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Bracket Study: Textual, Computational, and Digital

by

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ABSTRACT

Bracket system is an important and characteristic component in the traditional Chinese architecture. Much has been studied about the system — its origin, historical evolution, structure, and composition — in the traditional way: documents, hand drawings, and physical models. In this thesis, non-traditional methods are applied to the research of the bracket system. The composition of bracket is illuminated in the language of a shape grammar; a computer implementation based on the grammar serves as a teaching tool as well as a design tool of the bracket system.

Through the study of the specific element, brackets, it has been explored about the application of the non-traditional research methods into the architectural historical research and education. Meanwhile, this thesis covers the topic of the computer implementation into shape grammars.

Thesis Supervisor: Terry Knight
Title: Associate Professor of Design and Computation
This thesis is dedicated to Liu, Jia.
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Chapter 1: Introduction

“*The tou-kung [bracket set] plays the leading role, a role so important that no study of Chinese architecture is feasible without a thorough understanding of this element, the governing feature of the Chinese ‘order’.***

— Liang, Sicheng

The architecture of China has the same long history as Chinese civilization. One of its basic characteristics is its indigenous timber-frame construction system which has been retained from prehistoric times to the present day. A typical structure consists of a raised platform, a timber column-and-beam skeleton, a bracket story and a pitched roof with overhanging eaves (Figure 1-1). This construction style is extremely flexible by its permitting complete freedom in walling and fenestration, therefore making it adaptable to any climate from that of the tropical southern part of China to that of the sub-arctic northern part just by adjusting the proportion between walls and openings.

The bracket system (*dougong*, or *tou-kung* in Wade-Giles Romanization\(^1\)) is a unique element of Chinese traditional architecture. It is a structural component in the timber-frame building system, connecting the upper part, the pitched roof, and the lower part, the column and beams system, transferring the load from the horizontal elements above to the vertical elements below. Meanwhile, it supports the overhanging roof by expanding its bays. The third function of brackets, not as apparent as the former two but important

\(^1\)As Chinese terminology is difficult, if not impossible, to translate into other languages in a manner that would preserve the original meaning, the concepts in this thesis are mostly used after they have been explained in English. The Romanization of Chinese is based on the *pinyin* transliteration. These *pinyin* Romanization are usually italicized. However, since many Chinese terms, such as Taoism (Daoism) and *I Ching* (*Yi jing*), are better known by their older Wade-Giles Romanization, they are used in these cases, though the *pinyin* transliteration is mentioned at least once in parentheses. Correspondingly, in order to facilitate the comparison of references and figures, the Wade-Giles form is sometimes added. In addition, the Chinese person’s names are given in the East Asian way with surname first, while other names appear in the so-called Western order (Steinhardt 1984).
Introduction

as well, is that the section size of the bracket arm is the basic volumetric unit of a structural module that defines the actual dimension of a building (Appendix I). The characteristic shape of the bracket is also a type of decoration of a building. In the later period the bracket was painted on the surface, which made it more ornamental. It can only be used in high-ranking buildings, such as palaces, halls, temples, etc. Its function and complex appearance make it the most widely discussed component. Together with the overhanging roof which it was created to support, the bracket system has become the symbol of Chinese architecture.

![Figure 1-1](image)

*Figure 1-1  The construction system of traditional Chinese architecture (Liang, 1984).*

The earliest source of the bracket system is a on a bronze vessel of the period of the Warring States (403 – 221 B.C.) of the Zhou Dynasty. It shows rudimentary bracket sets bearing the weight of ceiling, roof eaves, beams, and rafters (figure 1-2). Bracket sets were commonplace in all types of imperial structure by the Han Dynasty (206 B.C. – 220 A.D.) (figure 1-3). By the end of the Tang Dynasty in 907, the bracket set had assumed the complex shape that we envision today when we think of this element. Despite its necessity of strengthening the column-roof relationship in timber structure, bracketing had become a status symbol in the Tang Dynasty. In the mid Song Dynasty, the bracket system was formally defined and standardized for the first time. In the Yingzao fashi, the first official building standard in Chinese history, there are three chapters talking about
brackets. From then on, brackets became more and more decorative while its function as a bearing element faded. By the Qing period, brackets were almost purely decorative. As a result, the Qing buildings are generally less sturdy than those of the Song (Steinhardt, 1984).

![Figure 1-2: Bracket sets on a bronze vessel (Liang, 1984).](image1)

![Figure 1-3: Bracket sets on a monument pier in Han Dynasty (Liang, 1984).](image2)

At the end of the 1910’s, the discovery of the Yingzao fashi induced a strong interest in research on traditional Chinese architecture. In the 1930’s, a group of ancient structures built during the period of the Yingzao fashi were found and measured, such as Dule Monastery, Foguang Monastery, Chuzu Monastery, and Yingxian pagoda (Figure 1-4). The measurement provided luxuriant and direct information for study by architects. For example, one of the amazing discoveries during the investigation of Yingxian pagoda was the 54 different types of bracket set supporting the individual story eaves (Fairbank, 1994; Steinhardt, 1984). At the same time, these detailed drawings were compared with the rules and definitions in the Yingzao fashi, to help people understand and validate the standard.
Research and education are always two major parts in the academic area. A lot of research on Chinese traditional architecture has been done on the basis of the Yingzao fashi, the standard drawings and the existing buildings. Research results have been used in the education in architectural departments in China. All of these are done in a traditional way using textual documents, hand drawings, and physical models. Now people have begun to introduce new research methods and tools into their research and teaching. For example, Andrew Li, a professor in the Department of Architecture in the Chinese University of Hong Kong, has built a shape grammar of the Chinese timber-frame system (Li, 2001) and created a computer program to show his research results. The program was used in his teaching of the Chinese traditional architecture. Before that, he used computer models in his teaching (Li, 1996) which received positive feedback from his students.
In this thesis, non-traditional methods are used to explain the bracket system of the *Tang* and *Song* Dynasty, the so-called Period of Elegance (Liang, 1984), when it was at the height of its splendor in both form and function. The composition of brackets will be illuminated in the languages of shape grammar and computer program. Through the study of this specific element, the relationship between these methods and historical research and education will be explored, for example, what they can do and how to apply them. Meanwhile, the implementation of computer technology into shape grammars is another aspect to be considered.

The remainder of this thesis is structured as follows: previous research and documents on the bracket system are reviewed; a bracket grammar is formulated and a set of designs are listed; finally, a bracket program is created, followed by a discussion of areas for further investigation.
Chapter 2: Textual Research on Brackets

The *Yingzao fashi* (Building Standards)

The *Yingzao fashi* was published by the Office of Construction in 1103. The editor, Li, Jie, was the superintendent of this office. The aim of the book was to facilitate the accounts of public buildings for which the office were responsible. It is the first building standard in Chinese history, defining construction terms and materials, providing methods for estimating materials and labors, setting rules for the design of all parts of a building, from foundations, masonry buildings, wood-frame buildings, finish carpentry, to painted decorations. Since it recorded faithfully the building techniques of the time, it has become the most valuable reference for research on traditional Chinese architecture. Because timber is the principal material used in Chinese architecture, the chapters on “major carpentry” (structural framing, columns, beams, lintels, ties, brackets, purlins, rafters, etc.) are the most important part of the book for understanding the structural system. Chapter 4 of the *Yingzao fashi* is the main resource of my study, which described the components and composition of brackets. The book contains both texts and diagrams (Figure 2-1).

