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The grammar of Taiwanese traditional vernacular dwellings

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Abstract. A shape grammar, which can exemplify and visually explain the style of Taiwanese traditional vernacular dwellings, is presented in the form of rules of composition that are derived from considerations of traditional processes of design and construction, and from cultural influences.

Taiwanese traditional architecture

Taiwanese architecture is a branch of Chinese architecture with distinct peculiarities of its own. The late architectural historian, Professor Ssu-ch'eng Liang (1901–1972), has characterized Chinese architecture compositionally as having three main parts: the raised platform, body, and roof (Liang, 1984). Socially and technologically, building designs were regulated by laws that were established by the various Chinese dynasties. The two most famous construction laws (or 'grammar books') in Chinese traditional architecture, *Yíng-zào fă-shì*[1] (Building Standards, 1103 AD) of the *Sòng* dynasty and *Gōng-bù gōng-chéng zùo-fă zé-lì* (Structural Regulations, 1734 AD) of the *Qīng* dynasty, specify intricate details for the raised platform, body, eaves brackets (*Dŏu-gŏng*), and roof of a building. Most Chinese traditional architecture was built according to the laws of the *Qīng* dynasty (1644–1911 AD). *Zhì-shì* (or *fă-shì*, 'regulation style'), in general, refers to these two grammar books.

There are three basic ways of classifying any particular style of Chinese architecture: by people, by building type, and by construction type. For example, Taiwan is a typical immigrant society; each immigrant group had its own architectural style that was very similar to the architecture of original place from which the group had emigrated. In Taiwan, most *Hàn* immigrants—including the *Mĭn-nán* and *Kè-jiā*—came from the southeastern part of mainland China, chiefly from the provinces of Fukien (*Fú-jiàn*) and Kwangtung (*Guăng-dōng*). Because the different *Hàn* people shared much the same culture, there is greater similarity between their architecture, which collectively can be regarded as representative of the Southern style. Taiwanese traditional architecture remains among best preserved examples of extant buildings of this Southern style.

In this paper, we explore the form of Taiwanese traditional vernacular dwellings. There were a number of factors that influenced Taiwanese traditional design of which site was perhaps the most important.[2] Figure 1, taken from Kwan (1989),

(1) The phonetic spellings for Chinese words in the paper are from *Learner's Chinese–English Dictionary* (8th edition) and correspond to the Pinyin system.

(2) The importance of site in Chinese architecture cannot be gainsaid. The Chinese believed that it was important to maintain balance and harmony between a building and its surroundings. The topographical features of the site were essential to the geomancer, for example, in his calculations on the orientation and the dimensional determinants of a building. See Chiou and Krishnamurti (1995) [footnotes (24) and (26)]. The Chinese likened the structure of a house to the human form. The proper siting of a house was considered analogous to the design of an ergonomically 'comfortable' chair.

illustrates site plans for Taiwanese traditional dwellings. It appears that site plans were developed by repetitions of massing elements. The basic rule appears to be to add a complete enclosure-courtyard at a time.

One of the pursuits of architectural history and criticism is the identification of the shared features that distinguish buildings designed in a particular fashion, or by a particular architect from other buildings. In this respect, shape grammars as rules of composition that underlie a building have been advocated as an approach (Flemming, 1987a, pages 247–248).

Shape grammars have their origins in the formal basis of natural language or phrase-structure grammars, as higher level abstractions for the description and representation of spatial reality. Architectural design contexts are often described in terms such as program (brief), vocabulary, relationships, and rules. The idea that

