COMPUTATIONAL CONSTRUCTS

ARCHITECTURAL DESIGN, LOGIC AND THEORY

美国麻省理工学院建筑系 论文集
MIT COMPUTATION GROUP

数字营造

建筑设计·运算逻辑·认知理论

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营造法式的运算解析

作者：Andrew I-kang Li
翻译：袁博

1 简介

12世纪的中国建筑手册《营造法式》（建筑规范）在中国建筑师中相当著名。它由宋代宫廷建筑师李诫编著，旨在减少腐败和提高效率。李诫为达到这个目标采用的方法是卓越的，建筑历史学家梁思成将之称为“文法”。例如，将确定屋面横剖面曲线的方法，称之为“举折”（图1）。

Computing the Yingzao fashi

Andrew I-kang Li

1 Introduction

The twelfth-century Chinese building manual Yingzao fashi - Building standards - is known to all Chinese architects. It was compiled by the Song dynasty court architect Li Jie as a way of reducing corruption and increasing efficiency. The approach Li took to this task was remarkable. To quote the architectural historian Liang Sicheng, it was “grammatical” (Liang 1984, 358). Take for

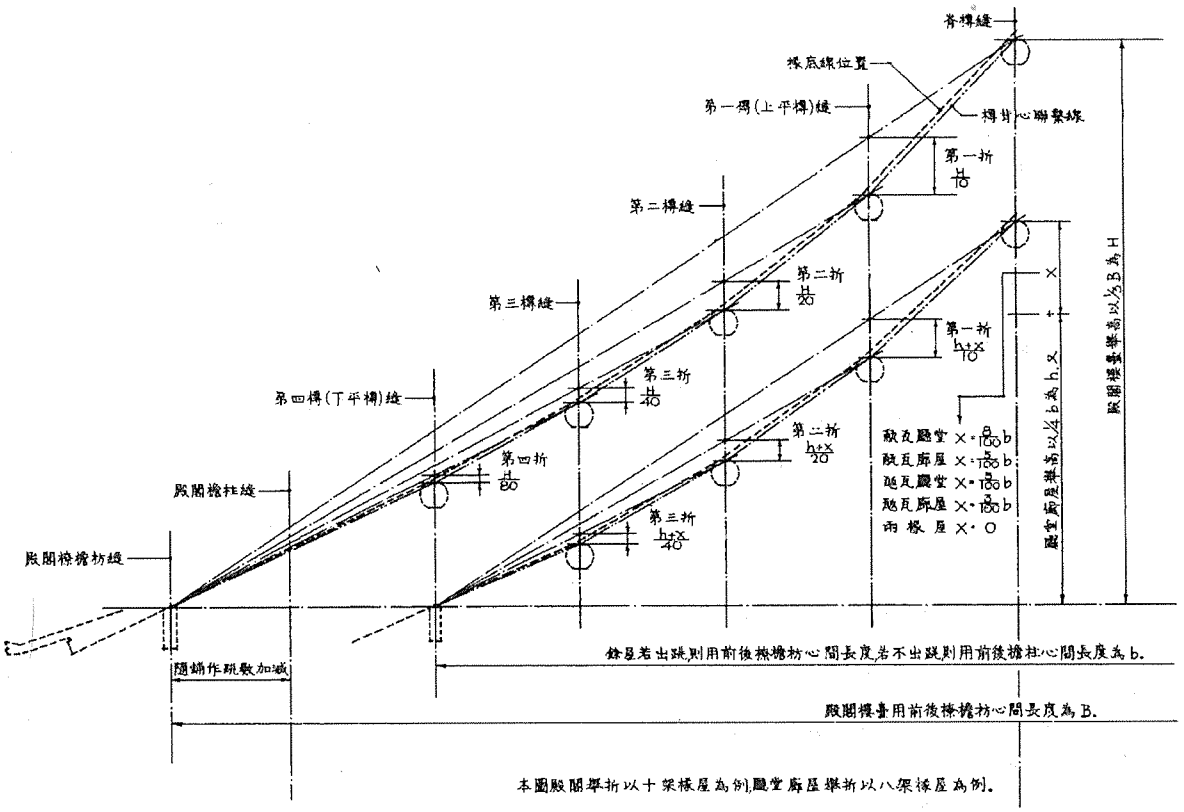


图1 确定屋架剖面的规则，即举折，梁思成绘制。通过这些规则，给定进深和建筑形式，准确的屋架剖面可以被计算出来。

Figure 1 The rules for determining the roof section, known as juzhe, as drawn by Liang (Liang 1983, 265). With these rules, and given the depth and type of a building, the correct roof section can be calculated

在传统的中式屋架中，一个屋面横剖面由一系列分段的椽子组成，每段椽子架在相邻的槫上。这样最低的椽子的底端架在檐槫上，它的上端则架在相邻的高些的槫上。紧邻的椽子架在第二、第三根槫上，直至最高的椽子，最高的椽子的上端架在脊槫上。欲确定屋架剖面则需确定每根槫的位置。

举折用了两步来确定屋架剖面。我们按《营造法式》先将建筑在进深方向上按椽数均分。比如说，8m进深的建筑，进深8架椽，每步1m。这些1m的间隔确定了槫在水平方向上的位置。第一步确定脊槫相对于檐槫的高度（屋架举高）。我们将建筑通进深按统一步长均分，我们在脊槫与檐槫之间画一条线，称之为工作辅助线。第二步确定脊槫下上平槫的高度。我们将上平槫缝与工作辅助线的交点下移10%屋架举高即可得到上平槫的位置。然后连接檐槫与上平槫，得到一条新的工作辅助线。我们重复第二步，确定其余槫的位置，下移的比例减为5%、2.5%，以此类推。

举折的意义不仅仅在于其形式美或者便于记忆，而是它给了我们三种可能性，帮助我们理解屋架剖面。第一，告诉我们如何从全新建筑剖面开始按照步骤建立一个新型屋架法式；第二，告诉我们如何通过观察一个建筑剖面的屋架是否符合举折之制来判断该屋架是否符合法式；第三，它解释了为何所有屋架剖面法式之所以被称为法式的原因。

