Algorithmic Architecture in Twelfth-Century China: the *Yingzao Fashi*

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The *Yingzao fashi* as algorithmic architecture

The *Yingzao fashi* [Building standards] was written by Li Jie (d. 1110), court architect during the late Northern Song dynasty (960–1127), and published in 1103. Li evidently meant to educate government officials who commissioned buildings and to set standards for the builders who built them. He set out rules for designing foundations, masonry buildings, wood-frame buildings (*da muzuo,* or structural carpentry), finish carpentry (*xiao muzuo*), and painted decoration. He also defined terms and provided methods for estimating materials and labor. The book includes numerous drawings, but these reflect a much later style – probably Ming (1368–1644) or Qing (1644–1911) – and so can be used as references for the Song only with caution.

In the classical Chinese literature, the *Yingzao fashi* is one of only two surviving books that deal with architecture. The other is the *Gongcheng zuofa zeli* (*Structural regulations*), published in 1733. These two books are important simply by existing, since architecture – or, perhaps more properly, building – was not an appropriate subject for literati. However, they are interesting on their own account, because they document what had developed as, and probably still was, an oral tradition of structural carpentry. In the case of the *Yingzao fashi,* that tradition used a few rules to create many designs. We will examine this approach in more detail, but for the moment let us just call it *rule-based.*

As an example of this approach, consider the curved roof section, so often identified as the characteristic feature of Chinese architecture. Li Jie does not list legal roof sections for the builder to choose from. Rather, he spells out in a two-rule procedure called *juzhe* how to create the roof section for a building of any given depth. We will see this procedure in detail later. For now, the important point is that, given these two rules and a building of any legal depth, we can always find the correct roof section.

Another example of this approach is the modular unit *fen.* The *fen* can have eight different values, from 9.6 mm. to 19.2 mm., depending on the grade or rank (*deng*) of the building. So, for example, a (modular) dimension of 10 *fen* can have eight possible (absolute) values, ranging from 96 mm. at the eighth grade to 192 mm. at the first grade. Li Jie stresses that the *fen* is fundamental and usually uses it when specifying dimensions. The user chooses the appropriate scale or rule, reads off the dimension in *fen,* and obtains the correct length. Again, few rules, many designs.

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Liang Sicheng (1901–1972), who pioneered the study of the *Yingzao fashi,* perceived the significance of this approach and called the manual a "grammar book of Chinese architecture."[1] I go one step further and formalize Li's rule-based approach. This allows us to see the *Yingzao fashi* as algorithmic, gives a graphic version of the text, and provides other benefits, as we will see.

Formalizing the *Yingzao fashi*

We begin our formalization with a definition: a style is a set or language of designs perceived to be similar.[2] There are two basic ways of defining a language of designs: by listing the member designs (enumeratively) and by showing how to create them (generatively).

The important difference between the two is that the second, by showing how to create the designs, helps explain why they look similar and thus why we perceive a style. This was Li Jie's approach. We can say that the *Yingzao fashi* is a generative definition of the official Song architectural style.

To formalize the text, we "translate" it into a formal language. (Here, distinguish *formal language* and *language of designs.*) The language we use is shape grammar, which is not only formal but also graphic: it manipulate shapes, like plans, sections, and elevations. This contrasts with most other formal languages, which manipulate symbols, like letters and numbers. Thus our grammar will appeal to designers.

How does shape grammar work? Here is an extremely brief and informal introduction. A shape grammar consists of an initial shape and replacement rules. An initial shape is often a point in the working plane or space. A replacement rule consists of two shapes – one on the left, one on the right – with an arrow in the middle.

To create a design, compare the left side of a rule to the current shape; if you are just beginning the process, this is the initial shape. If there is a match, subtract (that is, erase) the left-side shape from the current shape and add (draw) the right-side shape. This yields a new current shape. Continue until finished. There are precise definitions for *shape, compare, match, subtract* and *add,* but an intuitive interpretation of these terms will suffice for a general appreciation of the grammar.

