudden state of mind. The process of finding inspiration may be a momentary thought or a long and painful process. Experience indicates achieving the purpose of optimized design by exploring more possibilities after continuous trial and error.

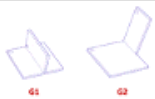
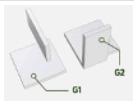
Therefore, a design method based on inspiration or experience will bring a limitation that it is difficult to make good designs without inspiration or experience. In fact, the design process is also a methodology to break away from inspiration. Because a lot of data needs to be resolved. If the design concept is not based on data analysis, it is difficult to be convincing. The reason why architecture needs a diagram is also because they need to be based on data. Design concepts can be put forward through data analysis, but there are many difficulties when converting concepts into architectural form. If combined with shape grammar, good results can be achieved by taking advantage of its shape-generated properties.

Shape grammar can provide inspire the generation of architectural forms. It can be employed not only to analyze the architectural form systematically and summarize its morphological rules but also as a design language for architectural forms generation to solve the pain of no design inspiration. Using shapes as basic elements, new form designs are generated with grammar. Various shapes can also be generated through differences in connection positions and rules. In an experiment, shape grammar was applied to the teaching process of a design studio at Hongik University to explore the impact of the generative properties of shape grammar on architectural forms. Table 3 presents an illustration of the shape grammar rules during the teaching process. First, two different original shapes a and

[Table 3] Rules for Shape Generation

Initial Shapes		
		
Grammar 1 (A ← B)		Grammar 2 (B ← A)
		
Design in Grammars		
		

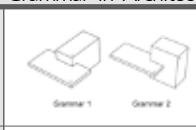
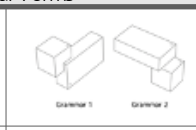
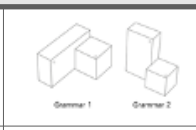
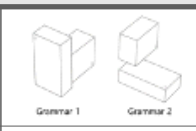
[Table 4] Forms Generated by Shape Grammar

Forms Generated by Shape Grammar			
Grammars			
Design in Grammars			
Grammars			
Design in Grammars			

b are set, and red stickers are put on the corners of shape a and shape b to help distinguish the direction of the shape. Then, two connection rules are set through the shape of a and b. Shape b connected to shape a is called grammar 1. Similarly, shape a connected to shape b is called grammar 2. Shapes a and b are joined by the two rules of the connection rule. This action is repeated over and over again to form the final form.

The forms in Table 4 are generated by students using shape grammar in the teaching process. The shape grammar explained in Table 3 is Learned, and the original shapes a and b are used to formulate the connection relationship between the two shapes. Then, shapes a and b are connected by rules 1 and 2 to generate the final architectural form. The resulting final form suggests that the final form is also different by changing the position of the shape connection and the regular changes, though the size and material of the shape are not much different. Shapes a and b are treated as spaces a and b. Similarly, their spaces are connected by two connection rules. The generated form is interpreted through architectural techniques (such as architectural elements and materials). As a

[Table 5] Application of Shape Grammar in Architectural Forms

Application of Shape Grammar in Architectural Forms				
Grammars				
Design in Grammars				
Architectural Transformation				

[Table 6] Analysis of Visual Features of Architectural Forms Generated by Shape Grammar

Analysis of Visual Features of Architectural Forms Generated by Shape Grammar							
Architectural Forms							
Visual Features	Symmetry	Translational Symmetry	Translational Symmetry	Translational Symmetry	Translational Symmetry	Translational Symmetry	Translational Symmetry
	Grouping	●	●	●	●	●	●
	Processing Fluency	●	●	●	●	●	●

result, its shape can be used in architecture to produce the value of its architectural form (Table 5). This is the value of shape grammar in the generation of architectural forms, enlightening the design of architectural forms.

