형상 문법으로 생성된 조형에서 느끼는 미의식의 구조 연구

Research on the Structure of Aesthetic Consciousness in Form Generated by Shape Grammar

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https://doi.org/10.46248/kidrs.2022.1.351

접수일자 2022. 2. 24. / 심사완료일자 2022. 3. 17. / 게재확정일자 2022. 3. 25.

This study was supported by the Global Scholarship of Hongik University (No. C0401601).
The China Scholarship Council funded Ms.Ranran Wei's graduate program in Hongik University (No. 202008260007)

Abstract

Shape grammar has encouraging implications for the production of architectural forms. However, the architectural form must also have aesthetic value. But, shape grammars generate architectural forms with inconsistent degrees of aesthetic appeal. The purpose of this paper is to explore why forms generated by shape grammar differ in terms of aesthetic appeal, and shape characteristics that influence judgments of aesthetic appeal. In this study, twenty-one forms generated by shape grammar were used as visual stimuli in a questionnaire survey. 331 participants were asked to perform a judgment task (judgment of aesthetic appeal) and an evaluation task (evaluation of the degree of aesthetic appeal). The results of the questionnaire show that shape orientation, the number of edges in the final form, and the type of space have an impact on the judgment and evaluation of a shape's aesthetic appeal. In the process of generating forms using shape grammar, by constraining shape generation to include these specified elements, the generated shape is more likely to be viewed as aesthetically appealing.

Keyword

Shape grammar, Form generation, Aesthetic appeal

요약

형상 문법은 건축 조형 생성에 긍정적인 의미를 지닌다. 하지만, 좋은 건축양식은 미적 가치도 있어야 한다. 그러나 형상 문법에 의해 생성된 조형의 미적 매력 정도는 일관성이 없다. 본문은 형상문법으로 생성된 조형이 왜 미적 매력의 차이를 보이는지, 미적 매력의 판단에 영향을 미치는 형태 특징을 탐구한다. 본 연구는 설문조사를 통해 형상 문법에 의해 생성된 21가지 조형을 시각적 자극의 대상으로 한다. 331명의 피험자가 판단 과제(미적 매력 판단)와 평가 과제(미적 매력의 정도 평가)를 수행하도록 했다. 설문조사의 결과는 형태 방향의 종류, 최종 조형의 경계 수, 공간의 형태가 미적 매력의 판단과 평가에 영향을 미치는 것으로 나타났다. 형상 문법을 이용하여 조형을 생성하는 과정에서 지정된 형태의 특징을 구속함으로써 조형이 더욱 미적 매력적일 수 있다.

Contents

1. Introduction

The concept of shape grammar was first proposed by George Stiny and James Gips in 1971. It is a design reasoning method that takes symbolic shapes as its basic elements and uses grammatical structure to then analyze and generate new forms. Shape grammar can be used for the purpose of shape generation, producing novel and original forms through different combinations of shapes (George Stiny, 1980). Shape grammar has been proven to have great flexibility in shape generation; it is widely used in product design, architecture, and urban design (Arus Kunkhet et al., 2012). Since it is a design language, it can be used to resolve the limitations of traditional architectural methods which rely mainly on inspiration and intuition (Anant Prakash et al., 2017). The value of using shape grammar for the purpose of generating shapes is seen as a positive advancement in the architectural field. It has been a welcome new technique, which, however, still has its drawbacks. The main issue is that what we consider to be a good architectural form must also have aesthetic value.[1] Shape grammar focuses solely on grammar,[2] but grammar itself cannot guarantee the production of forms with aesthetic value. The fact is that although shape grammar aids in increasing the generation of forms, it also produces shapes with no aesthetic value, which limits its applicability as a design aid.[3]

Architectural form refers to architecture's visual features. Since it is the visual feature of architecture that people first encounter, it heavily influences how any architectural project is judged in terms of aesthetics. The definition of architectural form can be restricted to the surface and edge contours of three-dimensional objects, independent of perceptible finishes such as materials and colors.[4] In architecture, the aesthetic appeal of a building is a key issue usually considered a subjective feature. However, in contrast with this view of aesthetic appeal as purely subjective, it is true that while some buildings receive worldwide praise, others receive widespread criticism. Given this, it is possible that there are certain formal architectural features that a majority will agree make buildings attractive.[5]