I have written a grammar of the *Yingzao fashi* that generates designs, each consisting of plan diagram, section diagram, plan section, roof section, elevation and text descriptions. In this paper I show only the part which creates roof sections.[3]

A grammar of roof sections

When considering the roof section in a Chinese building, it is important to remember that the purlins (*tuan*) support the rafters (*chuan*). The rafters span from purlin to purlin, forming the curved section. This is the opposite of the western practice, where the rafters support the purlins, and span from ridge to eaves in a straight line, forming a triangular section.

Li Jie's procedure for creating the roof section requires that we know the depth vy of the building, where v is the number of rafters and y is the horizontally projected length of

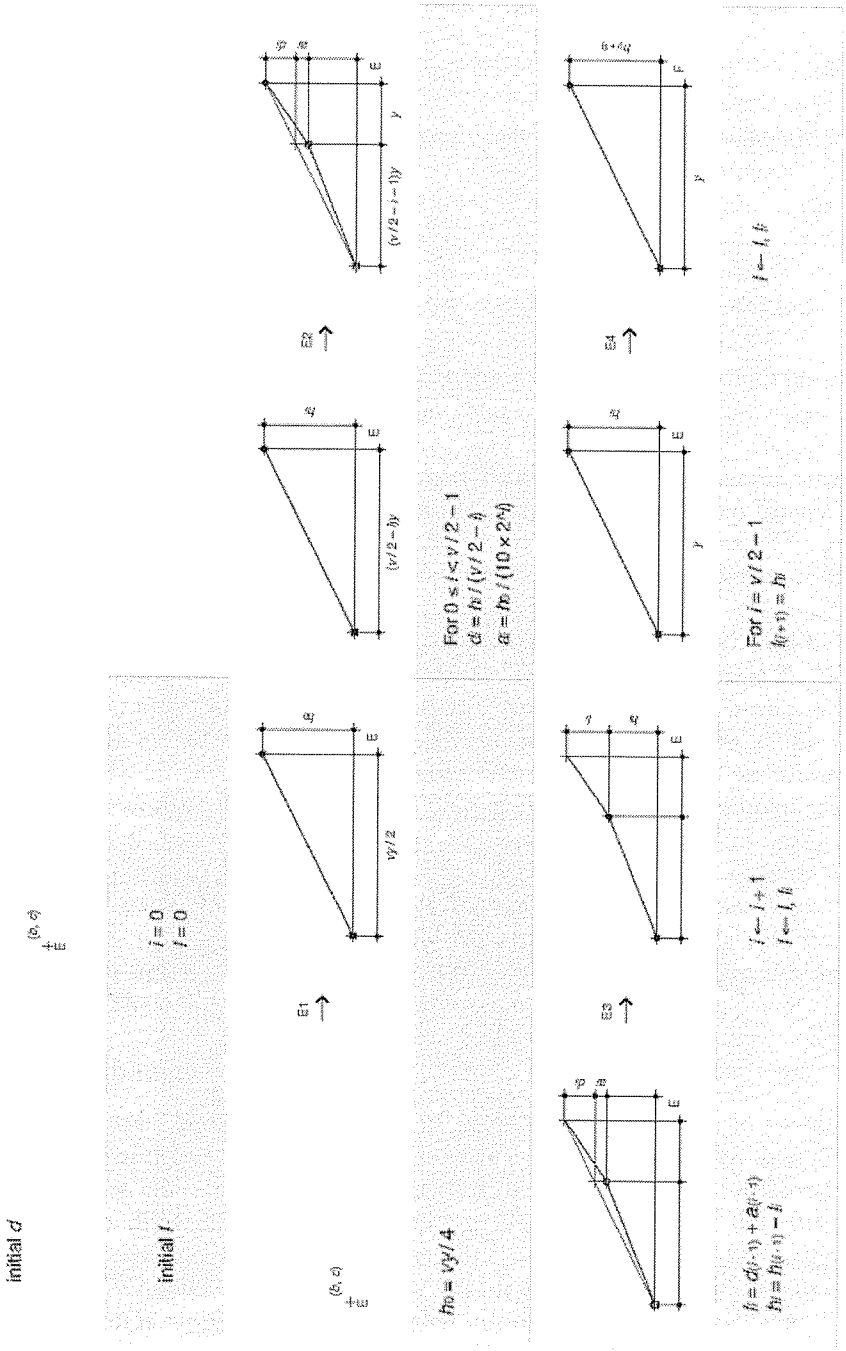

Figure 1. A grammar of roof sections

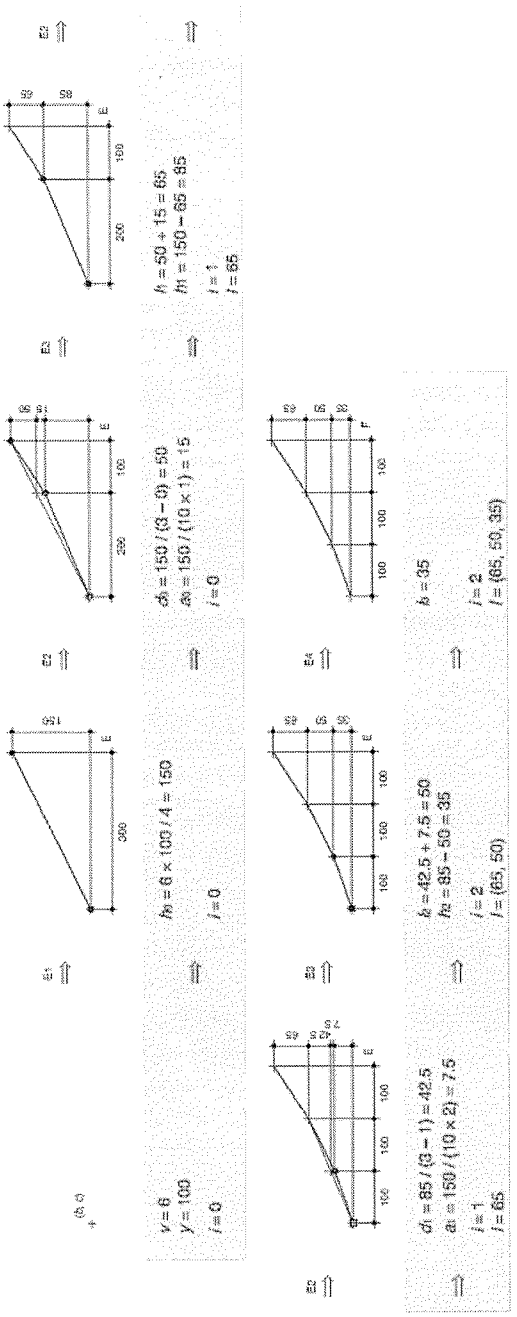

Figure 2. Derivation of the roof section of a building six rafters deep with rafters 100 *fen* long (i.e., $v = 6$, $y = 100$)

each rafter. We then calculate the height of each purlin, with the eaves purlin taken as zero. There are two steps: *ju,* 'raise,' and *zhe,* 'lower.'

First, find the height $h_0 = vy/4$ of (i.e., raise) the ridge purlin; call it the roof height. Draw a line connecting the ridge purlin and the eaves purlin; call it the working roof line.

Next, find the height of the first purlin below the ridge purlin. We already know its horizontal location: it is offset by y from the ridge purlin. Find the intersection of the working roof line and the vertical line at a distance of y. Lower this point a distance of $h_0/10$; the resulting point is the elevation of the purlin. From this point to the eaves purlin, draw a new working roof line. Repeat with the remaining purlins, each time halving the lowering: $h_0/20$, $h_0/40$, etc. For any set of legal starting conditions, there is exactly one legal roof section.[4]

Now let's translate this procedure into a shape grammar (Figure 1). The grammar consists of an initial shape, an initial description, and four rules. The initial shape consists of the point (b, c), indicated by a cross and the state label "E" that indicates that this is stage E, which deals with the roof section. Stage A creates the plan diagram, stage B the section diagram, and so on. Rule E1 corresponds to "raise," and rule E2 to "lower." Rules E3 and E4 perform housekeeping functions like erasing construction lines. The grammar generates, not only the section, but also a description l comprising the height differentials between purlins.