这一步一步的方法，梁思成将其称之为“做法”，这也是李诫在《营造法式》中的典型做法。然而不是手册中的所有部分都是符合做法的。例如，在塑造厅堂建筑空间问题上，我们用减少槫下直接设立的柱子的做法来腾出空间——减柱法。李诫没有提供这样的步骤，相反他提供了一系列（或一图集）示例：18个剖面(图2)，不难认定，它们每一个都是符合法式的。问题是，仅凭这些示例，我们不知道还有没有其他的符合法式的做法，如果有，它们又是如何的。我们可以从上文中讲

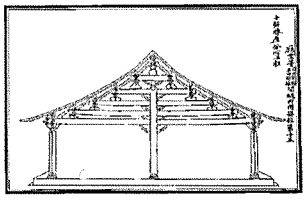
example the method for determining the curved roof section, a method known as juzhe (Figure 1).

In a traditional Chinese roof, the curved section is formed by a series of segmented rafters, each of which spans between two neighboring purlins. The lower end of the lowest rafter sits on the purlin at the eaves, and its upper end on the next higher purlin. The rafter above spans between the second and the third purlins and so on to the highest rafter whose upper end sits on the ridge purlin. To determine the roof section, it suffices to determine the positions of the purlins.

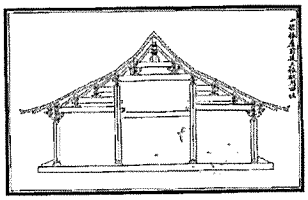
This is the function of juzhe, using a two-step procedure. One starts with the overall depth of the building which is subdivided into equal rafter lengths. For example, one might start with an 8-meter-deep building with 8 rafter lengths of 1 meter each. These 1-meter intervals determine the horizontal locations of the purlins. The first step is to determine the height of the ridge purlin above the purlin at the eaves. We do this by dividing the overall depth of the building by a constant. We draw a line connecting this point with the eaves purlin, and call this the working line. The second step is to determine the height of the first purlin below the ridge purlin. We do this by finding the corresponding point on the working line. We lower that point by 10% of the height of the ridge purlin; this lowered point is the location of the purlin. We draw a new working line from the eaves purlin to this purlin. For each remaining purlin, we repeat the second step, reducing the percentage by half: 5%, 2.5%, and so on.

The beauty of juzhe is that in addition to producing good results and being easy to remember, it helps us understand roof sections by providing three capabilities for analysis (Stiny and Mitchell 1978). First, it provides a definition for what constitutes a legal roof section. Second, it provides instructions for the creation of a legal roof section - start with a new building section and apply the procedure. Third, it provides instructions for determining whether a given roof section is legal - see whether there is a building section for which the procedure produces that roof section.

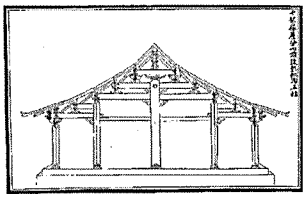
This step-by-step approach is what Liang referred to as grammatical and it is typical of Li' s approach in the Yingzao fashi.



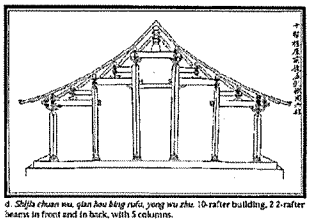
a. *Shijia chuan wu, fen xin, liyong[san zhu.* 10-rafter building, centrally divided, [with] 3 columns.



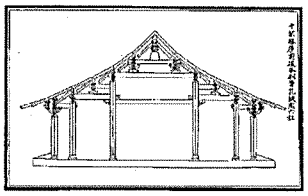
b. *Shijia chuan wu, qian hou zuochuan fu, yong si zhu.* 10-rafter building, a 3-rafter beam in front and in back, with 5 columns.



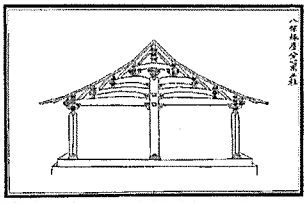
c. *Shijia chuan wu, fen xin, qian hou ruhi, yong wu zhu.* 10-rafter building, centrally divided, a 2-rafter beam in front and in back, with 5 columns.



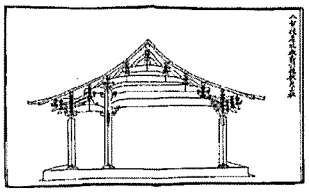
d. *Shijia chuan wu, qian hou bing ruhi, yong wu zhu.* 10-rafter building, 2 2-rafter beams in front and in back, with 5 columns.



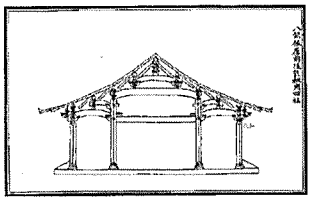
e. *Shijia chuan wu, qian hou ge zhaqian ruhi, yong liu zhu.* 10-rafter building, 1- and 2-rafter beams both in front and in back, with 6 columns.



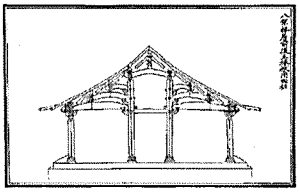
f. *Bajia chuan wu, fen xin, yong san zhu.* 8-rafter building, centrally divided, with 3 columns.



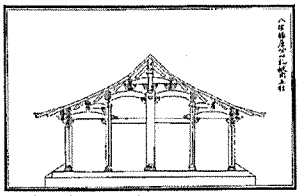
g. *Bajia chuan wu, ruhi dui liuchuan fu, yong san zhu.* 8-rafter building, a 2-rafter beam abutting a 6-rafter beam, with 3 columns.