There is already prior research showing that certain forms of design are preferred overall. Visual complexity has been named as one of the primary determinants of aesthetic value (Winsor 2004) and has been shown to be a key factor in consumer preference (Creusen et al., 2010). Visual complexity plays an important role in shaping aesthetic preferences (e.g., Jacobsen & Hofel, 2002; Jacobsen et al., 2006; Tinio & Leder, 2009). It is important to note what features comprise visual complexity. Such related factors that influence the popular perception of complexity can include the orientation of the shape and the number of edges (Munsinger H, Kessen W, 1964; Chipman SF, 1977; Nadal M et al., 2010). The number of edges is a determining feature of the form. Whether a form is registered as visually complex is decided by its edges (Sun Litian et al., 2018). Edges are one of the shape characteristics that affect personal aesthetic preference (Liu Jingshu, 2013). Lyonel Charles Feininger, one of the representative painters of Expressionism,

1) Alex Coburn, Buildings, Beauty, and the Brain: A Neuroscience of Architectural Experience, Journal of Cognitive Neuroscience, 2017, Vol.29, No.9, p.1521

2) Arus Kunkhet, 'Harmonised Shape Grammar in Design Practice', Doctoral thesis, Staffordshire University, 2015, p.48

3) Arus Kunkhet, 'Harmonised Shape Grammar in Design Practice', Doctoral thesis, Staffordshire University, 2015, p.48

4) K. Aysha Jennath & P.J. Nidhish, Aesthetic Judgement and Visual Impact of Architectural Forms: A Study of Library Buildings, Procedia Technology, 2016, Vol.24, p.1809

5) K. Aysha Jennath & P.J. Nidhish, Aesthetic Judgement and Visual Impact of Architectural Forms: A Study of Library Buildings, Procedia Technology, 2016, Vol.24, p.1808

identified edges as an essential aesthetic component (Gabriele Peters, 2007). Moving past the form of the object, another important aspect of aesthetic considerations is its spatial composition: the relative position of the objects to each other and their surrounding frame.[6] Compared with the arrangement of a space based on a single orientation, multiple variations in orientation are often considered more aesthetically attractive. In addition, space is an essential characteristic of architecture (Bruno Zevi, 1951). In an experiment that gauged people's preference for types of spaces, the results showed that semi-open space had the highest preference score, followed by closed space, and finally open space (Gao Tian et al., 2019). Many studies on evolutionary aesthetics show that people prefer limited, semi-open spaces to completely open spaces or tightly enclosed spaces. According to an evolutionary view, this is due to the nature of human adaptation in the evolutionary process, which has led to an innate preference for specific shapes and types of spaces. When applied to architectural design, the visual preference for these types of shapes and spaces also extends to the visual preference for certain architectural forms (Dosen & Ostwald, 2016).

In this study, twenty-one forms generated by shape grammar were used as visual stimulus objects. The twenty-one forms were classified according to three aspects: orientation, number of edges, and space type. 331 healthy adults were used as experimental subjects to determine which of these twenty-one shapes were identified as aesthetically appealing (Task 1) as well as the degree of their aesthetic appeal (Task 2), by means of a questionnaire. After collecting this data, the results of the questionnaire survey were used to analyze the shape characteristics that influenced the judgment and evaluation of aesthetic appeal. The purpose of this research is to reliably generate forms with higher aesthetic appeal by controlling specific shape features in the process of shape generation. By doing this, we hope to find a way to overcome the aesthetic limitations of shape grammar's use in architectural design.