![Figure 2-1: The Yingzao fashi: texts and diagrams (Li, 1933)](image)

The original goal to publish the *Yingzao fashi* was to set standards for the builders. However, probably Li, Jie could never imagine that, it was his book, or more accurately,
the discovery of his book, directly helped to establish the Chinese architectural historical study. Ironically, although Chinese history was recorded from two millennia ago, the historiography of this nation's architecture is just a century old. (In 1901 there was a group of Japanese architects photographed, measured and described the Forbidden City in Beijing, which marked the beginning of the study of the Chinese architecture.) The historians were not interested in this subject because in ancient China, architecture was not regarded as one of the arts, such as painting and calligraphy. There was no architectural profession, no architects, while all the buildings, public, private and religious alike, were erected by craftsmen.

The *Yingzao fashi* was well organized and illustrated, the forth part of which was the graphic representations of the rules. However, it could hardly be understood to the first group of researchers. As Chen pointed, "In the beginning, the book was a hard nut to us. Nearly every line couldn't be read through. Except those common terms like 'post' and 'beam', the book was full of odd terms which we did not understand what they were." (Chen, 1981). The first step of study was to understand the *Yingzao fashi* because it was written in ancient Chinese whose morphology and syntax were totally different from modern Chinese used nowadays. People can read the book but cannot understand its meaning. What's more, the standard is full of opaque terms, for example, a building element might have 5 to 6 different names which make readers more confused.

**Previous research**

Liang, Sicheng, the most famous Chinese architectural historian, who received his degree of architecture from the University of Pennsylvania, was the director of the group of scholars doing research on the *Yingzao fashi*. The aim is "the compilation of a history of Chinese architecture, a subject that has been virtually untouched by scholars in the past.” (Liang, 1984) His book, *Annotations on the Yingzao fashi*, covers part of the standard. Fortunately, the bracket is included in the finished part. In the introductions of this book, Liang mentioned that what he had done was "a translation work", translating the original standard from ancient Chinese into modern Chinese. In other words, despite going deeper into research on the contents, Liang contributed to the research of the *Yingzao fashi* by
explaining the terms literally item by item, and redrawing the diagrams in the book in modern drawing standards. Although there are some mistakes and some comprehension lacking of penetration and thoroughness in his book, it is still the most important work on the *Yingzao fashi* because it is the base of almost all the research afterwards. Another contribution by Liang is his fieldwork to explore the extant ancient architecture during the 1930's. Numerous buildings were discovered in his trip, some of which were mentioned earlier in Chapter 1. "We have, up till today, covered more than 200 *hsien* or counties in fifteen provinces and have studied more than two thousand monuments." (Liang, 1984) He and his group measured almost all the buildings and made drawings, providing the detail resource to the research, which is also a testimony to prove the validity of the *Yingzao fashi*. The wealth of his book and detailed drawings of those buildings has since become standard information in histories of Chinese architecture in both Chinese and other languages.

* * *

Chen, Mingda, Liang's assistant and the successor of Liang's work on the *Yingzao fashi*, restated the standard in a parametric way. He defined that the module system (*caif en* *zhi*) is the foundation of all the building system. The building grade is a parameter to determine the actual size of a building. He converted the specific dimensions recorded in the standard into *fen* and checked them with rules concerned. These dimensions were then compared with numbers of *caif en* found in representative actual examples, and proved to be similar to those actually used in the *Yingzao fashi* period. At last, he used all the dimensions in terms of *caif en* in the drawings and descriptions of the building parts. Chen also investigated the bracket system in detail and the structural forms of beam-and-column system and cross-section of roof frame (Chen).

After many years of research and investigation it is now possible to understand most of the text of the *Yingzao fashi*, but the essence of the content is still not thoroughly studied. On the other hand, although we have the *Yingzao fashi* and some books and drawings about it, it is still hard to understand how a building, including its bracket sets, was
Textual research on brackets

constructed unless one digs deeply into the books I listed above. As a result, the study of bracket is limited to a small range of scholars while most students and designers are not very clear about the composition of brackets and they don't have enough time to dig into this specific topic. However, understanding the bracket is very important for students and those who design traditional style Chinese architecture. Some powerful tools are needed to help us reach this goal. They may be not as comprehensive and detailed as the standard was, but will be helpful for people to have a basic view of brackets and its composition and get some new designs in a comparatively short time.

New theories and technologies can help us to solve these problems. In the next two chapters, a shape grammar and a computer program will be applied to the study of the bracket to reach this goal. The bracket grammar and program are developed on the basis of the basic components and their general relationships, while some exceptions and details are ignored. For example, in the bracket system, sometimes down-cantilever (xia ang) was used and sometimes up-turned brackets (juan tou); a bracket bay was sometimes reduced; position in height of bearing block on an ang should be lowered, etc. All of these are not included in this thesis.
Chapter 3: Bracket Grammar

The use of grammars in design has been twofold:

1. to analyze existing sets of designs and develop grammars that could be used to generate the set of existing designs, as well as new designs in the same style;
2. to generate new, stylistically consistent languages of designs. Grammars have also been used to transform existing styles in a new language of designs.

(Knight, 1984)

This parametric shape grammar generates the compositional forms of bracket sets.

The grammar is based on a corpus of existing bracket sets and the building standard “the Yingzao fashi”. Much has been researched about the system in the textual way – its origins, historical evolution, and its structure and compositions. However, the elusive and abstruse ancient Chinese language and descriptions do not explicitly inform us as to how bracket sets are constructed, and consequently provide little help in designing new members of this style. The introduction of new theory and technology will help us solve these problems. In this thesis, I will use shape grammar and an object-oriented computer program to analyze the bracket system and to generate new designs.

The definition and algorithms for a shape grammar system were firstly formally presented by George Stiny in 1975 (Stiny, 1975). A shape grammar is a rule-based system, in which a large number of varied and complex designs can be generated or computed from a given shape vocabulary with simple rules. Shape grammars have been used widely and successfully in analyzing and understanding designs in almost every visual and spatial area. Meanwhile, they are the tools to generate new and original designs.

In this thesis, the composition of bracket sets is shown to be based on a few simple spatial relations between parameterized three-dimensional building components. These spatial
Bracket Grammar

relations provide the basis for a parametric shape grammar that defines a language of the bracket system.