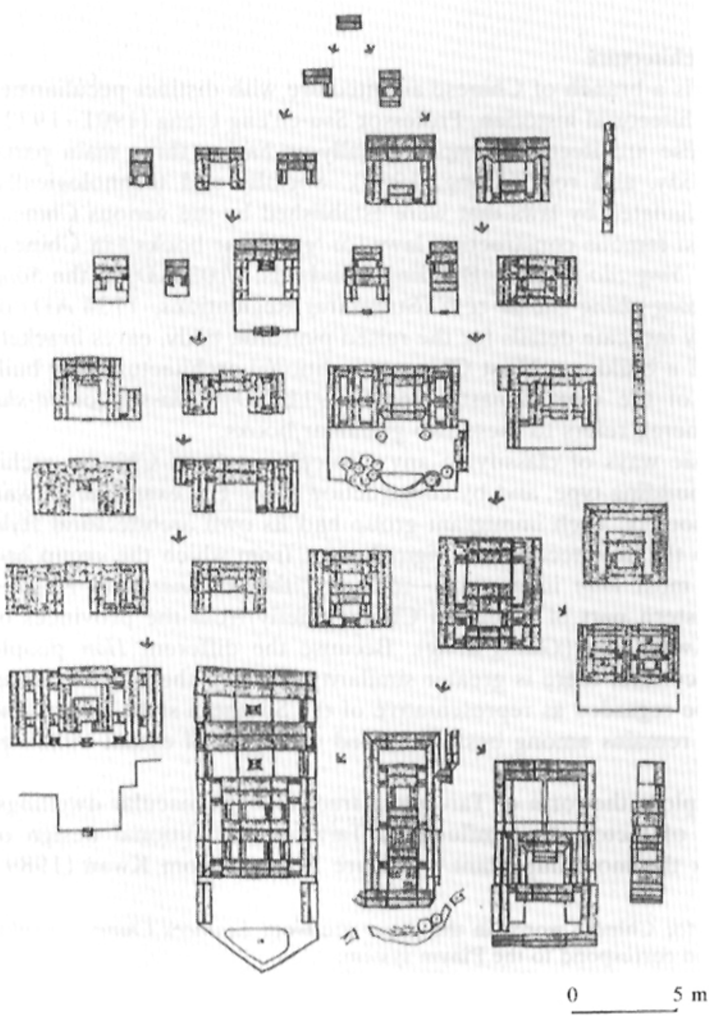

Figure 1. Site plans of Taiwanese traditional dwellings (after Kwan, 1989, page 36).

architectural design contexts are grammatical—that is, these can be described in terms of vocabulary, syntax, semantics, and style—is not novel.(3)

In the case of Taiwanese traditional buildings, nearly all were bilaterally symmetric. The axis of symmetry was located along the central line of the main hall (*tīng* or *táng*), considered the sacred (or holiest) of family spaces. For this reason, all of the main spaces (rooms) in the building lie on the axis of symmetry; other secondary spaces were located to the left or right of this axis. One of the doctrines of Chinese philosophy is the doctrine of the mean (*zhōng-yōng*). In fact, the Chinese character *zhōng* means balance, center, middle, and symmetry. This doctrine of balance was not only a philosophy of life, but also a philosophy of architecture.

Taiwanese traditional dwellings were made up of 'main' (*zhèng-shēn*(4)) and 'secondary' (*hù-lóng*(5)) buildings. The *zhèng-shēn*'s were transverse to the axis of symmetry; *hù-lóng*'s were parallel. The construction of a building proceeded in bays, which, in general, corresponded one-to-one to rooms or defined spaces in the building. For our purpose, in this paper, we will consider this to be the case. The spaces in a building were arranged in a particular fashion. The axis of symmetry always bisected the main central hall. All of the other spaces were developed through this central hall. Starting with the *zhèng-shēn* which includes the hall, two *hù-lóng*'s were generated. The *hù-lóng*'s were the basic elements of the *hé-yuàn*, the enclosure-courtyard. The *hé-yuàn* was basic to most Chinese traditional architecture; the spaces bordering the enclosure had openings facing the courtyard. The number of spaces in a *zhèng-shēn* ranged from one through nine, and never exceeded eleven; typically, it was seven; nine and eleven were reserved for the imperial palace. Each space in a *zhèng-shēn* (or *táng-wū*) had a unique name: *míng* (light), *àn* (dark), *shāo* (tip or end), *cì* (secondary), and *jìn* (finished). This concept is universal to Chinese