2. The Value of Shape Grammar

2-1. Shape Grammar in Architecture

Shape grammar was first developed by George Stiny and James Gips in 1971. Shape grammar is a design reasoning algorithm that uses shapes as its basic components and then generates new forms through specific combination grammars (George Stiny & James Gips, 1971). It is a design method based on the rules of arithmetic. Shape grammar is a visual rule system (George Stiny, 2018), which takes simple shapes and builds them into complex forms through the methods of translation, rotation, and more (Eleftheria Fasoulaki, 2008). Shape grammar saw its first applications in painting and sculpture (Stiny & Gips, 1972) before being popularized for use in architectural design (Stiny, 1980). Shape grammar is both descriptive and generative; not only can shape grammar be used to describe and understand the diversity of architectural forms, but it can also be used to generate new forms (Stiny & Mitchell, 1980; Terry W. Knight, 1991). Architecture students at MIT, Harvard, UCLA, and Yale have used shape grammar to analyze the design language of certain buildings, make various modifications upon that language, and then generate their own new languages on that basis.[7] The shape-generating properties of shape grammar allow for the generation of original formal designs through the novel application of different rules for shapes (George Stiny, 1980).

6) Stephen E. Palmer et al., Visual Aesthetics and Human Preference, Annual Review of Psychology, 2013, Vol.64, p.93

7) Bojan Tepavčević & Vesna Stojaković, Front Matter Volume 1, Proceedings of the 39th eCAADe Conference – Volume 1, University of Novi Sad, Novi Sad, Serbia, 2021, Vol.9, No.16, p.174

Shape grammar's generative abilities have found broad applicability in product design, architecture, and urban design, among others (Arus Kunkhet, 2012).

Design is usually considered subjective, based entirely on intuition and creative expression (Anant Prakash et al., 2017). However, for architectural design students, developing this intuition during the first years of study and after graduation is a major obstacle in the field (Anant Prakash et al., 2017). Developing intuition is necessarily time-consuming, which costs new entrants in terms of productivity. The shape-generating properties of shape grammar mean that it can be used in the early stages of both an architect's career and the first stages of any architectural design. The shape generated by shape grammar generally refers to its form or boundary (also called its outline or outer surface), rather than other surface attributes, such as colour, texture, material, etc. (Anant Prakash et al., 2017). Shape grammar can introduce spontaneity into the design process, helping to achieve a unique design rather than another variation on a standardized template. Therefore, the shape-generating properties of shape grammar have had an overall positive impact on architecture.

2-2. Aesthetic Limitation of Shape Grammar

In architectural design, designers pay more attention to form and aesthetics than any other factor.[8] Architectural form is the visual feature of a building that gives it a unique identity and distinguishes it from other buildings.[9] Two thousand years ago, the Roman architect Vitruvius emphasized beauty as one of the three core aspects of architectural design. Since then, the idea has not substantially changed, so that what is considered a good architectural model must have an aesthetic sense.[10] Therefore, aesthetic appeal is an important consideration in architectural design. Architectural form plays a crucial role in the aesthetic appeal of a building, the main perceptible visual feature of the building (K. Aysha Jennatha & P.J. Nidhishb, 2016). Therefore, while meeting basic functional requirements, good architectural models aim to improve and enhance the aesthetic appeal of the architectural form.