The main vocabulary of this grammar has five elements and element groups: arms (gong), blocks (dou), cantilever (ang), nose (shuatou) and purlin (fang). Amongst them, arms and blocks have their sub-elements, which have similar shape but different names and sizes according to their positions in a bracket set. The scale between the length, width, and depth of each component is fixed, but the actual dimension of the component may vary from design to design, which is decided by the grade of a building, the position of the bracket, and the expansion of the bracket.

In this thesis, every dimension will use fen as unit, which is a relative length unit in the Yingzao fashi. In buildings of different grades, one fen may be equal to different actual lengths, as Table 3-1 shows.

To simplify the presentation of the shape rule schemata in the grammar, explicit parameterization is omitted because as the four parameters are determined, the actual dimensions of the bracket set, as well as its components, are all set. Dimensions are shown in the definition of the vocabulary and rules.

It should be noted that hidden lines in elements are not drawn so as to avoid ambiguities. Thus, for example, the cap block with hidden lines drawn in figure 3-0-a is represented as shown in figure 3-0-b. In those cases where hidden lines are required for a complete specification of shape rule schemata, they are represented in dotted line. For example, in the additive rules, all the lines of the new component to be added are shown in red with visible lines in continuous style while hidden lines are dotted.

Figure 3-0-a: Drawing with hidden lines  Figure 3-0-b: Drawing without hidden lines
To make the representation clear, I will show the design from five different viewpoints: side elevation, front elevation, top plan, bottom plan and isometric drawing. Strictly speaking, this is a parallel grammar. Since the main transformation is in the side elevation, I will use it as the main derivation view. In other views, only design results are shown.

**Analysis of bracket:**

1. **components**
   The bracket system consists of five components: arms, blocks, cantilever, nose, and purlin.

- **Arms**
  The arms (gong) are the most important component of the bracket set. The expansion of transverse arms and ang support the overhanging roof.

There are five types of gong (Figure 3-1).

![Diagram of bracket components](image)

Figure 3-1: Arms

a). Petal arm (**hua gong**)
   The petal arm is the only transverse arm in a bracket set. Its length varies according to its position in the bracket because it may be used in successive bracket bays, each extending front and rear a certain distance
b). Wall arm (*nidao gong*)

The wall arm is the lowest longitudinal arm. It sits on the Cap block.

c). Oval arm¹ (*guazi gong*)

The oval arm is a longitudinal arm sits at the end of a petal arm or a cantilever but below the regular arm. (Note: These arms are connected by blocks. In this thesis when an arm *a* is mentioned to sit on another arm *b*, it means that *a* sits on the block which sits on the end or center of *b*.)

d). Regular arm (*ling gong*)

The regular arm is the highest arm in the bracket set. It sits on the end of the petal arm or the cantilever and supports the eaves purlin.

e). Long arm (*man gong*)

The long arm is all the other arms in the bracket set except the arms mentioned above. It sits on the wall arm or oval arm.

--- Blocks

The blocks (*dou*) are one of the two basic components of a bracket set. It is the base for other components to sit on, such as an arm or a purlin. It also connects the bracket set with other parts of the structure system. For example, the Cap Block (*lu dou*) connects the bracket set with the column or beam on which it sits; the Small Block (*san dou*) connects the bracket set with the roof elements, purlin. Block is also the connection of the other elements in the bracket set.

---

¹ There has been two ways to translate the components’ names into English. One identifies how they appear in the bracket cluster, for example, *guazi gong, man gong,* and *ling gong* can be translated into pumpkin arm, kidney arm, and order arm. The other specifies their relative shapes, for example, those three arms may be referred to respectively as oval arm, long arm, and regular arm, which are used in this thesis.
There are four types of block (Figure 3-2).

- **Cap block** *(lu dou)*
  - The cap block is the base of the bracket set, sitting on a column or a beam and connecting the bracket set with the lower part of a building.

- **Connection block** *(jiaohu dou)*
  - The connection block sits on the end of the transverse arms, in other words, petal arm or cantilever.

- **Center block** *(qixin dou)*
  - The center block sits on the center of an arm.

- **Small block** *(san dou)*
  - The small block sits on the ends of a longitudinal arm, in other words, wall arm, oval arm, regular arm and long arm.
- **Cantilever**

The cantilever (ang) is another transverse component in the brackets (Figure 3-3). Strictly speaking, it is a long slanting arm which is parallel to the cantilevered eave. The ang provide cantilever support for the eave's purlin. The weight of eaves is counterbalanced by the weight of the next higher purlin on the tail of the cantilever.

![Figure 3-3: Cantilever](image)

Generally, ang is only in the bracket set whose B>=2 (5 puzuo or more). When B=1, half of the petal arm could transform into cha ang, which has only the form of a cantilever instead of its function. In this thesis, I talk only about the ang which has both the function and the form.

Also, I ignore the inside (upper) cantilever which has the opposite function of outside cantilever. The upper cantilever is only in the inside part of a bracket set, which has very few examples in the existing buildings.

- **Nose**

The nose (shuatou) is a transverse element in the bracket set (Figure 3-4). It ends the expansion of bracket in the horizontal direction. It sits on the small block and connects with the regular arm (ling gong). (Remember the regular arm is the highest longitudinal arm in a bracket set.)

![Figure 3-4: Nose](image)
Purlin (fang) is a longitudinal element of a building (Figure 3-5). It connects the bracket set with the upper part of a building. Strictly speaking, it does not belong to a bracket set. However, since it ends the expansion of the bracket in the vertical direction, I define it as an element of the bracket to give a comprehensive view of the bracket.

There are different types of purlin according to their positions. But in this thesis, since their function, size and directions are all the same, I use it as a single element.

The purlin sits on the blocks. In the side elevation view diagram, because of the length of the purlin is beyond that of the bracket, it is represented in section instead of elevation, which is shown in bold lines.

2. parameters
   a) The building grade (G)

   This parameter, together with “the position of the bracket”, determines the range of parameters “number of bracket bays” and “number of bracket stories”. It also decides the real size of the bracket set. Its value follows:
   \[1 \leq G \leq 8\]

   All the buildings are ranked in 8 grades (Figure 3-6). The higher-ranking palaces and main halls are always more complex and have larger scales than the lower-ranking ones. The dimension of each grade’s timber unit is regulated by the module standard (caiffen zhi, refer to Appendix I). Each grade has a fixed value of fen, therefore the sizes of each component and
the whole building are determined. Figure 3-6 and table 3-1 show the timber units of the grades.