(3) In *The Natural House*, Frank Lloyd Wright (1954, page 181) wrote, "Every house worth considering as a work of art must have a grammar of its own. 'Grammar', in this sense, means the same thing in any construction—whether it be of words or of stone or wood. It is the shape-relationship between the various elements that enter into the constitution of the thing. The 'grammar' of the house is the manifest articulation of all its parts. This will be the 'speech' it uses. To be achieved, construction must be grammatical." To some, this may be Wrightian rhetoric. In 1981, two young architects, Eizenberg and Koning, took Wright's words to heart and developed a shape grammar to produce plans in the manner of the Prairie House. Knight (1986a) went one step further—in her dissertation on transformations of style—she showed how the Koning–Eizenberg description can be transformed into a shape grammar that produces designs in the manner of the Usonian House.

These are not mere happenstance, but are two of a number of well-considered analyses illustrating shape grammars in architectural analysis and design, many of which have appeared on the pages of this journal. See Stiny (1980a; 1980b; 1985; 1990), Stiny and Gips (1972) for an introduction to shape grammars. For applications to architectural analyses, see the work of Stiny on grammars for Chinese lattice designs (1977), and with Mitchell on Palladian villas (1978) and Mughal gardens (1980); Knight on Hepplewhite chairback designs (1980), Japanese tea-rooms (1981), meandering motifs on Greek pottery (1986b), and textured variations on shape grammars (1989; 1990); Flemming on Terragni's Casa Guiliani Frigerio (1981), Queen Anne Houses (1987b; 1987c), and with Downing on the bungalows of Buffalo (1981). In the area of painting and art, see Kirsch and Kirsch (1986; 1990). Krishnamurti and Stouffs (1993) discuss computational and related issues. Shape grammars are considered in some detail in the books by Stiny and Gips (1978), Schmitt (1988), and Mitchell (1989).

(4) In Chinese architecture, this is referred to as *táng-wū* (or *tīng-táng*, which translates literally as 'a building with a hall'). In Taiwan, a *zhèng-shēn* is also referred to as *cùo-shēn* (meaning 'the body of a building').

(5) In Chinese architecture, this is referred to as *xiāng-fáng*. In Taiwan, a *hù-lóng* ('protective dragon') is believed to shield the universal spiritual breath, *qì*. This is also referred to as *shēn-shǒu* (meaning the stretched-out hand of the building).

architecture, though the terminology was not; for instance, artisans in Taiwan did not use this terminology.

The number of *zhèng-shēn*'s, transverse to the axis of symmetry, is referred to as *luò* (or *jìn*, enclosure); this number does not appear to have exceeded five. Moreover, the rule of *luò* appears to be such that *zhèng-shēn*'s were arranged in order of decreasing heights from the rear-most building to the front. At the same time, the eaves in the front of a building were higher than those at the rear. The pitch of the roof was between 30° and 40°.

The secondary buildings are placed on axes called *lù* (route) which are parallel to the major axis of symmetry.

The *jiān*'s (bays) were dimensioned according to the scale defined by the fortunate dimensions of the central bay in a building. In plan, these dimensions had to be no larger than those for the central bay and in section, no higher.

The grammar of Taiwanese traditional dwellings is given in a sequence of seventeen stages each comprising one or more shape rules. The initial shape is the location of the *key brick*(6) and, nominally, assigned to be the origin of the coordinate system in which the shapes are defined.

The grammar

There are seventeen stages.

Stage 1: Establish the fortunate numbers

The initial shape consists of a single point which is identified by an asterisk (*), and notionally represents the key brick, the location which the geomancer marks as fortunate for the owner. The key brick may be removed after construction but this rarely happens.