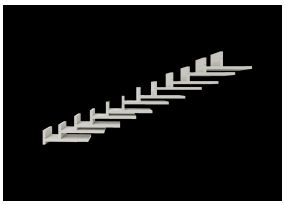
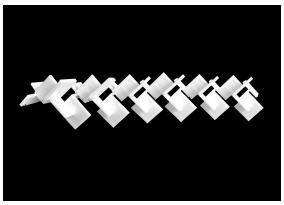
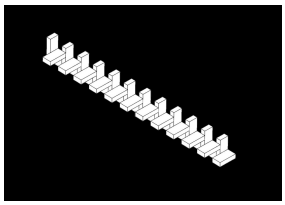
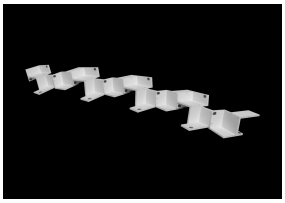
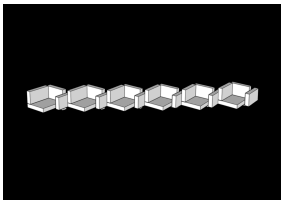
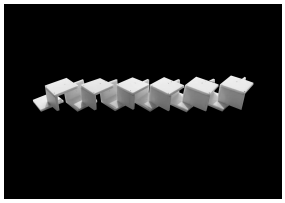
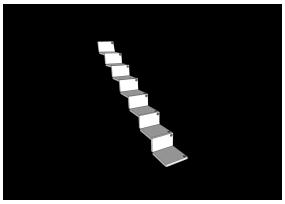
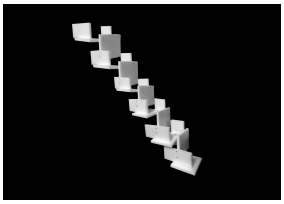
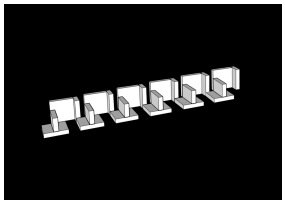
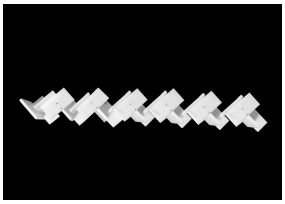
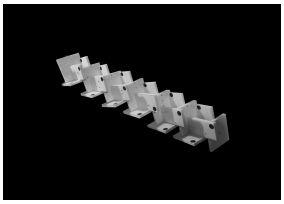
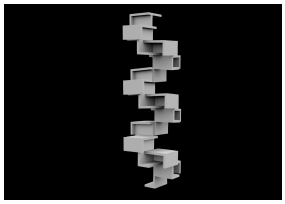
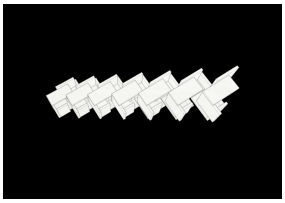
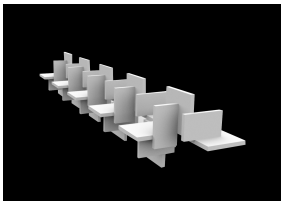
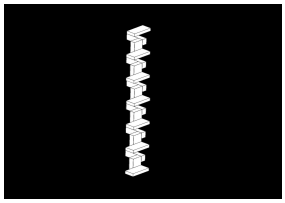
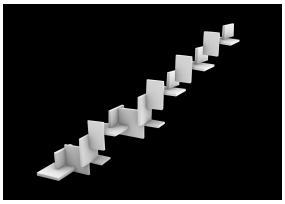
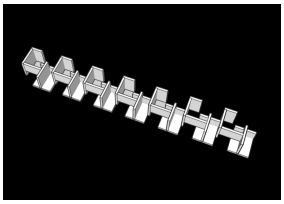
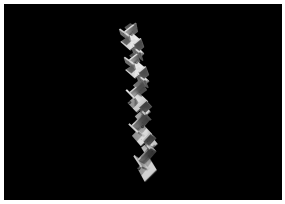
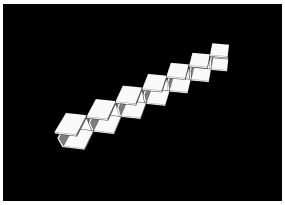
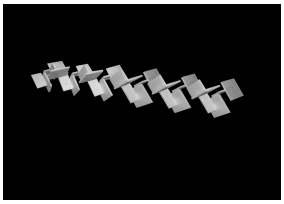
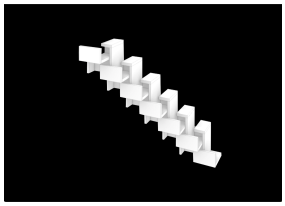
It is the unique stimulating attributes of aesthetic objects that evoke specific emotions or emotional responses in the viewer. Individuals experience aesthetic pleasure when they appreciate nature, artwork, music, or other manmade works (Packard & Berlyne, 1974; Armstrong & Detweiler Bedell, 2008). Although aesthetic appeal is subjective, there are still consistent results on what is generally considered beautiful and what is not, so that it is possible to define the components of aesthetic appeal (Ernestasia Siahaan et al., 2014). Kant pointed out that aesthetic pleasure is an emotional response of individuals to both artistic works and natural beauty, triggered by the form of beauty (Teng Shouxiao, 1998). People are able to distinguish between the different physical and psychological sensations of multiple forms, and then will select the form that best meets their needs from among various possibilities. They will subsequently develop a good impression of their chosen form. Those forms or combinations of forms that are subject to favoritism are accumulated in people's minds as taste and are classified and standardized (Wu Huanjia, 2013). Shape grammar provides a method for the generation of architectural forms by the rules of transformation to produce infinite formal designs. Although the generated shape does exhibit some