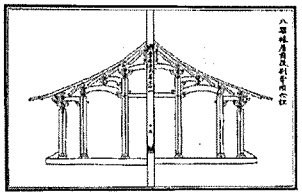
h. *Bajia chuan wu, qian hou ruhi, yong si zhu.* An 8-rafter building, a 2-rafter beam in front and in back, with 4 columns.



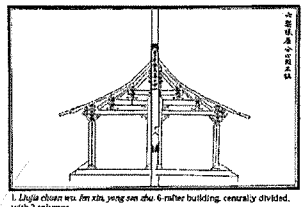
i. *Bajia chuan wu, qian hou zuochuan fu, yong si zhu.* 8-rafter building, a 3-rafter beam in front and in back, with 4 columns.



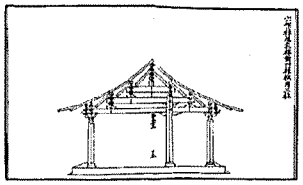
j. *Bajia chuan wu, fen xin, qian hou ruhi, yong wu zhu.* 8-rafter building, centrally divided, a 2-rafter beam in front and in back, with 5 columns.



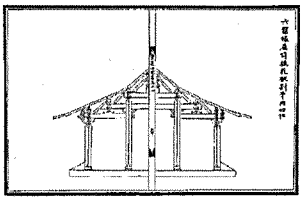
k. *Bajia chuan wu, qian hou zhaqian [ruhi], yong liu zhu.* 8-rafter building, a 1- [and a 2-] rafter beam in front and in back, with 6 columns.



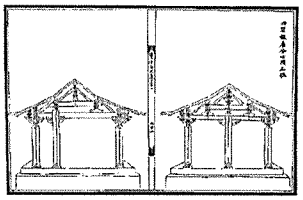
l. *Liujia chuan wu, fen xin, yong san zhu.* 6-rafter building, centrally divided, with 3 columns.



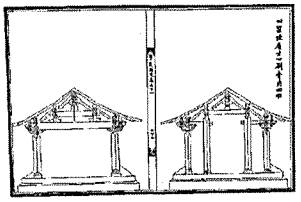
m. *Liujia chuan wu, ruhi dui sichuan fu, yong san zhu.* 6-rafter building, a 4-rafter beam abutting a 2-rafter beam, with 3 columns.



n. *Liujia chuan wu, qian hou ruhi, yong si zhu.* 6-rafter building, a 2-rafter beam in front and in back, with 4 columns.



o. Left: [*Sijia chuan wu, zhaqian dui sanchuan fu, yong san zhu.* 4-rafter building, a 1-rafter beam abutting a 3-rafter beam, with 3 columns.]
Right: *Sijia chuan wu, fen xin, yong san zhu.* 4-rafter building, centrally divided, with 3 columns.



p. Left: [*Sijia chuan wu, tongyan, yong er zhu.* 4-rafter building, clear span, with 2 columns.]
Right: *Sijia chuan wu, qian hou zhaqian, yong si zhu.* 4-rafter building, a 1-rafter beam in front and in back, with 4 columns.

图2　营造法式（梁1983，313-321）中的18个厅堂剖面

Figure 2　The 18 ting hall sections shown in the Yingzhao fashi (Liang 1983, 313 – 321)

到的三个依据来理解运用这些示例：第一，我们可以从系列示例中选择一个式样来建造一个新的合乎法式的厅堂断面，但是我们不能建造出第十九种断面式样，然后肯定它也合乎法式；第二，我们可以用已经在册的例子去验明一个先前不了解的剖面，但是如果有个剖面的做法不在册，我们也不能简单否定它；最后，我们不知道为何系列示例只包含这18个剖面而没有更多的，册中并未注明。

2 厅堂剖面做法

什么是形式文法？它好比一种特殊的计算机程序，它接受输入信息之后，将其编译，然后再输出信息。例如，一个平衡你银行户头收益支出的程序。输入信息包括初期余额、存款及支出。程序处理这些输入信息，将存款减去支出。最终，在一系列操作之后，程序得出最后的输出信息，也就是最终结余。形式文法的运作原理与其类似，但是它接受的是图像化的信息，例如建筑图；它们通过对图像局部的增删来实施图像的转变，经过一系列形式间的变形（transformation），最终得出的还是图像信息——另一幅图。输入信息叫做初始形式，每一步的形式间变形叫做一种通例（或通则）。形式文法的图像化性质使得像我们这样的建筑问题迎刃而解。

我们的形式文法包括四个初始剖面形式（四、六、八、十架椽的厅堂剖面、每个包括地面线、两个柱子和若干榑）(图3-a)和14个通例（图3-b）。通例的分类以及相应增设柱梁方法如下。

A组只包含通例1，不增柱，对剖面不作改动。这样我们得到的是没有内部柱子的剖面。B组只包含通例2，增设一中柱，位于脊榑之下。C组可进一步分成两个小组。小组C1包含规则3至8。每个通例增设一柱以及架设在该柱和该柱之前柱子上的梁。两柱间形成一空间。通例根据梁的长度不同而不同：通例3增设了搭牵（一椽空间），通例4增设乳袱（二椽空间），以此类推。小组C2包含通例

However, not all parts of the manual are grammatical. The creation of spaces inside a particular type of building called a ting hall is accomplished by eliminating columns located directly beneath purlins. Li does not provide a procedure for doing this, rather, he provides a list (or corpus) of 18 example sections (Figure 2). The problem is that given only these examples, we do not know whether there are other allowable sections. We can put this in terms of the three capabilities mentioned above. First, we do not know why the list contains these 18 sections and not others. Second, we can create a new legal ting hall section by choosing one from the list, but we cannot create a 19th with any assurance that it is allowable. Third, we can only confirm a section is allowable by comparing it to those on the list.

If we had a procedural method of analyzing these 18 sections we could better understand space in ting halls. In fact, there is such a method. Using a technique called "Shape Grammars", which we will explain in this article, we can provide the three capabilities for analysis mentioned above.