The two rules in this stage are shown in figure 2. Rule 1 generates the orientation. This rule defines the axis of symmetry, indicated by the line KK'. The orientation of this axis is a function of a number of parameters such as the actual site, the owner's birthday(7), the start date of construction(8), and so on.(9) In practice, to ensure that the orientation is easily determined, a second mark (typically, a stick) is placed at the front of the site.

(6) The *key brick* is a single brick or a pair of duo-bricks. The geomancer marked a line on the single brick or used the adjacent line of the duo-bricks to identify the orientation. See Chiou and Krishnamurti [1995, footnote (28)].

(7) The birthday must be translated into the lunar calendar and a Chinese cycle (*jĭa-zĭ*). A Chinese cycle consists of sixty elements. Every element has two Chinese characters. The first character belongs to the 'celestial stems', which have ten elements, *jiă*, *yĭ*, *bĭng*, *dīng*, *wù*, *jĭ*, *gēng*, *xīn*, *rén*, and *guĭ*. The second character belongs to the 'terrestrial branches', which have twelve elements, *zĭ*, *chŏu*, *yín*, *măo*, *chén*, *sì*, *wŭ*, *wèi*, *shēn*, *yŏu*, *xū*, and *hài*. A person's day of birth is broken into four parts (year, month, day, and time); each part is represented by a pair of characters. Each such pair is determined from the Chinese cycle. The Chinese thus use eight characters (*bā-zì*) to represent one's day of birth and, hence, one's fate.

(8) The start of construction was celebrated by a ceremony known as *dòng-tŭ* (literally translated as 'breaking ground').

(9) All of these factors were considered by the geomancer who traditionally provided this information to the owner and artisans on red sheets of paper. To the Chinese, red indicates good or happy events; white indicates bad or sad events (such as death and funerals).

With this line, scales[10] of intentions can also be defined.[11] These scales are determined by a number of factors from the owner's expectations, customs, and construction laws. There are three parameters that specify the scale of the building. Each parameter is specified by a dashed line of a certain length. The parameters are ΦΦ, the number of main buildings (*jìn*'s) which, in general, does not exceed five; ΠΠ, the number of bays (spaces or rooms, *jiān*) in a building and does not exceed nine; ΩΩ, the number of secondary buildings (*lù*'s) which is arbitrary.

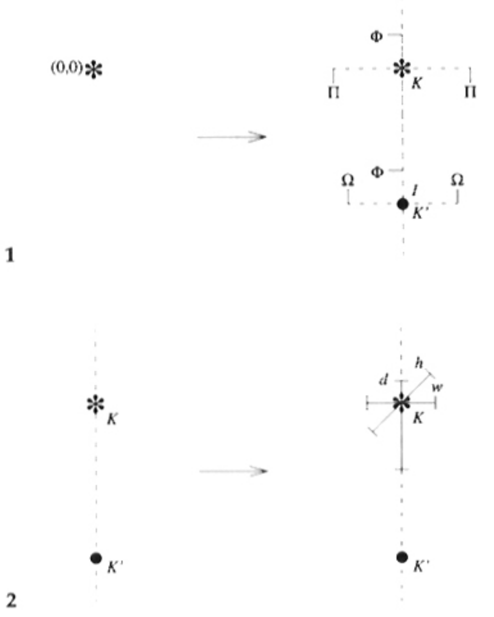

Figure 2. Stage 1: Establishing the fortunate numbers.

