INTEGRATING SYMBOLIC AND SPATIAL INFORMATION IN SHAPE GRAMMARS, WITH AN EXAMPLE FROM TRADITIONAL CHINESE ARCHITECTURE

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Abstract. Stiny’s (1981) formulation of descriptions is applied to building sections and their descriptions found in the twelfth-century Chinese building manual Yingzao fashi.

1. Introduction

Stiny (1981) has pointed out that designs are of interest not only as spatial objects, but also for the symbolic descriptions – often informal and verbal – that can be associated with them. His formulation of symbolic descriptions of designs has two important attributes. First, they are characterized generatively: they are generated by applying functions recursively to transform an initial description. In this respect, they are like other production systems (Gips and Stiny, 1980). Second, an individual function can be associated with an individual shape rule. Put another way, a shape rule can be extended to transform both a design and its description. It follows that a shape grammar can be extended to generate, using a single algorithm, a language of both spatial and symbolic objects, i.e., designs and their descriptions.

At least in theory. Stiny gives an example which illustrates the process, but it still remains to apply this formulation to a problem from history or practice. The twelfth-century Chinese building manual, Yingzao fashi (Building standards) by Li Jie (d. 1110), offers such an example. An important part of this book is its detailed, largely prescriptive treatment of the official wood frame style of the Song dynasty (960–1127). In this style, the structural frame of a building 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 18 possible transverse frames, drawn in section, and provides terse written descriptions of
these (Liang 1983, 313–321) In this paper we apply Stiny’s formulation of descriptions to the various types of information provided by this historical example.

2. The Sections and Their Descriptions in the Yingzao Fashi

It is well to remember that, unlike western buildings, in which the rafters support the purlins, in Chinese buildings the purlins support the rafters. The rafters are segmented and make possible the characteristic curved roof section. A rafter is not more than about 1.80 meters long in horizontal projection, and is used as a unit of length for beams and of depth for buildings. Hence we speak of three-rafter beams (sanchuan fu) or four-rafter buildings (sijia chuan wu).

Each description has the three parts described below. Each part characterizes one aspect of the transverse frame.

1 Depth, in rafters. This is an even number.
2 Subdivision, expressed in various combinations of three terms: clear span, central division, and beams. Of the 18 descriptions, none containing the term clear span also contains the terms central division or beams. A description not containing clear span contains central division or beams or both.
   a Clear span (tong yan). In a clear-span building, there are no interior columns, only the two in the front and back walls.
   b Central division (fen xin). In a centrally divided building, there is a column in the central position, below the ridge purlin.
   c Beams (fu). The length of the beam indicates the size of the bay it spans. Only the outermost beams are specified; the inner beams are merely implied.
3 Total number of columns. The minimum is two, in a clear-span building. The maximum is one more than the number of rafters, but this possibility is not seen among the 18 variations.

As an example, consider this description:

6-rafter building, centrally divided, 1-rafter beam in front and in back, with 3 columns (liujia chuan wu, fen xin, qian hou zhaqian, yong san zhu).

The building has four bays which, from front to back, are two, three, three, and two rafters deep. The two outside bays are specified; the two inside bays are merely implied (figure 4).
As we mentioned above, we want to find a single algorithm that generates both the section and its description. The algorithm has three parts:

A Generate the characteristic features of both the section and its description; each step involves a shape rule and an associated function.
B Complete the section generated by part A; each step involves only a shape rule.
C Reduce the description from its “characteristic” form generated by part A to that found in the text; each step involves only a function.

3. Part A: Generating the Characteristic Features of the Sections and Their Descriptions

There are four possible initial shapes and descriptions, depending on the depth of the building (i.e., four, six, eight, or ten rafters). The initial shape consists of a base and two columns, one in the front wall and one in the back wall. The algorithm instantiates each beam specified in the description and the columns that support it. It works from the outside in: first the front, then the back, repeating once if necessary.

The sections are generated here as single-line diagrams because they are used to encode global dimensions, not details of form. At a later stage, the sections will be used to guide the instantiation of individual building components; at that point, the components will be represented in more detail. With each shape rule are associated two functions. One operates on the Chinese description; the other operates on an equivalent English description.

Rule A1 (clear span, tong yan) (figure 1) can be applied only to the initial shape. It does not alter the shape – it bypasses all other instantiation of beams – and goes straight to complete the section. It alters the labels and the description. Having this rule prevents this section from being a default condition. Rule A2 (central division, fen xin), like rule A1, can be applied to the initial shape. However, in this case, beams can still be instantiated afterwards with rules A3–A8. It instantiates the central column, thus dividing the interior into equal front and back halves. Rules A3 through A14 instantiate beams of lengths measured in rafters. We start from the outsides (front and back) of the building and work towards the center. For each beam in front, we instantiate one in back. We can repeat the cycle once, if the section is deep enough. Rules A3–A8 instantiate beams in front which are 1 through 6 rafters long and updates the description. Rules to instantiate longer beams could be added. Rules A9–A14 instantiate beams in back which are 1 through 6 rafters long and updates the description. Rule A15 terminates beam instantiation.
Figure 1. Part A: rules for generating the characteristic features of the sections and their descriptions. With each shape rule are associated two functions; one operates on the Chinese description, while the other operates on an equivalent English description.
Figure 1, continued. Part A: rules for generating the characteristic features of the sections and their descriptions. With each shape rule are associated two functions; one operates on the Chinese description, while the other operates on an equivalent English description.