8) 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, p.191

9) K. Aysha Jennath & P.J. Nidhish, Aesthetic Judgement and Visual Impact of Architectural Forms: A Study of Library Buildings, Procedia Technology, 2016, Vol.24, p.1808

10) Alex Coburn, Buildings, Beauty, and the Brain: A Neuroscience of Architectural Experience, Journal of Cognitive Neuroscience, 2017, Vol.29, No.9, p.1521

[Table 1] Form Number

No.	Form	No.	Form	No.	Form
1		2		3	
4		5		6	
7		8		9	
10		11		12	
13		14		15	
16		17		18	
19		20		21	

design principles and basic transformation rules, it does not guarantee mass aesthetic appeal (Huang et al., 2009; Arus Kunkhet, 2012). Shape grammar is as concerned with syntax as any other grammar.[11] Shape grammar has great advantages in the large-scale generation of architectural forms, and it can also be used to overcome the limitations of traditional architectural methods relying on inspiration or feeling, which take years of experience to develop. However, in an aesthetic sense, even though shape grammar can produce infinite forms, it seems to generate a large number of meaningless shapes, making it inefficient as an architectural design aid (Arus Kunkhet, 2015, pp.48-49).

3. Questionnaire Survey

3-1. Material

The objects used in this study as visual stimuli included twenty-one forms generated by shape grammar (see Table 1). These twenty-one shapes were selected from the work of students in the Department of Architecture, Spatial and Visual Design at Hongik University. A 90° vertical connection between shape A and shape B is used in shape grammars. Based on the shape generating properties of shape grammar, the visual features of twenty-one shapes are analyzed from three aspects. First, we take the visual primary as the centre, and the spatial rectangular coordinate system (xyz-axis) as the coordinate system for orientation recognition, and we observe the types of positions (one, two or three) of the shape a/b in the final form. Second, according to different connection rules, the number of edges of the final form is taken into consideration. Finally, this paper discusses the potential value of shape grammar for architectural modelling, which is inseparable from the perception of space. The twenty-one shapes are divided and classified according to the type of space; they can be divided into open space (n<3 surfaces) and semi-open space (n≥3 surfaces). Semi-open as a space type can be further subdivided into two types: covered and uncovered. Therefore, this study analyzed the shape characteristics of twenty-one forms from three aspects: coordinate orientation (xyz-axis), number of edges, and spatial type (see Table 2).

[Table 2] Classification of Shape Features

Shape Feature			Form No.
Orientation (xyz axis)	1(x/y/z) kind		1, 3, 7, 15
	2(xy/xz/yz) kinds		4, 5, 6, 8, 9, 10, 11, 12, 14, 16, 17, 19
	3(xyz) kinds		2, 13, 18, 20, 21
Number of Edges	More		2, 6, 8, 10, 11, 12, 13, 14, 16, 18, 20, 21
	Less		1, 3, 4, 5, 7, 9, 15, 17, 19
Spatial Type	Open		1, 3, 7, 15
	Semi-open	Covered	6, 10, 12, 13, 16, 19, 21
		Uncovered	2, 4, 5, 8, 9, 11, 14, 17, 18, 20

3-2. Participants and Methods

A total of 331 adults participated in the questionnaire survey. The designers of the twenty-one forms were not mentioned in the questionnaire. The rationale behind this decision was to minimize the influence of attitudes and memory on the participants' judgment of aesthetic appeal. Participants in the questionnaire performed a judgment task and a mandatory evaluation task. In the questionnaire, the twenty-one forms were coded sequentially (see Table 1). Participants were asked to judge the aesthetic appeal of each of the twenty-one forms generated by shape grammar (Task 1: Judgment of Aesthetic Appeal) and judge the

11) Arus Kunkhet, 'Harmonised Shape Grammar in Design Practice', Doctoral thesis, Staffordshire University, 2015, p.48

degree of aesthetic appeal (Task 2: Judgment of the Degree of Aesthetic Appeal) in terms of high, medium, and low (see Table 3).