2 A Grammar of Ting Hall Sections

To understand Shape Grammars it is helpful to make an analogy with a computer program. A grammar accepts some input, applies a set of transformations on the input, and subsequently produces some output. For example, a computer program can balance your bank account by taking as input the initial balance, deposits, and withdrawals. The program acts on the input by adding deposits and subtracting withdrawals from the initial balance. The output returned is the resulting balance. Shape grammars work similarly but they take graphic information, such as a drawing, on which they execute graphic transformations, by adding to and erasing parts of the drawing, and they return graphic information, such as another drawing. The input is called the initial shape and each transformation is called a rule. The graphic nature of shape grammars makes them well-suited for architectural problems such as the ting hall.

Our shape grammar consists of four initial shapes (ting hall

图3-a 厅堂剖面文法的四个初始形式

Figure 3-a The four initial shapes of the grammar of ting hall sections

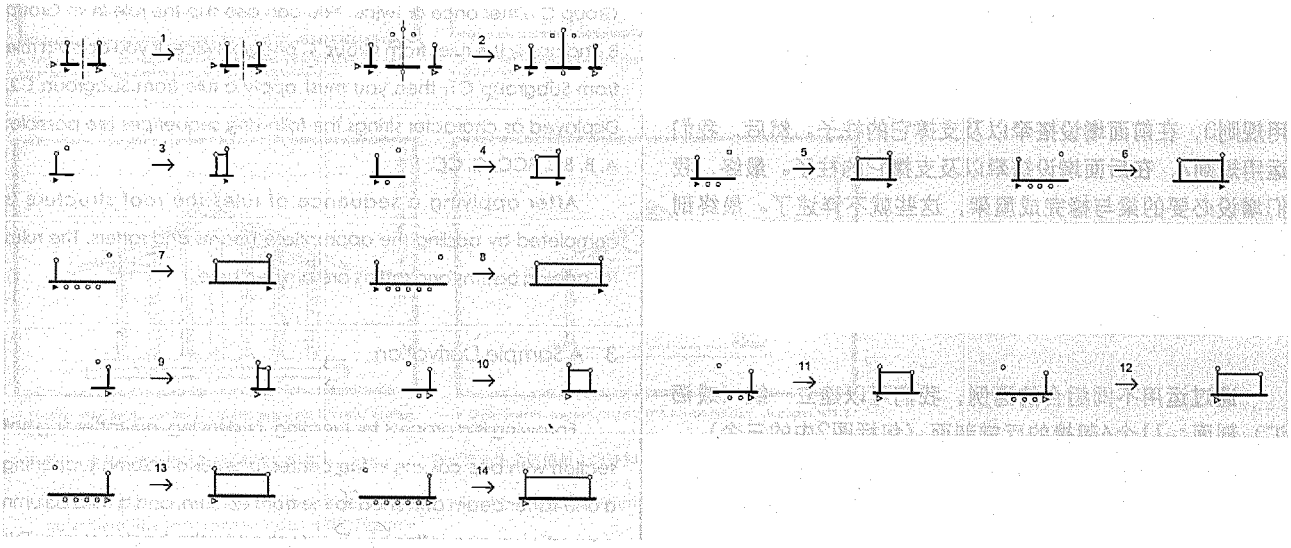


图3-b 厅堂剖面文法的14个规则

Figure 3-b The 14 rules of the grammar of ting hall sections

9~14。它们与通例3~8类似，只是它们厅堂的后面开始增设柱梁。

通例的用法如下。如果你用A组里的通例，则不能再运用其他通例，结果就是一个没有内柱只有一个大隔间（bay）的剖面。如果你用B组里的通例，你可以就此为止或者运用C组里的通例们一到两次。你也可以跳过B组通例直接运用一到两次C组的通例。如果你运用了C1小组的通例，则必须接着运用C2组中的一个通例。总之，有如下可能组合：A, B, BC, BCC, C, CC。

在你运用了一系列的通例之后，你就可以通过增设相

sections of 4, 6, 8, and 10 rafters, each consisting of a ground line, two columns, and purlins) (Figure 3a) and 14 rules (Figure 3b). The rules form groups and add columns and beams in the following way.

Group A contains only rule 1, which adds no columns. This gives us a section with no interior columns. Group B contains only rule 2, which adds a central column, i.e., a column below the ridge purlin. Group C contains two subgroups, Subgroup C1 and Subgroup C2. Subgroup C1 contains rules 3 through 8. Each rule adds one column and one beam spanning between that column and the column in the front of the hall. These two columns form a bay. The rules vary according to the length of the beam: rule 3 adds a one-rafter beam (and a one-rafter bay), rule 4 adds a two-rafter beam (and a two-

应的梁与椽最终完成屋架结构了。增设梁椽的具体规则这里恕不详述。

3 一个派生出来的样式

打个比方，我们要建立一个6架椽的厅堂剖面，中央有一根柱子，第二根柱子与前柱支撑前搭牵，第三根柱子与后柱支撑后搭牵（图4）。我们首先从一个6架椽的初始剖面开始。我们运用规则2，在中央增设一柱。接着，我们运用规则3，在前面增设搭牵以及支撑它的柱子。然后，我们运用规则7，在后面增设搭牵以及支撑它的柱子。最终，我们增设必要的梁与椽完成屋架，这些就不详述了。最终剖面如图。

4 厅堂剖面语汇

通过运用不同组合的通例，我们可以建立一组（或语汇）剖面：11个6架椽的厅堂剖面（包括图2中的三个）；图5中展示了5个。如果我们考虑所有大小的厅堂，我们可以建立122个剖面。不同的文法衍生不同的设计组合。

我们的文法用来建立剖面：它建立厅堂剖面正像用举折确立屋架剖面一样。它像举折一样给了我们三个可能性：第一，我们可以通过运用不同的通例组合，创造出新的剖面；第二，我们可以用我们的文法能否生成某个断面，来检验一个我们事先未知的断面；最后，也许是最关键的，这些通例们解释了为什么某些剖面在法式图集中，

rafter bay), and so on. Subgroup C2 contains rules 9 through 14. These are like rules 3 through 8, but they act from the back of the ting hall.