To show how the grammar works, let's use it to create the roof section of a building 6 rafters deep with rafters 100 *fen* long; that is, $v = 6$ and $y = 100$ *fen* (Figure 2). We apply rule E1 to raise the ridge purlin to a height of 150 *fen* above the eaves purlin. We apply rule E2 to find the elevation of the next purlin down. The intersection at the working roof line is 150 / 3= 50 *fen* below the ridge purlin. Rule E3 increments the counter i and calculates the new working height (150 – 65 = 85 *fen*) and erases the construction lines. The description is $l = 65$. We still have another purlin to locate, so we apply rule E2 again. The third purlin is lowered 42.5 + 7.5 = 50 *fen.* Rule E3 establishes the new working roof line, erases the construction lines, increments i, and updates the description $l = (65, 50)$. Now we have finished with all the purlins, so we apply rule E4, which removes the labels, updates the description $l = (65, 50, 35)$, and changes the state label from "E" to "F." The design is ready for the next stage of generation.

Formalizing the human role

We have now seen how the explanation of *juzhe* that Li Jie wrote in words can be expressed formally and graphically as a shape grammar. We have also seen that, given any appropriate starting conditions, we can always create a roof section. Different starting conditions lead to different sections, but there is always a section at the end. This is because the generative definition is complete. But in practice, the information is not always complete. When there are gaps, then the design can be completed only if the missing information is supplied. Where does that information come from? Is it reliable?

The answer to both questions involves us, the users. We have three roles in the generative definition of a style. This is easy to explain in formal terms. First, we perceive