4. Part B: Completing the Sections

Here we complete the sections: we insert the non-characteristic components not instantiated by part A. The description is left untouched. The algorithm is to move up from the eaves to the ridge, at each purlin instantiating a beam or, if there is already a beam, just moving on. In the examples, we move first from the front and then from the back, but the order is immaterial.

Rules B1 through B3 (figure 2) instantiate beams along with supporting columns at their beginning points. At their end points, there may be no column
(B1), a column of the same height (B2), or a column that is higher (B3). Rules B4 through B6 instantiate beams from existing supporting columns at their beginning points. The end conditions are the same as for B1 through B3. Rule B7 moves the marker and adds a beam. Rule B8 moves the marker when a beam is already present. Rule B9 through B11 instantiate the topmost, 2-rafter beam. They may add two (B9), one (B10), or no (B11) supports. Rule B12 instantiates the king post and removes all the labels. The section is complete.

\[ \text{B1} \quad \text{B7} \]
\[ X \quad \rightarrow \quad X \quad \quad X \quad \rightarrow \quad X \]

\[ \text{B2} \quad \text{B8} \]
\[ X \quad \rightarrow \quad X \quad \quad X \quad \rightarrow \quad X \]

\[ \text{B3} \quad \text{B9} \]
\[ X \quad \rightarrow \quad X \quad \quad X \quad \rightarrow \quad X \]

\[ \text{B4} \quad \text{B10} \]
\[ X \quad \rightarrow \quad X \quad \quad X \quad \rightarrow \quad X \]

\[ \text{B5} \quad \text{B11} \]
\[ X \quad \rightarrow \quad X \quad \quad X \quad \rightarrow \quad X \]

\[ \text{B6} \quad \text{B12} \]
\[ X \quad \rightarrow \quad X \quad \quad X \quad \rightarrow \quad X \]

Figure 2. Part B: rules for completing the sections. The descriptions are unchanged; thus there are no associated functions.

5. Part C: Reducing the Descriptions

Here the section is unchanged. We reduce the descriptions from their underlying form to that seen in the text of the *Yingzao fashi*. We define an intermediate standard form thus: *a in front, b in back*, where *a* and *b* are the specified beams.

Rule C1 (figure 3) is for sections with four beams specified, i.e., with two cycles of instantiation. It combines the front beams and back beams into the standard form. Rules C2 and C3 modify the standard form. If *a* = *b*, then C2 is applied to get *a in front and in back*. If *a + b* = total number of columns, then C3 is applied to get *a abutting b*, and the number of columns is reduced by one. In all other cases, the description is left unchanged.

After the standard form has been modified, the description may be modified again if the front and back are symmetrical, i.e., if the description has the form *a*
in front and in back, where \(a\) is two beams. If the form is \(aa\) in front and in back, then C4 is applied to remove the repetition, giving \(double a\) in front and in back. If the form is \(ab\) in front and in back, then C5 is applied optionally to give \(ab\ both\ in\ front\ and\ in\ back\). In the sample, we find both forms of the description.

![Figure 3. Part C: rules for reducing the descriptions. The sections are unchanged; thus there are no shape rules.](image)

6. An Example

As an example, let us generate the section and the description of a 6-rafter building, centrally divided, 1-rafter beam in front and in back; with 3 columns (figure 4). The initial shape is 6 rafters deep; the initial description is 6-rafter building, \(e\), with 2 columns. Part A generates the characteristic features of the section and its description. Rule A2 instantiates the central column; the associated function adds centrally divided to the description, and increases the number of columns from 2 to 3. Rule A3 instantiates a 1-rafter beam in front, along with the column that supports it; the associated function adds 1-rafter beam in front to the description, and increases the number of columns from 3 to 4. Rule A9 instantiates a 1-rafter beam in back, along with the column that supports it; the associated function adds 1-rafter beam in back to the description, and increases the number of columns from 4 to 5. Rule A15 changes the labels so that rules from part A can no longer be applied.

In part B the section is completed; the descriptions are unchanged. Rule B8 moves the triangular marker from the frontmost purlin in to the next purlin; the 1-rafter beam and both columns supporting it are present, so no additional building components are instantiated. Rule B7 instantiates a 2-rafter beam and moves the marker in one purlin. Rules B8 and B7 are repeated at the back of the section. Rule B9 instantiates the topmost 2-rafter beam. Rule B12 instantiates the king post and completes the section.

In part C, the descriptions are reduced; the section is unchanged. Rule C2 reduces the repetitious 1-rafter beam in front, 1-rafter beam in back to the economical 1-rafter beam in front and back. The descriptions are in their final form.
Figure 4. Derivation of a 6-rafter building; centrally divided, 1-rafter beam in front and in back; with 3 columns.
7. Conclusion

The algorithm we have inferred is not obvious from examining only the sections of the *Yingzao fashi*. Rather, it follows as well from the written descriptions of those sections, which reflect the names and categories used by the author Li Jie and his readers. Both the symbolic and the spatial information have informed the writing of the grammar. As a result, the grammar has to some extent the “look and feel” of Song practise. Such an outcome endorses Stiny’s comprehensive formulation and suggests a way of approaching descriptive adequacy, first brought up by Stiny and Mitchell (1978).

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Note

1 For a general introduction to this aspect of the *Yingzao fashi*, see Glahn (1984) or Liang (1984).