![Figure 3-6: Building grades (Glahn, 1984)](image)

<table>
<thead>
<tr>
<th>Grade</th>
<th>Value of fen</th>
<th>Size of the arm section (height x width)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inch</td>
<td>inch</td>
</tr>
<tr>
<td>1</td>
<td>0.60</td>
<td>9.00 x 6.00</td>
</tr>
<tr>
<td>2</td>
<td>0.55</td>
<td>8.25 x 5.50</td>
</tr>
<tr>
<td>3</td>
<td>0.50</td>
<td>7.50 x 5.00</td>
</tr>
<tr>
<td>4</td>
<td>0.48</td>
<td>7.20 x 4.80</td>
</tr>
<tr>
<td>5</td>
<td>0.44</td>
<td>6.60 x 4.40</td>
</tr>
<tr>
<td>6</td>
<td>0.40</td>
<td>6.00 x 4.00</td>
</tr>
<tr>
<td>7</td>
<td>0.35</td>
<td>5.25 x 3.50</td>
</tr>
<tr>
<td>8</td>
<td>0.30</td>
<td>4.50 x 3.00</td>
</tr>
</tbody>
</table>

Table 3-1: Grades and timber units

The unit of a building is the same as the cross-section of a bracket arm. The actual size of a unit varies, but once the grade of a building was known, the actual size of the building’s unit was determined to begin construction.

Throughout the manual the basis for calculation is some specific unit. The most important unit of construction is the timber unit. Chapters four and five describe
the rules for carpentry. In any case, the height and width of a unit is 15 *fens* and 10 *fens*. The size of all the building parts, the depth of the eaves and the curvature of the roof, all have this unit as the basis of the rules.

b) The position of the bracket (P)

This parameter, together with “the building grade”, determines the range of parameters “number of bracket bays” and “number of bracket stories”. Its value follows:

\[ 1 \leq P \leq 4 \]

Figure 3-7 shows the diagram of the different bracket positions in a typical hall plan.

![Figure 3-7: The positions of brackets](image)

P = 1, 2, 3, 4

- P = 1 on the top of a column on the outside wall
- P = 2 between the columns on the outside wall
- P = 3 on the top of a column inside a hall
- P = 4 at the corner of a hall
c) the number of bracket bays (B²)

Figure 3-8: The number of bracket bays and the number of bracket stories

Bracket bay, or tier, (tiao, literally ‘jump’) represents the expansion of a bracket set in the horizontal direction (Figure 3-8). The number of bracket bays indicates the number of expansions. When a longitudinal component, a petal arm or a cantilever is added to the bracket, the number of bracket bays will increase 1. The length of each expansion is 30 fens. According to Yingzao Fashi, the length of expansion cannot be more than 150 fens. As a result, the maximum of B is 150/30 = 5. B can be 0 in case there is no longitudinal component, for example, the simplest bracket Batou Jiaoxiang zuo (Figure 3-11).

The rage of B is constrained by G and P. Its value follows:
0 <= B <= 5

For example, if G = 2 and P = 1, B could be selected from 0~5.

---

2 The Capital B, as well as Bo and Bi, means that it is the grammar’s parameter. The lowercase b, bi and bo represent the parameter’s value during the derivation. When the first stage of the derivation (the generation of grids) is finished, these equations must be followed: b = B, bi = Bi, bo = Bo.

3 In real buildings, the length is flexible around 30 fens to match a certain condition. For example, the length of the most outside bay of a B=5 bracket could be 26 fens. In this grammar, these details are ignored and a fixed dimension of 30 fens is used.
Bracket sets expand both inside and outside. It could be symmetric, with the number of inside bays \( B_i \) the same as the number of outside bays \( B_o \); it could be asymmetric, while \( B_i < B_o \). \( B_o \) is equal to \( B \) because the outside part always has the full expansion. Only brackets in the positions 1, 2 and 3 can have fewer inside bracket bays than outside bays. The rules of the subtraction of inside bays are as follows:

If \( B = 0 \sim 2 \), then \( B_i = B_o \);

If \( B = 3 \sim 4 \), then \( B_i = B_o \) or \( B_i = B_o - 1 \);

If \( B = 5 \), then \( B_i = B_o \) or \( B_i = B_o - 1 \) or \( B_i = B_o - 2 \).

d) the number of bracket stories ([S])

Bracket story, \( (pu, \text{literally 'spread'}) \) represents the expansion of a bracket set in the vertical direction (Figure 3-8). The number of bracket stories indicates the number of expansions. There are two types of stories: the arm story which is 15 fens high and the block story which is 6 fens high. This parameter is actually a local parameter which is determined by the number of bracket bays: \( S = 2 * B + 4 \). Its value follows:

\[ 4 \leq S \leq 14 \]

The inside number of stories \( S_i \) and the outside number of stories \( S_o \) also can be calculated by this equation. If a bracket set is asymmetric, \( S_i < S_o \).

All the possible parameter sets are listed in table 3-2.

<table>
<thead>
<tr>
<th>( B )</th>
<th>( (B, B_o, B_i) )</th>
<th>( (S, S_o, S_i) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(0, 0, 0)</td>
<td>(4, 4, 4)</td>
</tr>
<tr>
<td>1</td>
<td>(1, 1, 1)</td>
<td>(6, 6, 6)</td>
</tr>
<tr>
<td>2</td>
<td>(2, 2, 2)</td>
<td>(8, 8, 8)</td>
</tr>
<tr>
<td>3</td>
<td>(3, 3, 2)</td>
<td>(10, 10, 8)</td>
</tr>
<tr>
<td></td>
<td>(3, 3, 3)</td>
<td>(10, 10, 10)</td>
</tr>
<tr>
<td>4</td>
<td>(4, 4, 3)</td>
<td>(12, 12, 10)</td>
</tr>
</tbody>
</table>
Bracket Grammar

<table>
<thead>
<tr>
<th></th>
<th>(4, 4, 4)</th>
<th>(12, 12, 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>B = 5</strong></td>
<td>(5, 5, 3)</td>
<td>(14, 14, 10)</td>
</tr>
<tr>
<td></td>
<td>(5, 5, 4)</td>
<td>(14, 14, 12)</td>
</tr>
<tr>
<td></td>
<td>(5, 5, 5)</td>
<td>(14, 14, 14)</td>
</tr>
</tbody>
</table>

Table 3-2: Parameter sets: “number of bracket bays” and “number of bracket stories”

Bracket grammar:

1. Vocabulary

The main vocabulary of the grammar is shown in table 3-3. As mentioned earlier, the proportion of each element is fixed, and their actual lengths are determined when the parameter grade is decided.