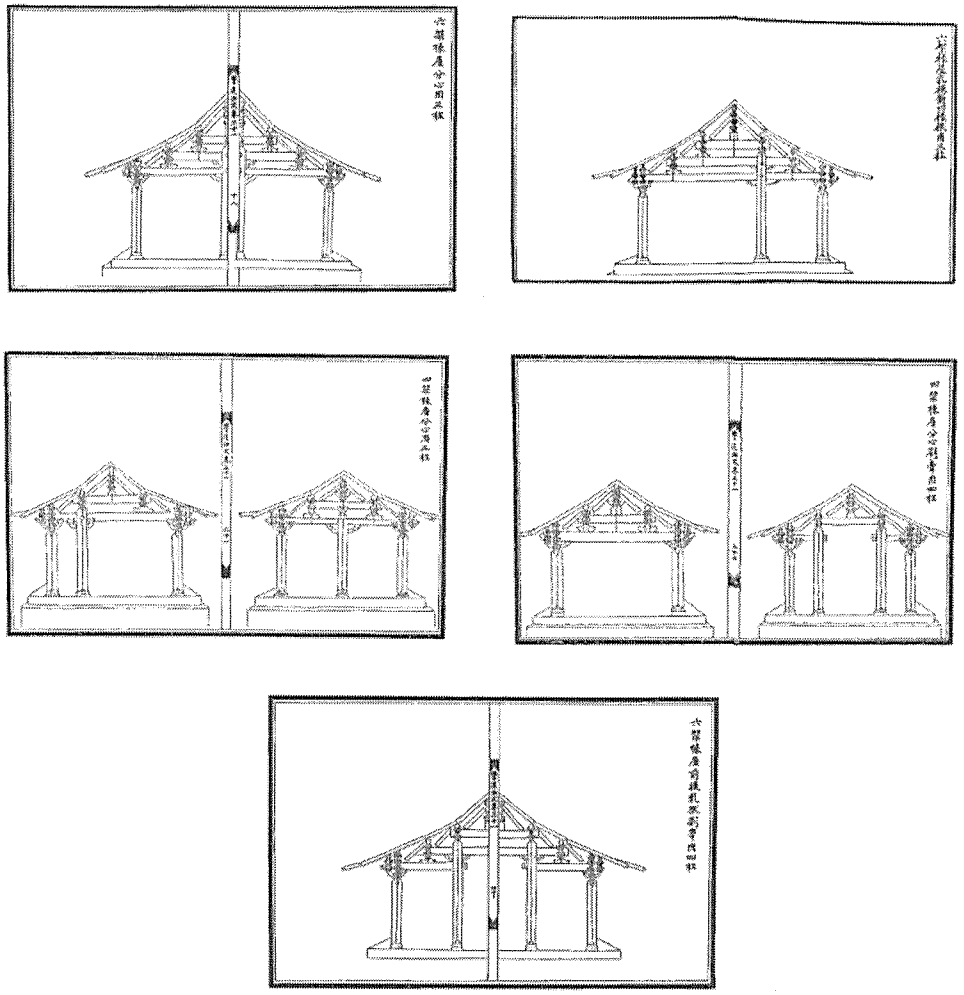

Figure 3. The *Yingzao fashi* contains eighteen sections of *ting* halls from four to ten rafters deep. Five are of 10-rafter halls, six are of 8-rafter halls, three are of 6-rafter halls, and four are of 4-rafter halls. The seven sections of 4- and 6-rafter halls are shown here. From Liang Sicheng, *Yingzao fashi zhushi* (The annotated *Yingzao fashi*), (Beijing: Zhongguo Jianzhu Gongye, 1983), pp. 319–321