Rules are applied in the following ways. If you apply the rule from Group A, you cannot apply any other rules. The result is a section with no interior columns and a single large bay. If you apply the rule from Group B, you can stop or you can apply the rules from Group C either once or twice. You can also skip the rule from Group B and apply the rules from Group C once or twice. If you apply a rule from Subgroup C1, then you must apply a rule from Subgroup C2. Displayed as character strings the following sequences are possible: A, B, BC, BCC, C, CC.

After applying a sequence of rules the roof structure is completed by adding the appropriate beams and rafters. The rules for adding beams and rafters are omitted here.

3 A Sample Derivation

Following is a process for creating, or deriving, a 6-rafter ting hall section with one column in the center, a second column supporting a one-rafter beam attached to the front column, and a third column supporting a one-rafter beam attached to the back column. This derivation begins with the 6-rafter initial section. Rule 2 is applied which adds the column in the central position. Next rule 3 is applied which adds a one-rafter beam in front, along with the column that supports it. Then rule 7 is applied which adds a one-rafter beam in back, along with its supporting column. Finally beams and rafters are added as required to complete the roof structure (these steps are

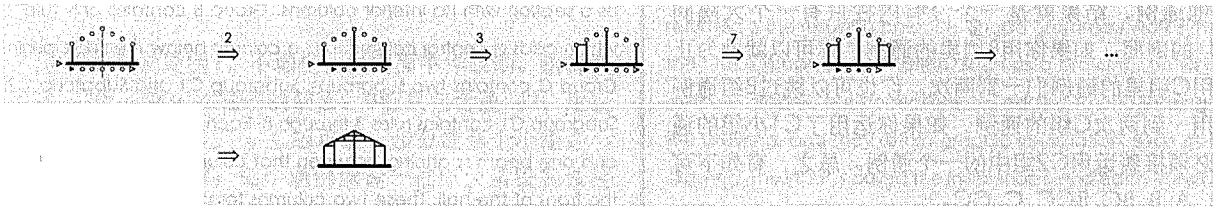
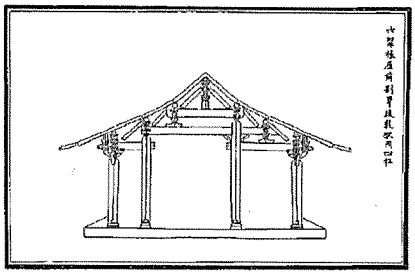
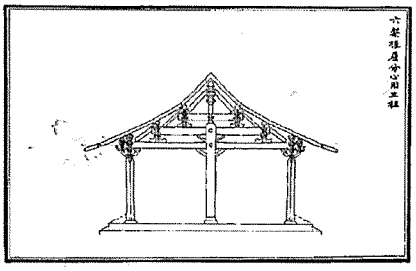


图4 6架椽厅堂示例。通过运用规则2、1和7来得到特殊的形式。我们省略了完成屋顶结构的过程。图5，根据营造方式重新绘制，其中展示了上述过程

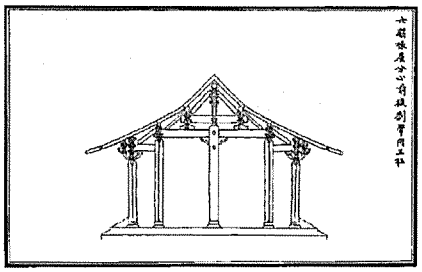
Figure 4 The derivation of a 6-rafter ting hall. We apply rules 2, 1, and 7 to establish the distinctive features. We omit the process of completing the roof structure. It is shown in Figure 5, redrawn as in the Yingzao fashi



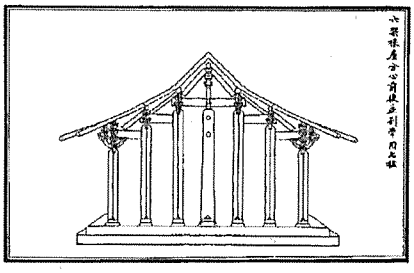
a. *Liujia chuan wu, qian zhaqian hou rufu, yong si zhu.* A 6-rafter building, a 1-rafter beam in front, a 2-rafter beam in back, with 4 columns.



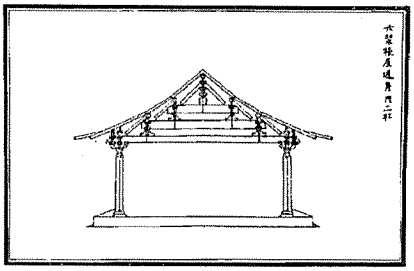
b. *Liujia chuan wu, fen xin, yong san zhu.* A 6-rafter building, centrally divided, with 3 columns.



c. *Liujia chuan wu, fen xin, qian hou zhaqian, yong wu zhu.* A 6-rafter building, centrally divided, a 1-rafter beam in front and in back, with 5 columns.



d. *Liujia chuan wu, fen xin, qian hou bing zhaqian, yong qi zhu.* A 6-rafter building, centrally divided, 2 1-rafter beams in front and in back, with 7 columns.



e. *Liujia chuan wu, tong yan, yong er zhu.* A 6-rafter building, clear span, with 2 columns.

图5　由文法衍生出的新的6架椽厅堂剖面。它是否属于官式规则由文法使用人去评判。在图4中可以看到第三个剖面的衍生过程

Figure 5　Five new 6-rafter ting hall sections derived with the grammar. Whether or not they are legal is for the user of the grammar to determine. The third section is derived in Figure 4

另一些不在。

5　文法假设

我们的文法定义了122个剖面组合（未展出）。我们是如何知道这些都是合乎并且是全部的法式剖面？换句话说，我们如何证明我们的文法是正确的？实际上，我们的文法是一个假设，它是临时的。它建立在有限的现有资料上（图集）并据此作出预测，也就是说语汇中的122个剖面是合乎法式的剖面，而其他的是不合乎法式的剖面。

下一步，要测试预测并在必要的情况下修改假设。科学家通过设立和进行试验来验证假设的真实性。换句话说，他们设计出问题，并且操控自然去作出回答。在语言学里，生成性语法制造了句子，句子的好与坏则要听说母语的人的评价。

omitted). The resulting section is shown in Figure 4.