<table>
<thead>
<tr>
<th>element</th>
<th>name</th>
</tr>
</thead>
<tbody>
<tr>
<td>a_p</td>
<td>Petal arm</td>
</tr>
<tr>
<td>a_w</td>
<td>Wall arm</td>
</tr>
<tr>
<td>a_o</td>
<td>Oval arm</td>
</tr>
<tr>
<td>a_r</td>
<td>Regular arm</td>
</tr>
<tr>
<td>a_l</td>
<td>Long arm</td>
</tr>
<tr>
<td>b_cp</td>
<td>Cap block</td>
</tr>
<tr>
<td>b_cn</td>
<td>Connection block</td>
</tr>
<tr>
<td>b_cr</td>
<td>Center block</td>
</tr>
<tr>
<td>b_s</td>
<td>Small block</td>
</tr>
<tr>
<td>c</td>
<td>Cantilever</td>
</tr>
<tr>
<td>n</td>
<td>Nose</td>
</tr>
<tr>
<td>pn</td>
<td>Purlin</td>
</tr>
</tbody>
</table>

Table 3-3: Vocabulary

All the drawing conventions specified in this section are employed to simplify the presentation of the shape rule schemata in the grammar and the design that they are applied to generate. The schemata are in two stages: the first apply to generate the
underlying grid of the side section; the second apply to generate the compositional forms of bracket. In this sense, the grammar generates brackets to correspond to the analysis of the designs mentioned earlier.

2. Rules of stage 1: generation of the grid

The grid is an auxiliary tool to generate a bracket. This stage is determined. Once all the parameters, \{G P [B] [S]\}, are decided, the number of outcomes is limited. On the base of the grid, components of brackets are added to form a design. O (0, 0, 0) is the starting point of the generation. The x axis represents the expansion in the horizontal direction, that is, the number of bracket bays. The y axis represents the expansion in the vertical direction, that is, the number of bracket stories. The y axis divides the grid into two parts. The left represents the inside part, and the right represents the outside part. The conventions to generate the grid are encoded and elaborated in shape rules 1-9 specified in Figure 3-9.

In each rule, the dashed horizontal line stands for story, while the dashed vertical line stands for bracket bay. The description under each graph shows the transformation of parameters.

Figure 3-9: Rules 1-9 of stage 1
Rule 1 applies to the initial shape of grammar, consisting of the origin point $o (0, 0, 0)$, to establish a starting status of the grid, which has a vertical axis and a horizontal axis intersecting at point $o$.

Rules 2 and 3 apply to the expansion of the bracket bay. If $b_i < B_i$ and $b_o < B_o$, rule 2 is applied and the vertical axis is offset on both side. If $b_i < B_i$ while $b_o = B_o$, rule 3 is applied with the axis offsets only on the right side.

Rules 4 and 5 end the bay expansion on both sides. Rule 4 is for the left side and rule 5 is for the right side. The labels on the horizontal direction are deleted when $b_i = B_i$, and the label * is deleted when $b_o = B_o$.

The next step is the addition of the bay story. Parameter $[S]$ could be calculated from $[S]$ following the equation $S = 2 * B + 4$, $S_i = 2 * B_i + 4$, $S_o = 2 * B_o + 4$. There is only one vertical axis in each rule. Generally there are more in a design, so the rule has to be applied to each vertical axis.

Rule 6 applies to add the story of cap block. It is the beginning of the addition in the vertical direction. Rule 7 applies to add an arm and a block story. Rule 8 applies to add the last story of the grid, that is, the story of purlin. Rule 9 is the end of the vertical expansion. The labels on the vertical direction are erased.

3. Rules of stage 2: generation of the bracket

On the base of the grid created in stage 1, the actual bracket is generated by applying rules 10 – 19. They are all additive rules.
Rule 10 applies to the first step of every bracket design to create the base of a bracket set. It adds a cap block c_b with the center of its bottom on the origin point o.

Rules 11 – 13 apply to add an arm on a block. Rule 11 adds a transverse arm (a_p) on a block while rule 12 adds a longitudinal arm (a_w, a_o, a_r) on one block. Rule 13 adds an arm (a_p, a_l) on two blocks on both longitudinal and transverse directions.

Rule 14 and 15 apply to add a block on an arm. Rule 14 adds a block (b_cn, b_s) at the end of an arm, while Rule 15 adds a block (b_cr) at the midpoint of an arm.

Rule 16 applies to add a nose on a block. This is the end of the expansion of the horizontal direction. Notice that this rule can be applied as a mirror. That is, the direction of the nose in figure 3-10 is facing left; it can also be applied facing right.

Rule 17 applies to add a purlin on a block. This is the end of the expansion of the vertical direction.
Rules 18 and 19 are about the component cantilever. Rule 18 adds a cantilever on a block, and Rule 19 adds a block on a cantilever.

**Derivation samples:**
These three samples are all from the existing brackets.

Sample 1: The simplest bracket (Figure 3-11).
_Baotou jiaoxiang zuo_ is the simplest form of a bracket set. Its $B = 0$, $S = 4$.

Sample 2: A symmetric bracket (Figure 3-12).
This sample is a symmetric bracket set with its $B = 1$, $S = 6$.

Sample 3: An asymmetric bracket (Figure 3-13).
This sample is a symmetric bracket set with its $B = 3$, $Bo = 3$, $Bi = 2$, $S = 10$, $So = 10$, and $Si = 8$. 
Stage 1:

\[
\begin{align*}
\text{Stage 2:} \\
\end{align*}
\]

Figure 3-11: Derivation of *Baotou jiaoxiang zuo* with B = 0 and S = 4.
Stage 1:

Figure 3-12: Derivation of a symmetric bracket with $B = 1$ and $S = 6$
Stage 2:

Figure 3-12 (continued): Derivation of a symmetric bracket with $B = 1$ and $S = 6$
Figure 3-12 (continued): Derivation of a symmetric bracket with \( B = 1 \) and \( S = 6 \)
Figure 3-13: Derivation of an asymmetric bracket with $B = 3$, $B_o = 3$, $B_i = 2$, $S = 10$, $S_o = 10$, and $S_i = 8$
Stage 2:

Figure 3-13 (continued): Derivation of an asymmetric bracket with $B = 3$, $Bo = 3$, $Bi = 2$, $S = 10$, $So = 10$, and $Si = 8$
Figure 3-13 (continued): Derivation of an asymmetric bracket with $B = 3$, $Bo = 3$, $Bi = 2$, $S = 10$, $So = 10$, and $Si = 8$
Figure 3-13 (continued): Derivation of an asymmetric bracket with $B = 3$, $Bo = 3$, $Bi = 2$, $S = 10$, $So = 10$, and $Si = 8$
Figure 3-13 (continued): Derivation of an asymmetric bracket with $B = 3$, $Bo = 3$, $Bi = 2$, $S = 10$, $So = 10$, and $Si = 8$
Design list:
All the possible design results are shown in Table 3-2. A list of designs with the $S = 3$ is shown in Figure 3-14.

![Design list with the parameter $S = 3$](image)

Figure 3-14. The design list with the parameter $S = 3$

Evaluation
Three categories of designs are used to evaluate the feasibility of the bracket grammar: the brackets in the existing ancient buildings, the brackets in a Japanese pagoda, and new designs.