4-2. Visual Stimulation of Aesthetic Preference

Shape grammar focuses on grammar like other grammars (Arus Kunkhet, 2015). Shape grammar emphasizes that form is generated by strict deduction of certain rule. In the process of form generation, the order is formed through rules. In the process of repeated deduction of rules, the combinatorial relations between their shapes are repeatedly emphasized to form grouping relations in the way of translational symmetry. Table 6 presents the architectural forms generated by shape grammar. The visual characteristics of architectural forms are analyzed. Multiple shapes can be grouped into a group through repeated combinations of specific rules. The rules continue to be repeated, resulting in the group translational symmetry of the architectural form. In architectural aesthetics, the visual systems of humans generally have a positive sensitivity to forms with symmetry, grouping, and perceptual fluency. It is also easier for the forms with these characteristics to induce humans' aesthetic preferences.

Our perception of beauty is formed automatically. The brain can easily tell beautiful things or shapes. Nevertheless, it is difficult to create beautiful things or shapes. In the process of shape generation, shape grammar applies visual features that easily induce visual aesthetic preference to the visual features of architectural form by means of emphasis or exaggeration. Therefore, the architectural form generated by the shape grammar will exaggerate the visual expression of aesthetically sensitive features in the final form. This process can more forcefully activate the neural mechanisms that originally had primordial form activation. Thus, more actively induce the occurrence of aesthetic feelings. This visual property of shape grammar can be applied to pattern recognition and aesthetic preference stimulation of architectural form. Architects can grasp the visual essence or characteristics stimulating aesthetic preference and apply them to the design of architectural forms to evoke direct emotional reactions.

5. Conclusion

In this paper, the shape generation value and aesthetic value of shape grammar were analyzed, followed by the positive influence on architectural forms. Architectural design is essentially a scientific and artistic creative activity. The form design of the architecture is the most direct way to express the architecture. The building must meet the aesthetic needs of people while satisfying the use function. Therefore, creating architectural forms more efficiently and making the created forms more in line with people's aesthetic needs are emphasized in the architectural design. This paper proposes to recognize the shape value and aesthetic value of shape grammar and play its application value in architecture. Simultaneously, it would provide a new method for the creation of architectural forms. Shape grammar is a design language for shape-generating and beauty. It can be employed to improve the limitations of traditional methods of form design relying on inspiration and experience and enhance the aesthetic preference of architectural forms for people. However, it should not be blindly treated as a mechanical means of generating architectural forms. The use function of the space and the coordination with the surrounding environment need to be fully considered, as well as the use and function of the space and the coordination with the surrounding environment, so as to perfectly realize the value of the Architectural itself.