4　A language of ting hall sections

By applying the rules in different combinations, we can create a set (or vocabulary) of sections. Eleven sections of 6-rafter ting halls are shown, three in Figure 2 and five in Figure 5. If we consider all sizes of ting halls we can create a set of 122 sections. Different grammars produce different sets of designs.

Our grammar is a procedure for creating sections; it does for ting hall sections what juzhe does for roof sections. This gives us the same three analytical capabilities as juzhe. We can create a new section by applying rules in different combinations, we can evaluate a previously unknown section by testing whether we can produce it with our grammar, and we can explain why some sections are in the set and not others.

在我们的“营造法式”中，我们也设立了假设，但是因为没有所谓的“原设计者”，我们只能自己来评估它。我们来看按照我们的文法做出的五个设计（图5）。第一个和图集示例中的均不一样，但是它也并非明显地不合法式，它很可能符合。第二个辑录在图集中，因此即为图集中的法式。第三个和图集中的比较类似，应该是合乎法式。第四个侧面进深没有大过一架椽的，使得它很难使用，几乎肯定是不合法式的。第五个无内柱，跨度很大，6椽袱。这种情况只在4椽袱中见到，但是6椽袱在图集中的8架椽厅堂中见到，所以这有可能是合乎法式，也可能不是。

我们可以校正我们的文法，使得按照它不会做出不合法式的设计。例如，如果我们认为第四个设计是不合法式的，因为将搭牵用在了当中的跨度里，我们可以仅在C组规则的第一轮中运用规则3和9。这样，搭牵就只会出现在首跨和末跨。如此，我们不断精炼我们的假设直到它定义出在我们认知范围内最好的语汇。我们的文法精确地表达了我们的假设的同时，也给我们留下了阐释的余地。这就是它的本意。

6 对文法教学的启示

能够构建设计语言——即风格——的假说的能力，牵涉到了几个话题，首先就是如何教授法式的问题。我认为，学生学习《营造法式》，不仅仅要理解李诫写下来的内容，更要明白如何完成对我们21世纪的人来说尚不完整的画卷。常规的分析方法是向学生讲述一套专家的说法，然后，就被专家的阐释当成了权威的阐释。

相比之下，我所运用的方法，清楚地告诉学生这样的阐释是怎样得来的；实际上，它鼓励学生去构建他们自己的阐释。他们运用文法并且不断调试直到他们认为满意为止；他们摄取信息，解析它，捍卫他们的解析成果，这些都在一个清晰的框架之中。在这里我们学到样式并不是一个遥远的陌生概念，而是一种人文建构。样式可以被规格

5 Grammar as Hypothesis

Our grammar defines a language of 122 possible sections. How do we know that these are all and only the legal sections? In other words, how do we know that the grammar is correct?

Actually, the grammar is only a hypothesis. It is based on finite empirical evidence (the corpus) and makes predictions - namely that the 122 sections in the language are legal, and that all others are illegal. The next step is to test the predictions and revise the hypothesis as necessary. In science, this is done by inventing and conducting experiments.

In the case of the Yingzao fashi, we are also making a hypothesis that must be tested. Consider five of the designs generated by our grammar (Figure 5). The first design is not exactly like any other in the original corpus, but it is not obviously illegal either - it is probably legal. The second design is in the original corpus and therefore is legal by definition. The third design is similar to others in the corpus and is probably legal. The fourth has no bays deeper than one rafter, making it difficult to use and is likely to be illegal. The fifth design has a clear span 6-rafter beam. The clear span is seen only in the 4-beam ting hall, but the 6-rafter beam can be found in an 8-rafter ting hall in the corpus. Maybe this design is legal, maybe not.

We can revise our grammar so that it does not result in illegal designs. For instance, if we think that the fourth design is illegal because there are 1-rafter beams in the inner bays, we could allow rules 3 and 9 to be applied only in the first round of rules from Group C. Then the 1-rafter beams would appear only in the front or back bays. In this way, we refine our hypothesis until it defines what we understand to be the appropriate language. The grammar expresses our hypothesis precisely, while still leaving room for interpretation.

6 Implications for Teaching

This ability to formulate hypotheses about languages, or styles, of design has several implications, beginning with how it is taught. It seems to me that students of the Yingzao fashi need to understand

化，尽管它并非客观的。

我们可以通过支持文法的电脑软件来强化这种教学方法。这种软件工具可以自动筛选过程中不相关的部分，例如那些在我们的例子中被删掉的部分（图4）。这可以让学生们集中在文法上及其剖面语言上。

我发明了适用于厅堂剖面规则的软件（Li 2002）。目前，它可以让学生们简单明了地建立厅堂剖面。他们很喜欢这个并且马上希望尝试改变不同的规则。这超出了软件的功能，我和我的同事有了更新的软件(Li et al. 2009)能够随心所欲地改变规则。

7 建筑部件之外

我的这种以文法见长的分析方法还能够帮助产生新的知识。在试图“翻译”李诫的文字内容——重现他心里想的那个断面的过程中，我们看到，他省略了我们这些现代读者需要的信息。例如，他没有解释如何界定厅堂的材等，面阔几许，进深几何，或是上述讲到的空间划分。这些我们可以将其称之为建筑层面的参数，我们需要它们全面地描述一个厅堂。

陈明达所要致力阐明的，正是这些建筑层面的参数。他是隐含地理解着这些参数，而我们今天能清楚地说明这些参数。通过清楚地说明李诫文字的意思，我们可以更为精确地说出——并探究——李诫没有写下的东西。例如，什么是决定着建筑层面参数的那个系统？我们可以用文法去表达这个系统。

8 厅堂剖面之外

在建筑构件的层面，仍然有许多等待挖掘。为了清楚地完成剖面，我们需要弄明白每个独立的部件：每根柱子，每个梁和每个单元。部件如何根据情况不同有不同的组合以及他们是如何组装的？

not only what Li Jie wrote, but also how to complete what appears to be an incomplete picture to us in the twenty-first century. A typical approach would be to present the analytical interpretation of an expert - an interpretation which is considered authoritative on the subject. However, the shape grammar approach instructs students on how to construct their own interpretation, and guarantees the legitimacy of that interpretation. A grammar can be tested and revised as desired. Students can find information, interpret it, and defend their interpretations all within a clearly defined framework. The lesson here is that style does not exist outside of a human construct. Style can be formalized, but it is not objective.