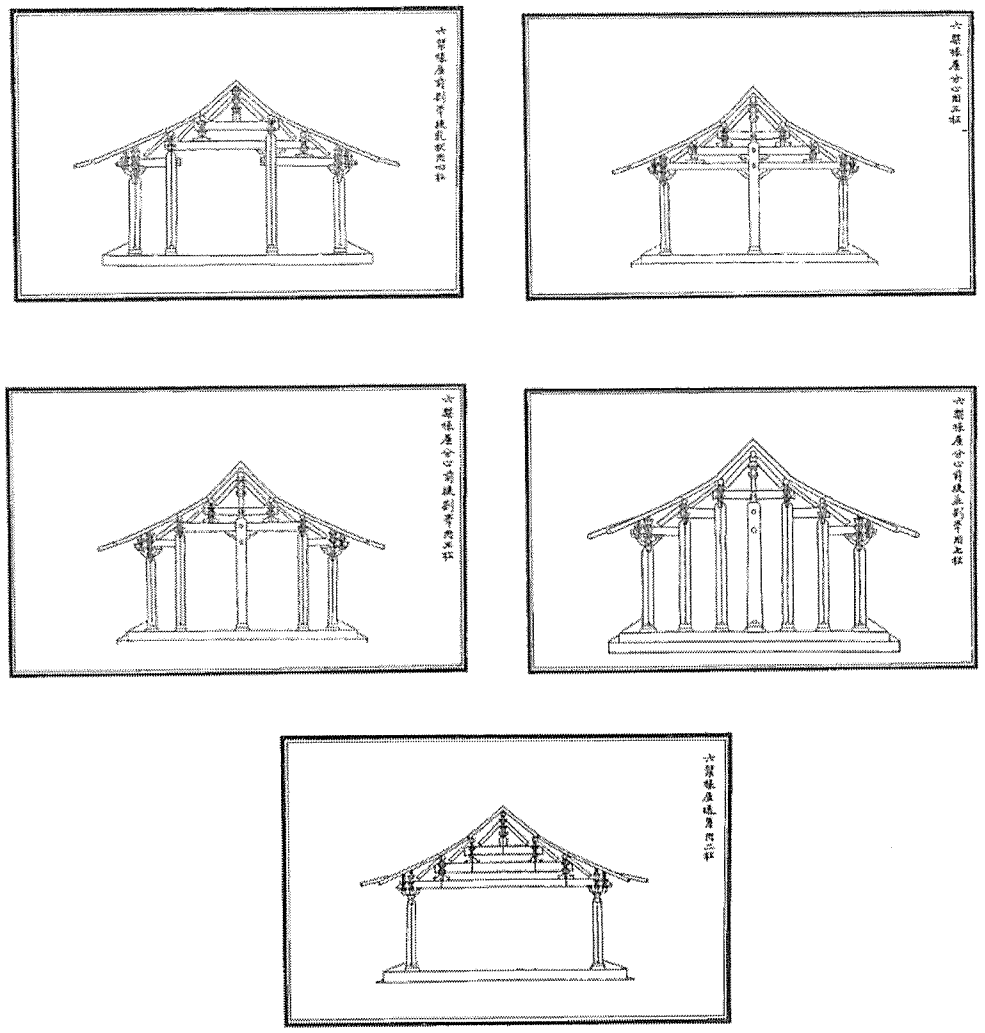

Figure 4. Five 6-rafter sections generated by the grammar. Whether or not they are legal is for the user to determine

the initial similarity. Second, we propose the hypothetical definition. And third, we evaluate whether new designs created by the definition belong to the language.

As an example, take the sections of a building type called a *ting* hall (Figure 3). The structural frame of a *ting* hall is composed of repeated transverse frames (*liangjia*) perpendicular to the front elevation. Each of these transverse frames is composed in turn of columns (*zhu*) and transverse beams (*fu*). The *Yingzao fashi* shows eighteen transverse frames drawn in section.

Our first act is to accept this corpus of eighteen sections as being similar. The question immediately comes to mind: what is the relation between this corpus and the language of sections? By accepting the eighteen sections as similar, we have also assumed that they are legal (i.e., in the language). This implies that the language contains all eighteen sections and possibly more; that is, the corpus is a subset of the language.

Our second act is to propose a grammar of the language.[5] It generates, among others, the following five sections of six-rafter buildings (Figure 4). That is, we formulate a hypothesis that makes five predictions.

Our third act is to evaluate these sections. Do they belong to the language? Are the predictions true? The first section is not exactly like any of the eighteen, but it is not obviously illegal either; it is probably legal. The second is in the corpus; definitely legal. The third is not very different from any of the eighteen; probably legal. The fourth has no spaces deeper than one rafter, which makes the building difficult to use; it is almost definitely illegal. The fifth has a clear span, which is seen in the smaller section (four rafters) but not in the larger sections (eight and ten rafters); maybe legal, maybe not.

If we accept as legal all sections but the fourth, then we can revise our grammar so that it no longer creates that section. One way is to allow one-rafter bays to be created only once, at the exterior of the building. With the revised grammar, we can generate more designs. If the designs seem dissimilar from those known to be in the style, we revise the grammar again. In this way, we refine our hypothesis until it defines the style as best we understand it.

Formalizing the student's role

This suggests another role for our grammar: to provide a useful experience for students learning about the style of the *Yingzao fashi.* I believe that the most useful such experience is to participate in composing and testing the hypothetical definition. Thus, our grammar generates all and not only (in other words, more than) the designs that are likely to be in the language. As the grammar reflects the imperfections of the text, so do its products, which the student can evaluate.

This differs from the usual analytical approach, in which the author is also the judge, because he is aiming for an authoritative definition. We might call this the expert approach. The advantage of our approach is that the student, not the teacher, aims for the authoritative definition. We give her no more information than there already is, so she must confront the gap between what she knows and what she needs to know. What information is missing, and why? Was it knowledge common to Li Jie and his readers,

but now lost to us? Was it overlooked by Li? Was it specialized builder's knowledge that, whether by design or by ignorance, Li omitted? What assumptions are needed, and are they justified? We might call this the naïve approach.