Rule 2 computes the fortunate dimensions of the building. This rule specifies the basic dimensions for the design, based on calculations dependent on the orientation and principles of *fēng-shuǐ* (Chiou and Krishnamurti, 1995). The dimensions are given by the height, h, the depth, d, and the width, w. There may be many possible values for these numbers and the application of the rule selects one set of values. The fortunate dimensions usually have the following constraints[12]:

$$h = \mathrm{f}_h(\text{orientation}, \Phi\Phi)\,;$$

$$w = \mathrm{f}_w(\text{orientation}), \text{ and possibly } w \leqslant h\,;$$

$$d = \mathrm{f}_d(\text{orientation}), \text{ and } d \approx 1.3 \times h\,.$$

That is, the width does not exceed the height and the depth is approximately 1.3 times the height. In traditional design, it was mandatory to use the formal instructions for measuring heights in *Lu Ban* feet and, possibly, inches (Chiou and Krishnamurti, 1995). It was not the case for widths and depths; about 70–80% of

[10] Here, scale refers to the range of dimensions and size (the number of massing elements).

[11] In practice, these scales were determined by negotiation between the owner and the artisans—carpenters and masons—after the geomancer had done his initial task of suggesting a good orientation.

[12] Each dimension x is associated with a function f_x that returns a value for x.

the traditional designs used widths that were calculated by formal means, and in about 50% the depth was formally determined. For convenience, we can assume $w = h$ and $d = 1.3 \times h$.

Stage 2: Generate the central room in the principal building

A dwelling may have more than one main building. The rear-most main building, referred to hereafter as the *principal building*, contains the key brick. It was always the first building to be constructed.

The rules in this stage generate the plan of the main hall (or central room) in any principal building. There are four rules in this stage as shown in figure 3. Rule 3 creates the central room in the principal building. This central room is located on the axis of symmetry with its center coincident with the key brick. The dimensions of the room were determined by rule 2. Occasionally, one finds an additional space within the central room.(13) This was probably used as a storage space. Rule 4 creates this additional space, indicated by the label B, to the rear of the central room.

Shape rules 5 and 6 further refine the central room. There are two basic types of central rooms—with and without a front porch. Both rules specify a raised

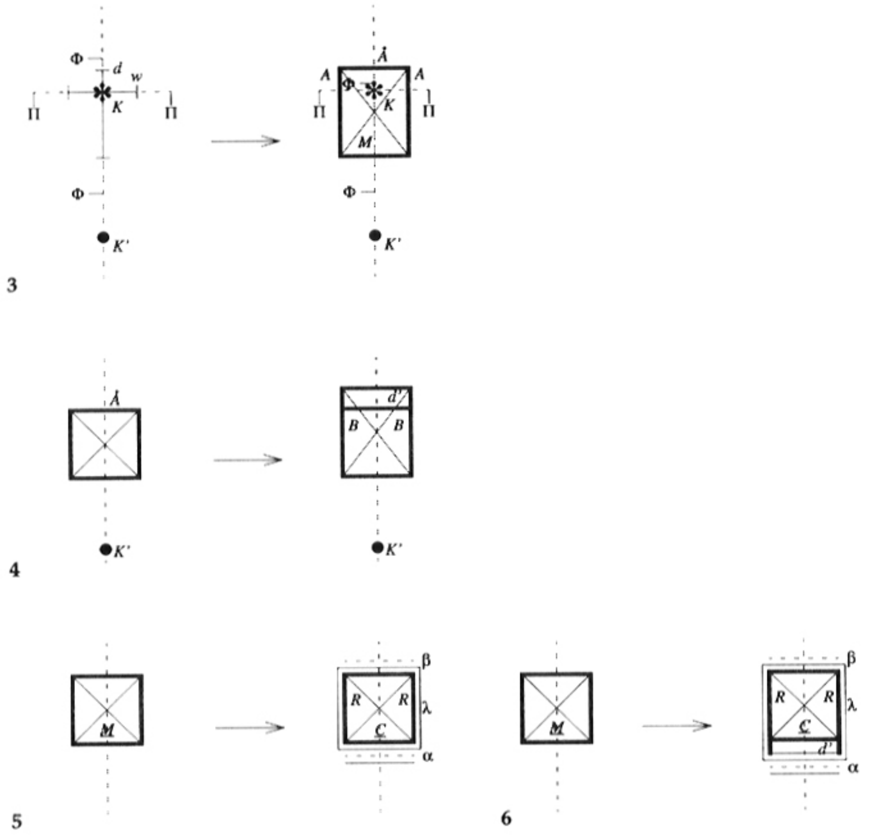

Figure 3. Stage 2: Generating the central room in a main building.