This approach to teaching can be enhanced by computer-based tools that support grammars. Such tools can automate irrelevant parts of the process such as those omitted in our examples (Figure 4). This allows students to concentrate on the grammar and the language of sections that it defines. I have developed such software for the ting hall section grammar (Li 2002). Currently the software allows students to easily and transparently create sections. Based on observation, the students enjoy this process and immediately want to be able to change the rules of the grammar. This was beyond the capability of the initial software. My colleagues and I have recently developed software which allows the rules to be changed at will (Li et al. 2009).

7 Beyond Building Components

An explicitly grammatical approach to design can help create new knowledge as well. In trying to “translate” what Li Jie wrote – to create the same sections he envisioned – it becomes clear that he omitted information that modern readers need. For example, he did not explain how to determine the grade of the ting hall, its width in bays, its depth in rafters, or the spatial subdivision discussed above. These may be called building-level parameters and they are necessary to describe a ting hall completely.

It was these building-level parameters that Chen Mingda (1993) worked to clarify. By saying precisely what Li Jie wrote, we can say –

再次重申，李诫只说了部分故事。他给出的远远不是构筑部件组合的所有细节，这里仅有一些适用于有限场合的图片。如何组织这些变量？无疑这些是建设者的问题——也许这超出了李诫自身的知识——但是建设者们肯定有个办法。再次，如果我们希望能理解这个办法，我们就必须能够设置（校正）新变量。形式文法直接处理事物的形式，如建筑部件，因此适合于这样的研究。

要清楚地了解部件和建筑的形式，我们自然需要借助三维模型。它们通过电脑辅助技术例如快速原型制造（Rapid Prototyping），得以实现，因为它们的逼真程度而具有巨大的优势：它们有重量，摸得着，能够组装和分解。假设是能够通过实体来检验了。[1]

这里谈论的剖面的文法是更大的平面文法、屋架剖面文法、立面文法和厅堂解析(Li 2001)文法的一部分。高一层次的文法能被延伸包含殿堂等更多其他的建筑类型。这能帮助我们更好地理解主要建筑类型间的联系。

9 营造法式之外

众所周知，营造法式是一本建筑技术规范的著作，因此将它当作一本考量现存建筑的参考书来使用则更合理。然而，在我们将这些建筑与营造法式中的作比较并且研究它们的联系时，我们需要一个理论框架来研究这些建筑。我们的文法式规则提供的正是这样的理论框架。它就是这么使用的。

如果我们有个文法能够衍生出营造法式中提到的建筑语汇，则我们研究现存建筑就有了一个正式的参考依据。如果现存建筑符合文法规范，它就是营造法式语汇的一个完美实例。如果建筑需要通过文法修改，则这个修改就体现了建筑与参考依据的差别。

如果我们进行了大量的现存建筑规则与文法规则的比对，并且正式地汇编这些差异，我们就可以研究其中的规律，也正式地表达出来。我们寻找规律可以建立在比如说

and investigate – more precisely what he did not write. Chen understood this implicitly; now we can state it explicitly. What, for example, was the system for determining building-level parameters? We can now characterize this in a grammar.

8 Beyond Ting Hall Sections

At the level of building components, there is also much to be understood. In order to complete the sections we have to specify each individual component explicitly; each column, each beam, each block. How does the form of each component vary with its context, and how are all the components assembled? Here again, Li Jie told only part of the story. Despite all the detail he gave for forming the components of a bracket set, these were only prototypes, used in some cases but definitely not in all. How are these variants formed? Perhaps this was within the purview of the builders. It is possible these details were beyond Li Jie' s own knowledge, but the builders must have had a method. Again, if we aspire to understand that method, we must be able, to create new (and conformal) variants. Shape grammar deals directly with the shapes of objects, like building components, and as a result is well-suited for pursuing this investigation.

Being precise about the shapes of buildings and components is best accomplished by three-dimensional representations. These are made using computer-aided techniques like rapid prototyping, and offer important advantages because they are tangible - they have material weight, they can be touched, assembled, and disassembled. Hypotheses about their use in construction can also be tested physically.[1]

The section grammar discussed here is part of a more comprehensive grammar that creates plans, roof sections, elevations, and descriptions of ting halls (Li 2001). This larger grammar can be extended to include dian halls and other building types. A study of this larger grammar would help us understand the relationships among the main building type designs.

建造的日期或者地点上。如此，我们可以理解蕴含在现存建筑中作为文法演化的风格演化了。Knight将这种研究风格变化的方法用于研究希腊陶器母题。

这将在我们现在已经熟悉的三个方面帮助我们。第一，比如说，告诉我们时代、地点、功能，我们可以设计一个符合法式的建筑。第二，如果发现了一个之前未知的建筑，我们可以判明它是不是符合法式。现在如果我们的预测是正确的——我们的设计或者一个新近发现的建筑被判定为符合法式——那么就支持了我们的假设（虽然，还当然不能说已被证实）【证实与否是考古问题，这里讨论的是形象上像不像】。如果我们的预测错了——一个不同的建筑被发现或者我们研究的成果被判明是不符合法式，则我们的假设就要作相应调整。第三个意义当然就是我们能有一个对文本和对现存建筑关系的统一的解释。这个解释通过我们的文法假设表现出来，我们可以通过在实地调研、文献研究或者其他类型的研究中不断发现的相关信息精炼这个文法假设。它实际上告诉了我们如何去寻找需要的信息。