In our example of the sections, the student need not agree with my evaluations. She may, for instance, consider that six-rafter-long beams are impractical, making a clear span unlikely in a six-rafter-deep building (Figure 4, fifth section). She could then modify the grammar to limit the length of clear spans to four rafters. The important thing is that she can consider the question because it has been made clear, indeed almost inescapable. The lesson here is that style is not "out there"; it is a human construct.

Conclusion

We have seen that the *Yingzao fashi* as a definition of style is primarily generative, and have used shape grammar to characterize that definition formally and graphically. This has clarified, not only where the gaps are in the definition, but also how we users are responsible for filling those gaps. This in turn has suggested an explicitly experimental approach to teaching the style.

From here it is easy to imagine automating a grammar to emphasize the user's interaction with it: what she decides and when she decides it. In this case, we need not actually implement the shape grammar mechanism; we can merely simulate it. This allows the user to concentrate on the overall structure and logic of the grammar as a characterization of the style.

To test the feasibility of this approach, I have used Macromedia Flash to begin a prototype simulation of the section grammar, generating – in real time – a large number of designs. Freed of the distraction of executing the grammar manually, the user can consider issues of more direct interest: what her choices are at any stage, how those choices affect the design, which designs are in the language and which are not. One drawback is that the simulation cannot be modified by the user; it generates this one language of designs and no other. There is no immediate solution to this, but the benefit is clear: it shows how designers can use grammars to think about design more practically.

Other possible future work is a comprehensive comparative study of Chinese wood-frame architecture. The *Yingzao fashi* prescribes a style that evolved until just after the beginning of the Ming. At that point, there was a great stylistic break, after which the style changed markedly and virtually ceased to evolve.[6] Coincidentally, for this period we have the *Gongcheng zuofa zeli* of 1733 (already mentioned). This sets up a series of comparisons that can be done with shape grammar. For instance, now that we have a grammar that generates buildings in the style of the *Yingzao fashi,* we can formalize the relation between the manual and the extant pre-Ming buildings: how does the grammar have to be modified to produce those buildings? Then, since the extant buildings change through time, we can see how the grammars evolve, as Knight does.[7] Similarly, we can construct grammars of the style of the *Gongcheng zuofa zeli* and of that of Ming–Qing buildings. We can compare them with each other and with their pre-Ming counterparts.

Thus we can do a shape-grammatical study of Chinese wood-frame architecture from the eighth to the twentieth century; if we consider indirect evidence, we can begin even earlier. This would be a complete formal statement of a long tradition, and an appropriate extension of the studies, begun by Liang Sicheng, of this "grammar book" of Chinese architecture.

Notes

1. Liang Sicheng,"Zhongguo jianzhu zhi liangbu 'wenfa keben' " ("The two 'grammar books' of Chinese architecture")," *Liang Sicheng wenji* (*The collected works of Liang Sicheng*), vol. 2 (Beijing: Zhongguo Jianzhu Gongye, 1984), pp. 357–363.
2. George Stiny and William J. Mitchell, "The Palladian Grammar," *Environment and Planning B: Planning & Design* 5 (1978): 5–18.
3. For the complete version, see Andrew I -kang Li, "A Shape Grammar for Teaching the Architectural Style of the *Yingzao fashi,*" Ph.D. Diss., Massachusetts Institute of Technology, 2001.
4. This account of *juzhe* is slightly simplified, but it serves our purpose.
5. Li, "Shape Grammar."
6. Liang Ssu-ch'eng [= Liang Sicheng], *A Pictorial History of Chinese Architecture: A Study of the Development of Its Structural System and the Evolution of Its Types,* Wilma Fairbank, ed. (Cambridge, MA: MIT Press, 1984), p. 103.
7. Terry Weissman Knight, *Transformations in Design: A Formal Approach to Stylistic Change and Innovation in the Visual Arts* (Cambridge: Cambridge University Press, 1994).