The existing ancient buildings
The grammar is based on the *Yingzao fashi* and the bracket sets of that period. Does it work on the brackets built before or after that period? Some diagrams of those brackets are shown in Figure 3-15.
These brackets are from the main hall of Foguang Monastery, the gate of Dule Monastery, Jinci, and Shanhua Monastery (Chen, 1981). Most of them perfectly match the grammar. For example, the second sample of Jinci can be generated by the grammar with the parameter set $B = 2$ and $S = 8$. There are also a few exceptions. For example, the second sample from the gate of Foguang Monastery. The rules in stage 2 work well in this example, i.e., the spatial relations between the components are the same as those are defined in the grammar. But its grid is different from that could be generated in stage 1 with the staggered stories of the outside and inside. The reason of this exception could be the bracket had to fit in a limited space, and space constraints are commonplace in a building. Another reason for exceptions is the evolution of the bracket system. The brackets' sizes and the dimension of the bracket bays and stories are always different according to the different historical period, generally, the later, the smaller.
Hokkiji pagoda
The pagoda of the Hokkiji Monastery was built during 685-706 (Figure 3-16). In the 1970s, a group of the restorers dissembled the entire building, then put it back together again. They measured every single wooden member. As a result, we now have the first-hand resources of this building (Ledderose, 2000).

Figure 3-16: Hokkiji pagoda (Ledderose, 2000)

The brackets in this pagoda are robust by supporting the outer corner of the first floor roof which extends more than 5 meters (about 17 feet) out from the corner of the building. The composition of the brackets are simple, most of which have only one bracket bay and can be easily explained by the bracket grammar. But the sizes are large in the proportion of the building compared with that of the *Yingzao fashi* period. Since the pagoda was built hundreds of years earlier, it matches the bracket system’s evolution rule.

Figure 3-17 ~ 19 show the assembling process and some of the bracket components.
New designs:
Beside their ability to analyze the existing designs, shape grammars can generate new designs in a language. Figure 3-20 is the derivation of a new design created by the bracket grammar. Notice the “new” here means that this design cannot be found in the
existing buildings and resources. However, it is possible that this bracket set existed in a certain building during the ancient time.
Stage 1:

Figure 3-20: Derivation of a new design with $B = 2$ and $S = 8$
Stage 2:

Figure 3-20 (continued): Derivation of a new design with $B = 2$ and $S = 8$
Chapter 4: Bracket Computer Implementation

The goal and function of the program
An enormous development in computer technology has been witnessed over the past twenty years. Computers have become a part of everyday life, production and research. Until now, the advantages and possibilities offered by this technique and the related organizational concepts have been used only occasionally in critical and historical research in architecture, mostly in ways that are totally secondary to the aims of the research, such as creating databases and producing images, which is only the replication of traditional drafting techniques. On the other hand, within the architectural and computer theorist realm there has been a call for the development of the computer’s potential for new analytical and design techniques as opposed to the simple usage just mentioned.

This section explores the unique potential of computer-aided design as it is applied to the critical analysis of the bracket system. Critical theories regarding the bracket, the textural documents and the bracket grammar, are tested through the application of computer techniques. This process informs and conveys the composition of the bracket.

In this study, the computer and its organizational concepts typical of information science play a key role. It is not merely used as a means of storing data and producing images, but as a privileged partner of the researcher, supporting the process of analyzing, interpreting, understanding and illustrating the bracket system studied. The computer model delineates and illustrates these concepts as an educational tool.

This bracket program is a teaching tool for architectural students and people who are interested in brackets. It will give them basic instruction on the bracket’s components, their spatial relationships and how they are combined to form a bracket set. The theoretical source is the bracket grammar built in Chapter 3. It is a user-centered program.
Users can choose the rules freely and apply them to the components, so as to generate designs which can help them obtain a complete understanding of the bracket’s composition. It is also a design tool to help users obtain diagrams of the bracket designs once they choose a set of parameters.

Meanwhile, this program is an interpreter of the bracket grammar. It is an application of shape grammar to the explanation of the bracket system. Despite its theoretically wide range of application, shape grammar has been found difficult to use in practice. Some interpreters have been created to bridge the gap. Most of the existing shape grammar systems are shape grammar interpreters, which help in generating shapes from shape grammars. Either the developer entered shape grammars into the computer shapes in the language, or the user guides the program by selecting the rules to be applied and where in the current shape to apply them. One type of interpreter is to explain the general shape grammar. For example, Shaper (Wang, 1998) is a Java-based 3D grammar implementation; GEdit (Tapia, 1999) is a general shape grammar interpreter made in LISP under the Mac environment. Another type of the interpreter has a particular shape grammar built in which can only generate a certain kind of designs. For example, the Coffee maker grammar program (Agarwal and Cagan, 1998) is a Java-based design tool to generate coffee makers using the coffee maker grammar; The prototype interactive simulated shape grammar (Li, 2002) is an education tool to create sections of wood-frame buildings on the basis of Li’s shape grammar for teaching the architectural style of the Yingzao fashi (Li, 2001).

The bracket grammar program belongs to the latter type, an interpreter for a specific grammar — the bracket grammar created in Chapter 3. Therefore, the initial shapes and rules are pre-defined. But the user can decide about the rule choosing, which will be described in the section “operation the program”.

The function and the goal of the program, a teaching tool and a shape grammar interpreter, determines its design, the design of the user interface, the choice of language and the design of its operation.
User interface design

The user interface is where users interact with computers or other products. The design of a user interface is context-sensitive (Landsdale 1994). Designers must be clear about the task they are designing for. Some basic questions should be answered before the designing. For example, what is the goal and function of the program? What kind of tool is it? Who will be the end user? How will the user operate the program? etc. Only when these questions are clearly answered can the design of interface start.

Compared to traditional CAD system interfaces, which have become quite sophisticated over many years’ development, the interfaces of grammar-based programs are still in the exploration phase. To create a grammar interpreter, developers have more to consider. Following are some questions and answers for the bracket program.

- In the grammar application, who will control the rule selection and object selection?

  The derivation of a design in the bracket grammar can be accomplished by the end user or by the computer. In each step of the derivation, the current status determines the matching condition while a rule to apply is selected from the applicable rule set.

According to the definition of the user interface model for the grammar-based design system by Scott Chase (Chase, 1999), this program is a partial user control model. The developer creates the grammar, and the computer decides the matching condition, while the user decides the rule and object selection. Since the grammar has already been built, the first main stage of building a grammar interpreter—development of grammar, that is, constructing the vocabulary, rules and initial state—can be ignored. The program focuses on the second stage—application of grammar, i.e., a series of rule invocations.
The user interaction model explains how users apply rules (Figure 4-1). Users select a rule from the available rules list, then the program will simulate the transformation if this rule is applied. If the result is what users want, then this rule will be applied and the program moves to the next step. If the result is not what the users want, then the program will go back to the initial status and users can make another choice.

The order of the rules to be applied is strictly controlled in the Yingzao fashi style. As a result, user will have a clear idea of how a bracket is generated from bottom to top, from the cap block to purlin. In many steps of the derivation process, there is only one rule that can be applied. If the user finds there are several rule options to choose, that means different designs will be generated.