References

1. Alexander V. Voloshinov, Symmetry as a Superprinciple of Science and Art, The MIT Press, 1996, Vol.29, No.2
2. Alexandros A. Lavdas, Aesthetic preference is related to organized complexity, PLoS ONE, 2020, Vol.15, No.6
3. Bojan Tepavčević & Vesna Stojaković, Shape grammar in contemporary architectural throry and design, Architecture and Civil Engineering, 2012, Vol.10, No.2
4. Buthayna Eilouti, Shape grammars as a reverse engineering method for the morphogenesis of architectural façade design, Frontiers of Architectural Research, 2019, Vol.8, No.2
5. Chiu Wanting & Chiou Shangchia, Discussion on theories of bionic design, International Association of Societies of Design Research, Energy Conversion and Management, 2019, Vol.63, No.1
6. Dosen & Ostwald, Evidence for prospect-refuge theory: a meta-analysis of the findings of environmental preference research, City, Territory and Architecture, 2016, Vol.3, No.4
7. Etcoff et al., Cosmetics as a Feature of the Extended Human Phenotype: Modulation of the Perception of Biologically Important Facial Signals, PLoS ONE, 2011, Vol.6, No.10
8. Flemming, More than the sum of parts: the grammar of Queen Anne houses, Environment and Planning B: Planning and Design, 1987, Vol.14, No.3
9. Frith & Nias, What determines aesthetic preferences, Journal of General Psychology, 1974, Vol.91, No.3
10. George Stiny, Introduction to shape and shape grammars, Environment and planning B: planning and design, 1980, Vol.7, No.3
11. Gourav Nandkishor Vinchu et al., Application of Aesthetics in Architecture and Design, International Journal of Engineering Research and Technology, 2017, Vol.10, No.1
12. Harold Osborne, Aesthetic Experience and Cultural Value, The Journal of Aesthetics and Art Criticism, 1986, Vol.44, No.4
13. Harold Osborne, Symmetry as an aesthetic factor, Computers & Mathematics with Applications, 1986, Vol.12, No.1-2
14. Helmut Leder et al., A model of aesthetic appreciation and aesthetic judgments, the british psychological society, 2014, Vol.95, No.4
15. James Daichendt, The Bauhaus Artist-Teacher: Walter Gropius's Philosophy of Art Education, Teaching Artist Journal, 2010, Vol.8, No.3
16. Koning, H. & Eizenber, The language of the prairie: Frank Lloyd Wright's prairie houses, Environment and Planning B, 1981, Vol.8, No.3
17. Little et al., Facial attractiveness: evolutionary based research, Philososphocal Transactions of the Royal Society B, 2011, Vol.366, No.1571
18. Lyu Xin & Cho Taigyoun, Research on the Differences of Aesthetic Judgment between Visual and Cognitive Aspects Based on Evolutionary Psychology and Cognitive Neuroscience, The Korean Society of Design Culture, 2019, Vol.25, No.4
19. Nadal et al., Emotional, behavioral, and cognitive reactions to microaggressions: Transgender perspectives, Psychology of Sexual Orientation and Gender Diversity, 2010, Vol.1, No.1
20. Paul H. Morris et al., High heels as supernormal stimuli: How wearing high heels affects judgements of female attractiveness, Evolution and Human Behavior, 2013, Vol.34, No.3
21. Ramachandran & Hirstein, The science of art: a neurological theory of aesthetic

experience, Journal of Consciousness Studies, 1999, Vol.6, No.6-7

22. Reber et al., Processing Fluency and Aesthetic Pleasure: Is Beauty in the Perceiver's Processing Experience, Pcrsonality and Social Psychology Review, 2004, Vol.8, No.4

23. Rena Thapa, Rhythm in architecture: an aesthetic appeal, Journal of the Institute of Engineering, 2017, Vol.13, No.1

24. Rhodes, The Evolutionary Psychology of Facial Beauty, Annual Review of Psychology, 2006, Vol.57

25. Rolf Reber et al., Effects of perceptual fluency on affective judgments, Psychological Science, 1998, Vol.9, No.1

26. Semir Zeki, Beauty in Architecture: Not a Luxury - Only a Necessity, Architectural Design, 2019, Vol.89, No.5

27. Singer & Gray, Visual Feature Integration and the Temporal Correlation Hypothesis, Annual Review of Neuroscience, 1995, Vol.18

28. Stiny & Mitchell, The grammar of paradise: on the generation of Mughul gardens, Environmental and Planning B, 1980, Vol.7

29. Thornhill & Gangestad, Facial attractiveness, Trends in Cognitive Sciences, 1999, Vol.12, No.3

30. Wang Naige et al., Neural correlates of aesthetics, Advances in Psychological Science, 2010, Vol.18, No.1

31. Wei Ranran & Cho Taigyoun, Research on the Influence of the Order Formed in Nature on the Architectural Modeling, The Korean Society of Design Culture, 2021, Vol.27, No.2

32. Wilson & Chatterjee, The assessment of preference for balance: Introducing a new test, Empirical Studies of the Arts, 2005, Vol.23, No.2

33. Zhong Feifeng, Research on the Innovative Application Methods of Lingnan Traditional Elements in Architectural Design, MATEC Web of Conferences, 2018

34. Fasoulaki E., Integrated design: A generative multi-performatiove design approach, master thesis, MIT, 2008

35. www.google.com

36. www.naver.com