[Table 3] Survey Questionnaire

Task 1	Judgment of Aesthetic Appeal		
	Yes	No	
Task 2	Judgment of the Degree of Aesthetic Appeal		
	High	Medium	Low

[Table 4] Questionnaire Results (T: Task, Y: Yes, N: No, H: High, M: Medium, L: Low)

No.	T1	T2
No.1	N>Y	L>M>H
No.2	Y>N	M>H>L
No.3	Y>N	L>M>H
No.4	Y>N	L>M>H
No.5	Y>N	L>M>H
No.6	Y>N	H>M>L
No.7	Y>N	L>M>H
No.8	Y>N	M>H>L
No.9	Y>N	L>M>H
No.10	Y>N	H>M>L
No.11	Y>N	M>H>L
No.12	Y>N	H>M>L
No.13	Y>N	H>M>L
No.14	Y>N	M>H>L
No.15	N>Y	L>M>H
No.16	Y>N	M>H>L
No.17	Y>N	L>M>H
No.18	Y>N	M>H>L
No.19	Y>N	L>M>H
No.20	Y>N	M>H>L
No.21	Y>N	H>M>L

3-3. Results

From the results of this questionnaire(see Table 4), the forms judged to be aesthetically appealing in the judgment task of aesthetic appeal (given a "Yes" answer in Task 1) included forms No. 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20, 21. The forms judged as having no aesthetic appeal (given a "No" answer in Task 1) were No.1, and 15. In Task 2, the forms identified as having high aesthetic appeal (H>M>L / H>L>M) are: No.6, 10, 13, 14, 21. The forms which received the rating of medium aesthetic appeal were No. 2, 8, 11, 12, 16, 18, 20. The forms which were recognized as having low aesthetic appeal (L>M>H / L>H>M) were: No. 1, 3, 4, 5, 7, 9, 15, 17, 19. In general, most of the forms generated by shape grammars were judged to be aesthetically appealing. However, in the evaluation task of the degree of aesthetic appeal, there were marked differences in the degree of aesthetic appeal.

4. Discussion

4-1. Task 1: Factors Affecting Judgment of Aesthetic Appeal

In Chapter 3, the shape characteristics of twenty-one forms are analyzed from three aspects: orientation (xyz-axis), number of edges, and spatial types (see Table 2). The first task in the questionnaire survey is to judge whether the twenty-one forms have aesthetic appeal. The results of Task 1 show that the aesthetic appeal of shapes generated by shape grammar is related to specific shape features. Table 5 calculates the proportion of shape features that are judged to have aesthetic appeal. For example, there were four forms with only one coordinate orientation (No. 1, 3, 7, 15), but only one form among them (No. 3) was judged to be aesthetically appealing. Therefore, this shape feature's aesthetic appeal has a probability of 25%. Through this method, the other shape features are measured in turn to calculate the aesthetic appeal of the ratio (see Table 5). The shape features considered to be 100% aesthetically appealing are: three-coordinate arrangements of shape A/B in the final form (xyz-axis), a large number of edges, and covered semi-open space. Secondly, a two-coordinate arrangement orientation (xy/xz/yz-axis) was judged to be aesthetically attractive in 83.3% of shapes, and the shape feature of semi-open (uncovered) space was judged to be aesthetically

attractive in 81.8% of shapes. The portion of shape features with a lower number of edges was judged to be aesthetically attractive in 77.8% of shapes. The shape features judged to have the lowest aesthetic appeal were in a single coordinate direction (x/y/z-axis) and the open space type. In these types of shapes, the ratio of aesthetic appeal is only 25%. Therefore, a shape a/b with two or more arrangement orientations and a shape with a larger number of edges is more likely to be judged as an aesthetically appealing shape. In addition, compared to open spaces, the shape of semi-open spaces is more likely to be judged as aesthetically appealing. In the semi-open space type, a form with a top or roof is more likely to be favored by people.