![User interaction model diagram](image)

Figure 4-1: User interaction model

- Who will set the parameters?
  Users will set the parameters.

- How does the system present choices to users?
  The system presents choices to users at three points:
  1. choosing the parameters;
2. choosing the rules;
3. choosing the design results.
The interaction of the way to make a choice is described in the section “Operation of the system” in this chapter.

- Can the control range be modified by users?
  Yes. Users can make a choice between applying the rules step by step or leaving the derivation process to be generated by the system.

- Is it a 2D or 3D program?
  It is a 2D program, but the designs are depicted in a 3D way. In other words, there are five drawings of different views including top plan, bottom plan, side elevation, front elevation and axonometry to describe a design during the derivation.

- How many possible designs are presented?
  All the possible results will be presented once the parameters are decided.

- Does the system allow undoing rule applications and returning to a previous state of a derivation?
  Yes. Users can use “backward” and “forward” buttons to control the derivation process.

The program has two sections. The first is the introduction, which shows the components, rules and parameters of the bracket grammar. The layout of this part, as Figure 4-2 shows, has three parts: the menu bar, the description bar and the content window.
The second section is the core of the program: derivation. The layout of this section has four parts: the menu bar, parameter bar, rule window and design window. The menu and parameter bars are on the top of the screen. Below it, the right window shows the rules. According to the two stages of the grammar, the 19 rules are separated into two stages: rules 1 – 9 are in stage 1, the generation of the grid, and rules 10 – 19 are in stage 2, the generation of the bracket. The left window shows the design result with its preceding derivation. In stage 2, the main derivation of the side-elevation view is shown in the middle left window, while the other orthographic views of the design, top plan, bottom plan, front elevation and axonometry, are shown in the four bottom left windows.
Figure 4-3: User interface of the derivation of stage 1

Figure 4-4: User interface of the derivation of stage 2
Language choosing

This program is developed using ActionScript.

Programming languages are used to send information to and receive information from computers. They are collections of vocabulary and grammar used to communicate just like human language. This similarity also exists in the shape grammar. For example, vocabulary corresponds to components while grammar corresponds to rules. As a result, to build a shape grammar program is somewhat like creating a translator, to interpret a grammar from one language into another, both in semantics and syntax.

Using a programming language, we communicate with a computer by telling it what to do or asking it for information. It listens, performs the requested actions and gives a response. In other words, programming is designing a way of communicating with computers.

ActionScript

ActionScript is Flash’s scripting language. One can use ActionScript to control objects in Flash movies to create navigation and interactive elements and to extend Flash to create highly interactive movies and Web application. ActionScript is an object-oriented programming language. In object-oriented scripting, one organizes information by arranging it into groups called classes. One can create multiple instances of a class, called objects, to use in the scripts. There are predefined classes in ActionScript and users can build their own.

When the user creates a class, he or she defines all the properties (characteristics) and methods (behaviors) of each object created, just as real-world objects are defined. For example, a person has properties such as gender, height, and hair color and methods such as talk, walk, and throw. In this example, "person" is a class and each individual person is an object, or an instance, of that class.
Objects in ActionScript can contain data or they can be graphically represented on the Stage as movie clips.

ActionScript is powerful for making vector-image movies. One of the most important characteristics, also the primary tool in building this program, is the ability to create interactivity provided by ActionScript. In an interactive program, the user uses the keyboard, the mouse, or both, to jump to different parts of program, implement the functions, enter information into forms, and perform many other interactive operations.

Developers create interactive movies by setting up actions—sets of instructions written in ActionScript that run when a specific event occurs. The events that can trigger an action are either the playhead reaching a frame, or the user clicking a button or pressing keys on the keyboard.

**ActionScript vs. Java**

ActionScript is a kind of object-oriented language, just like Java. However, the advantages of ActionScript over Java make it the proper language for building the bracket interpreter.

1. the emphasis on interactivity

   For the language itself, Java is more powerful than ActionScript. However, in this study, since we are building an education tool to teach how to build a bracket, the interaction between the user and the computer is the most important aspect to consider. On the basis of the same object-oriented programming concepts and structure, ActionScript focuses more on the creating of user interaction.

2. direct interface view
During the process of building a program, the design and coding of the user interface occupies almost ninety percent of the whole workload. If the time and energy spent on the coding of the user interface are effectively saved, the developers can focus more on the design of the user interface and the function, structure and flow of the program itself. Through ActionScript (and Macromedia in which it is embedded), the design of the user interface is visual and WYSIWYG, i.e., what you see is what you get. Using other programming languages such as Java, thousands of lines of codes must be typed, debugged and transferred by an interpreter to get the same interface. The coding and testing process is painstaking. As a result, on the condition that all the requirements of the program are met by both, using ActionScript is more effective and time-and-energy-saving than Java.

Operation of the system

In the first section, users can click the buttons to reach the corresponding pages which have the introduction and images of the components, rules and parameters.

In the second section, users can determine the parameters of the grammar by choosing values from the parameter lists. During the derivation process, they can choose to apply a rule manually or automatically. In other words, the user can choose to apply the rule step by step by himself, or instead only choose the design result, while the computer will do the derivation. If the user chooses the former way, he or she can select rules from the rule list to create a design.

Choice of parameter setting

There are four parameter menus on the parameter bar, grade, position, number of bracket bays and number of bracket stories, which are corresponding to the four parameters of the
Bracket Study: Textural, Computational, and Digital

Bracket grammar. At the initial phase, only grade and position parameters are active (figure 4-5). Users choose the values from each menu list of these two parameters. Once the grade and position are determined, the parameters of the number of bracket bays and the number of bracket stories will be active (figure 4-6). Notice these two parameters will change simultaneously based on the formula: \( s=2*b+4 \) or \( b=(s-4)/2 \). Users only need to decide the value of one of them, the other one will be determined automatically (figure 4-7). After all the parameters are decided, users can begin the derivation process.

Apply a rule
In each step, only the rules which meet the current condition are active and applicable (Figure 4-8). The other rules are dim and inapplicable. Once the cursor is rolled over an active rule, the rule will be highlighted and the corresponding design will be simulated in the design window, also highlighted (Figure 4-9). If the design is not what the user wants, he removes the cursors from that rule and the design will go back to the former status. If the result is exactly what the user wants, he clicks the mouse to apply the rule. As a result, the design result is shown in the design window and the available rules of the next step is activated and highlighted (Figure 4-10).
Figure 4-8: Apply a rule: the current active rule

Figure 4-9: Apply a rule: the mouse is rollover one of the active rules
Choice of design

There are two ways to present the design choice.

1) At the beginning of each stage, all the possible designs are listed in the design window if the “sequence” option is unchecked. Once the user selects one of the designs, the computer will show the derivation process. This method is useful for the user to have an idea of how many designs can be generated and quickly select the ideal design from the list (Figure 4-11).