10 元代以后

梁思成指出中国木构建筑样式在明初有了一个显著的变化。明以前的建筑通常是根据《营造法式》建造，例如通过李诫术语学的运用。明清时期，《工程做法则例》是实行的建筑标准。因此我们可以运用上述的办法去寻找现存建筑与清朝的工程做法则例的联系。

明前和明清时期建筑的研究在比对相应时期建筑规则典章的基础上可以联系起来，便于对现存木构建筑的实地调研与更好的理解。如果我们再利用绘画、雕塑和其他间接证据，我们就能理解更早时期的作品。

11 结论

这些学习中国木构建筑的理念来自于形式文法的三个

9 Beyond the Yingzao Fashi

As noted, the Yingzao fashi was a book of standards and therefore only provides a reference for examining extant buildings. However, we still need a theoretical framework for comparing these buildings with the Yingzao fashi, and characterizing the relationships. Our grammatical approach offers just such a framework.

Once we have a grammar that characterizes the language of designs defined by the Yingzao fashi, we have a formal reference point against which we can compare extant buildings. If an extant building can be created by the grammar as proposed, then it can be said to be example in the language of the Yingzao fashi. However, if a building can only be created after modifying the grammar, then the modifications characterize the difference between the building and the reference point.

If we do this for a number of extant buildings and create a formally expressed compilation of all these differences, we can begin to look for patterns. We might look for patterns based on the date or place of construction. By doing so, we could understand the stylistic evolution of extant buildings as a grammatical evolution. A similar approach to stylistic change was demonstrated by Knight (1994) for Greek pottery motifs. This would help us in the three ways previously mentioned. First, given a date, place, and function we could create a building conforming with the rules of that time and place. Second, if a previously unknown building is discovered, we could determine whether it conforms with the rules of a particular style. If a newly discovered building is deemed to be in conformance then our hypothesis is supported (though not proven). However, if we find a non-conforming building, then our hypothesis must be revised. The third benefit is that we would have a complete explanation of what the text says and how it relates to extant buildings. Our grammatical hypothesis can be refined as relevant information comes to light, whether from fieldwork, archival study, or other types of research. Indeed, the hypothesis can tell us where to look for information.

重要特点。

第一，形式文法更加简单明了或者——更正式地说——正式。有方法读写形式文法，正好像有方法读写数学表达式一样。这使得文法像数学一样——从无生有，而且它还减少了含糊的情况。它使得对建筑的清楚明了的评述成为可能。

第二，形式文法定义语汇不是通过枚举设计实例，而是通过揭示如何设计，揭示其生成性与创造性，这正是授之以鱼不如授之以渔。因此，我们可以从有形的方面展示对建筑语汇的理解。

第三，文法既图像化又符号化，它们运用了建筑师熟悉的媒介也就是图形，也使用了更广泛的象征符号。这使得我们在同一个媒介中既能思考建筑又能表达建筑。

梁思成含蓄地强调了这些特点。当他写到《营造法式》由原理和比例基础上的规则组成时，他就涉及了简单明了和再创造的问题。而当他在《营造法式注释》中画了著名的插图时，他是遵从了现代建筑传统也就是作图像翻译。

这三个特点都被包含在形体文法之中了。是这样一种源于工作的分析工具（数学、语言学、人工智能、电脑编程）才让我们的时代叫做信息时代。另一方面，李诫的著作既启发着我们运用这些复杂工具去研究它的事实，也暗示着他在900多年前就已经在计算着营造法式了。

10 Beyond the Yuan

Liang (1984) has pointed out that in Chinese wood-frame architecture there is a significant stylistic divide that occurred at the beginning of the Ming dynasty. Pre-Ming buildings are associated with the Yingzao fashi. For the Ming and Qing dynasties, the Gongcheng zuofa zeli became the standard. We can use the strategy outlined above to look for patterns among extant buildings and their relations to the various texts.

These two analyses – the pre-Ming and the Ming-Qing – can then be combined by comparing the grammars of the two texts. This could lead to a unified framework for understanding wood-frame Chinese architecture. If we include paintings, sculptures, and other indirect evidence, we can extend the time span even earlier.

11 Conclusion

These ideas about studying Chinese wood-frame architecture follow from the three significant features of shape grammars. First, shape grammars are transparent or formal. There are rules for reading and writing shape grammars, just as there are rules for reading and writing mathematical statements. Using shape grammars it become possible to make precise statements about building designs. Second, shape grammars define languages by showing how to create designs, rather than by enumerating designs - they are productive or generative. Thus, we can explicitly demonstrate our understanding of a design language. Third, grammars are both graphic and symbolic; the symbols grammars use can be visualized as drawings - the preferred medium of architects. Thus we can both think about buildings and represent them through a common system.

Liang emphasized these qualities implicitly. When he wrote that the Yingzao fashi consisted of "formulas based on principles and proportions" (Liang 1984, 358), he had his finger on the ideas of transparency and productivity. And when he produced the remarkable drawings in the Yingzao fashi zhushi (Liang 1983), he

was following modern architectural conventions to make a graphic translation.

These three qualities are embraced by shape grammar, an analytical tool that derives from work (in mathematics, linguistics, artificial intelligence, computer programming) that has helped make ours the age of information. On the other hand, that Li Jie's work invites study with such sophisticated tools may suggest that more than nine centuries ago he was already computing the Yingzao fashi.

Notes

1 For an example of rapid prototyping in historical study, see Sass's (2000) study of Palladio's villas. On virtual versus physical modeling in teaching the Yingzao fashi, see Li and Tsou (1995).

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List of Chinese characters

chuan 椽
fen xin 分心
juzhe 舉折
Li Jie 李誡
Liang Sicheng 梁思成
ting hall 廳堂
tong yan 通簷
tuan 椽
Yingzao fashi 營造法式