4-2. Task 2: How to Improve Aesthetic Appeal

From the survey results of the questionnaire, we can demonstrate that the coordinate position, the number of edges, and the space type affects the judgment and evaluation of aesthetic appeal. This chapter focuses on analyzing the specific features of the forms within the range of different degrees of aesthetic appeal, from low to medium to high, and the proportions occupied by each of the shape features. It also summarizes how to use these shape features to make shape grammar generate more aesthetically appealing shapes. For this study, forms that received a judgment valuation of high or medium aesthetic appeal are considered to have a relatively high aesthetic appeal.

Table 6 shows that the shapes identified as having high and moderate aesthetic appeal have a relatively larger number of edges, while the shapes identified as having low aesthetic appeal have a smaller number of edges. Therefore, it can be determined that having more edges is a necessary condition for a form to be recognized as having high aesthetic appeal. Compared with the deterministic influence of edge number on judgments of high aesthetic appeal, coordinate orientation and spatial type are more uncertain factors. Table 7 shows that a form with three orientations is 100% affirmed as having higher aesthetic appeal in the judgment task; that is, the form was judged as having high or medium aesthetic appeal. In addition, with the semi-open space type, the form with a top (83.3%) was more likely to be recognized as a form with higher aesthetic appeal than the form without a top (70.7%) (see Table 7). Therefore, the shape

[Table 5] The Proportion of Aesthetic Appeal of Shape Features

/	Orientation (xyz axis)			Number of Edges		Spatial Type		
	1(x/y/z) Kind	2(xy/xz/yz) Kinds	3(xyz) Kinds	More	Less	Open	Semi-open	
							Covered	Uncovered
Form Numbers	No.1, 3, 7, 15	No.4, 5, 6, 8, 9, 10, 11, 12, 14, 16, 17, 19	No.2, 13, 18, 20, 21	No.2, 6, 8, 10, 11, 12, 13, 14, 16, 18, 20, 21	No.1, 3, 4, 5, 7, 9, 15, 17, 19	No.1, 3, 7, 15	No.6, 10, 12, 13, 19, 21	No.2, 4, 5, 8, 9, 11, 14, 16, 17, 18, 20
The Number of Forms with Aesthetic Appeal	No.3	No.5, 6, 8, 10, 11, 12, 14, 16, 17, 19	No.2, 13, 18, 20, 21	No.2, 6, 8, 10, 11, 12, 13, 14, 16, 18, 20, 21	No.3, 4, 5, 7, 9, 17, 19	No.3	No.6, 10, 12, 13, 19, 21	No.2, 4, 5, 8, 11, 14, 16, 17, 18, 20
Proportion	25%	83.3%	100%	100%	77.8%	25%	100%	81.8%

[Table 6] The Proportion of Shape Features in Different Degree of Aesthetic Appeal

Aesthetic Appeal (High)								
Form Number	Orientation (xyz axis)			Number of Edges		Spatial Type		
	1 Kind	2 Kinds	3 Kinds	More	Less	Open	Semi-open	
							Covered	Uncovered
No.6		●		●			●	
No.10		●		●			●	
No.12		●		●			●	
No.13			●	●			●	
No.21			●	●			●	
Proportion	-	60%	40%	100%	-	-	100%	-
Aesthetic Appeal (Medium)								
Form Number	Orientation (xyz axis)			Number of Edges		Spatial Type		
	1 Kind	2 Kinds	3 Kinds	More	Less	Open	Semi-open	
							Covered	Uncovered
No.2			●	●				●
No.8		●		●				●
No.11		●		●				●
No.14		●		●				●
No.16		●		●				●
No.18			●	●				●
No.20			●	●				●
Proportion	-	57.1%	42.9%	100%	-	-	-	100%
Aesthetic Appeal (Low)								
Form Number	Orientation (xyz axis)			Number of Edges		Spatial Type		
	1 Kind	2 Kinds	3 Kinds	More	Less	Open	Semi-open	
							Covered	Uncovered
No.1	●				●	●		
No.3	●				●	●		
No.4		●			●	●		
No.5		●			●			●
No.7	●				●	●		
No.9		●			●			●
No.15	●				●	●		
No.17		●			●			●
No.19		●			●		●	
Proportion	44.4%	55.6%	-	-	100%	55.6%	11.1%	33.3%