2) If the “sequence” option is checked, the user will generate the designs manually by applying the appropriate rules. How to choose rules are mentioned in the “Apply a rule” section. This method is useful for the user to learn the composition of brackets and how the rules are applied (Figure 4-12).
Figure 4-11: Choice of design: sequence is not checked

Figure 4-12: Choice of design: sequence is checked
Chapter 5: Conclusion

Studying a certain subject from different viewpoints and trying different approaches during the research process always brings unexpected successes. This has been demonstrated countless times. Similarly, introducing new theories and methods into the architectural historical research and education leads to new discoveries and better understanding of existing buildings and documents.

In this thesis, a shape grammar and a computer program were created to analyze and teach the composition of the traditional Chinese bracket system. Similar as the translation work of Liang, Sicheng, the bracket grammar converts the original textual rules into visual ones. The rules of the grammar are loyal to the *Yingzao fashi*. However, one of the most conspicuous features of the grammar is that it uses a grid as the underlying framework for bracket generation. The grid clearly explains the basic concepts of the bracket bays (*tiao*) and stories (*pu*), which are the essence of the bracket system. The derivation is a linear process. The first two parameters, the grade G and the position P, decide the range of the next two, the number of bracket bays B and the number of bracket stories S. The parameters B and S then determine the grid, on which brackets are located.

The bracket grammar and the program, together with the previous research result, form a teaching tool of the bracket system. The program is the media, or the skin of the tool. It is transparent, clear and easy to learn. The bracket grammar is the skeleton and frame of the tool, setting the rules of the designs. Although the program is not a general shape grammar interpreter, students can gain an idea of what a shape grammar is and how it works through interaction with the computer. The bracket system is the core of the tool, and the previous research documents are the basis for the grammar and the program. They are expressed through visual and digital approaches which make them clearer and easier to understand.

In my opinion, a textual method is always the first choice and most direct way when new research starts. Shape grammars can then be used to dig into the essence of the form.
Conclusion

generation, finding rules, applying rules and creating new designs. Computer technology helps research and education in many ways such as simulation, model building, collaboration, database, etc. There is still unlimited space to explore in this field.

Another important aspect of the program I want to mention is the grammar-based production system. Computer programs sharpen the power of shape grammars by doing intensive computational jobs and offering easy-handling user interfaces. This program is a specific shape grammar interpreter. It is possible to create a program frame or model for this kind of shape grammar, a model which has the same structure inside but different faces with different grammars.

This study is the first phase of the implementation of shape grammar and computer technology into the research of brackets. As I mentioned earlier, many details are ignored, and only the general composition rules are generated. The grammar still has a lot of space to be fulfilled. Meanwhile, there are many possibilities for computer applications. For example, a bracket design tool could be created which can export compatible results to other languages; a database of components could be built to count the amount of each component type, which is extremely helpful for constructions.

This thesis is a small step toward the goal of doing bracket research and exploring the relationships between designs, shape grammars and computer implementations. However, but it is an important step. I believe the power of shape grammars and computer technology will find more and valuable places in the areas of historical research and education.
Appendix I: Module – Cailfen

Brackets (dougong) could only be used in palaces, temples and other important high-ranking buildings. The standard-sized timber used for brackets was specified by the Northern Song dynasty in 1103 AD, in which the ratio of the bracket arm was a determinant of the dimensions of other structural elements and used as a module – a method of so-called Chinese Order.

The timber unit (cai, literally ‘material’) has eight grades corresponds to the eight building grades which were predetermined by the type and official rank of the building. The dimensions of cai in each grade were divided into 15 equal parts (unit fen), in depth and into 10 fens in width; the length unit fen varied in different buildings and could, during this stage, be considered merely a ratio rather than a measure. In addition, the dimensions of the bracket complex were specified by the vertical gap between the bracket arms, a unit called qi of 6X4 fens of the particular grade. The size and shape of the beams, on the other hand, varied according to their function, position and length, but the ratio between the depth and the width was always 3:2, i.e., the same ratio as in the cross section of the bracket arm of 15 by 10 fens. Cai also work on the regulations concerning the profile and shape of the roof, architrave, ties, hip rafters, purlins, common rafters as well as colors, decoration and other details.

Cai is a volumetric unit of a structural module that defined the actual dimensions of a bay (jian), which was a modular unit of spatial organization, an area to represent a room. Together they set the modules of a building.

But in a contemporary sense, if we consider the module an absolute measure that all other dimensions are multiples of, they cannot be regarded as standard modules, because they were variables that changed according to the period and location as well as to the type and official rank of the building. Hence, regardless of the actual size of a house a a building group in Chinese feudal society, the main aspect in the valuation of a building
Appendix I: Module – cai/fen

depended on the used module – that is, the dimensions of the structural members – specified by the status of the beholder.
Appendix II: Coding Samples

Coding in ActionScript is totally different from general computer languages such as Java. The codes are attached with each single frame, movie clip, button, and other objects. It is difficult to list all the codes of the program. The following list is some samples of coding which realize some feature functions of the program. The complete program is in the CD-ROM attached.

Codes of parameters setting

Action of the grade menu:

onClipEvent (load) {
    function onMenu (item, label) {
        _parent.grade = label;
        trace (label);
        trace (_parent.grade);
    }
}

Action of the position menu:

onClipEvent (load) {
    function onMenu (item, label) {
        _parent.position = label;
        trace (label);
        trace (_parent.position);
        if (_parent.grade == 2 && _parent.position == "on a column")
        {
            with (_parent) {
                gotoAndStop ("para-2");
            }
        }
    }
}

Action of the # of bracket bays menu:
onClipEvent (load) {
    function onMenu (item, label) {
        _parent.numBays = label;
        trace (label);
        trace (_parent.numBays);
        if (_parent.numBays == 1) {
            "with (_root)" {
                gotoAndStop ("b=1");
            }
        }
    }
}

Action of the # of bracket stories menu:
onClipEvent (load) {
    function onMenu (item, label) {
        _parent.numStories = label;
        trace (label);
        trace (_parent.numStories);
        if (_parent.numStories == 6) {
            "with (_root)" {
                gotoAndStop ("b=1");
            }
        }
    }
}

Codes of rule choosing
on (release) {
    gotoAndStop ("step-4-2");
}
on (rollOver) {
    gotoAndStop ("step-4-1");
}
on (rollOut) {
    gotoAndStop ("step-4-0");
}
Bibliography:


Li, Jie. 1933. *Yingzao fashi.* Shanghai: Shangwu Yingshuguan.

Li, Andrew I-kang. 2001. A shape grammar for teaching – the architectural style of the Yingzao fashi. Diss. Massachusetts Institute of Technology.


Stiny, George. 1975. Ice-ray: Pictorial and Formal Aspects of Shape and Shape Grammars. (Birkhauser, Basel, Switzerland)


Unless noted, all figures by the author.