[Table 7] Proportion (High, Medium Aesthetic Appeal) of Shape Features

/	Orientation (xyz axis)		Semi-open Space	
	2 Kinds	3 Kinds	Covered	Uncovered
Number of Forms With Higher Aesthetic Appeal	7	5	5	7
Total Number of Forms	12	5	6	10
Proportion	58.3%	100%	83.3%	70%

a/b with three orientations in its final form (100%) and the semi-open space with a top (83.3%) are more likely to be considered as having higher aesthetic appeal.

It is demonstrated that having a larger number of edges is one basis for whether a form is found to be aesthetically appealing and the degree of its appeal. By analyzing the data in Table 8, it can be found that the degree of aesthetic appeal is related to combinations of specific visual features. When the visual features of the form reach certain criteria, combining the "necessary factor" (meaning more edges) with"variable factor 1" (orientation kinds are greater than or equal to 2) and "variable factor 2" (covered semi-open space), the probability of the generated shape being judged as having high aesthetic appeal is 100%. When the necessary factor (more edges), variable factor 1 (orientation types $\geq$ 2), and variable factor 2 (uncovered semi-open space) appeared in combination, the shape was 100% identified as having a medium aesthetic appeal rating. It follows that it was the difference of having the feature of covered semi-open space rather than uncovered that played a decisive role in whether a form was judged to have high aesthetic appeal, given that the number of edges and orientation remained constant. More edges are given as a necessary condition for the form to achieve high aesthetic appeal. More edges, along with the kind of orientation ($\geq$2) of shape a/b in the final form is shown to be the basis for the occurrence of ratings of medium and high aesthetic appeal. In the end, it was the type of space, specifically semi-open space with a roof, which proved to be the decisive factor leading to a judgement of high aesthetic appeal. As a practical design method of shape generation, shape grammar can more reliably produce shapes with perceived higher aesthetic value by constraining the combination of the three shape features described above.

5. Conclusion

This paper attempts to propose a framework that can guide the use of shape grammar so that it generates more aesthetically appealing forms. Even though it has been agreed that the shape-generating property of shape grammar is of great value to architecture, shape grammar itself cannot actively select shapes for aesthetic value, limiting its potential use. This study attempts to improve upon the aesthetic limitations of shape grammar by analyzing and

[Table 8] Probability of High and Medium Aesthetic Appeal Occurring

High Aesthetic Appeal							
Necessary Factor		Variable Factor 1		Variable Factor 2		Proportion	Form Number
More number of edges	+	Orientation (3 Kinds)	+	Semi-open Space (Covered)	=	100%	No.13, 21
		Orientation (2 Kinds)		Semi-open Space (Covered)		100%	No.6, 10, 12
Above-average Aesthetic Appeal							
Necessary Factor		Variable Factor 1		Variable Factor 2		Proportion	Form Number
More number of edges	+	Orientation (3 Kinds)	+	Semi-open Space (Uncovered)	=	100%	No.2, 18, 20
		Orientation (2 Kinds)		Semi-open Space (Uncovered)		75%	No.8, 11, 14, 16

summarizing it from three aspects: necessary factors (number of edges) and variable factors (orientation and spatial type). By controlling the combination of variable factors, shape grammar can be used to reliably generate more aesthetically attractive forms. This study's overall purpose is to expand shape grammar's actual application value in architecture by improving the aesthetic value of the shapes it generates. This study focuses on three aspects of shape features that influence the judgment and evaluation of aesthetic appeal, but it has not yet expounded how exactly to incorporate these three features. This will be analyzed in more detail in the next study. This study suggests solution to improve the aesthetic limitations of shape grammar and makes a contribution to improving its application value in architectural design.

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