(13) The central room was used for worship, or as a living room. If the room behind the central room was a bedroom, it would have been assigned to the eldest member in the family because this room was hierarchically higher than the other rooms in the building.

platform[14], and associate the label λ with it. Labels α and β identify the positions for the front and rear roofs, respectively, to be specified by a later rule. The label, $\underline{M}$, associated with a main building is replaced, at the same position, by $\underline{C}$.[15] These two shape rules specify the allocation of a central room.

Rule 3 specifically applies to the principal building, the other three rules can apply to any central room in the dwelling.

Stage 3: Add doors and windows to the central room

The rules in this stage add openings to the central room. Windows are indicated by labels W. There are two types of doors, a main door (label D_m) and doors (label D). Main doors (or entrances) are always placed to the front of the central room. If the front wall of a room in a main building is open, its rear wall should likewise be open.

The height of the main entrance is an important factor in the design. In Taiwanese traditional architecture, the main beam and light beam are two holy dominants and have special meaning.[16] In order to protect these two important features, the artisan traditionally positioned the upper frame of the main entrance, the main beam, and the light beam on a straight line, namely *sān-hé* (figure 4).[17] Therefore, the upper frame of the main entrance can shield the main beam and light beam.

There are ten rules in this stage, and these are shown in figure 5. The shape rules are divided into three groups. The first group, comprising rules 7–9, create openings in the front wall of the central room. The second group, comprising rules 10–15, create openings in the rear wall. Shape rule 16 creates openings in both walls.

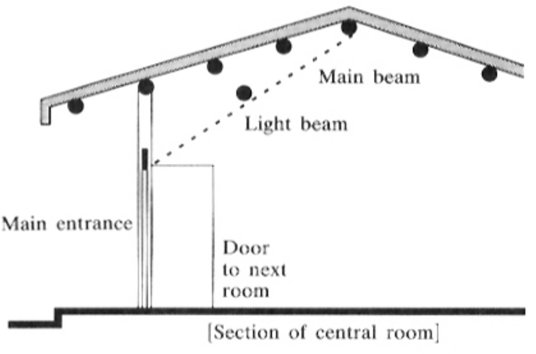

Figure 4. *Sān-hé:* the relation among main beam, light beam, and main entrance.

[14] In Chinese there is an idiom, '*dēng-táng-rù-shì*', which translates into 'ascend the hall into the inner chamber'. Ascend here implies that the hall is on a raised platform. Furthermore, it implies that one enters the hall (*táng*) prior to entering the chambers (*shì*).

[15] Any label shown underlined is a schema; it represents an element from a set with the given label and an associated superscript. For example, $\underline{M}$ represents an element from the set, $\{M, M', M'', ...\}$. In the case of shape rules 5 and 6 where $\underline{M}$ is replaced by $\underline{C}$, only the label is changed, but the superscript is preserved. That is, if $\underline{M}$ represents M'', then $\underline{C}$ represents C''.

[16] In Taiwanese pronunciation, light and boy (*dīng*) are the same. The light beam was also treated as the demarcation of gods and ghosts in a house. It is believed that ghosts cannot cross the light beam into the house.

[17] In Chinese culture, the number three (*sān*) appears to have some special meaning, such as balance, stability, cooperation, and so on. *Sān-hé* means three things that match, collaborate, and together have great powers. There is a verse in the *Dào Dé Jīng* (chapter 42),

> "Tao begat one; one begat two; two begat three; three begat all things.
> All things are backed by the shade [*yīn*] and faced by the light [*yáng*], and harmonized by the immaterial breath [*qì*]."

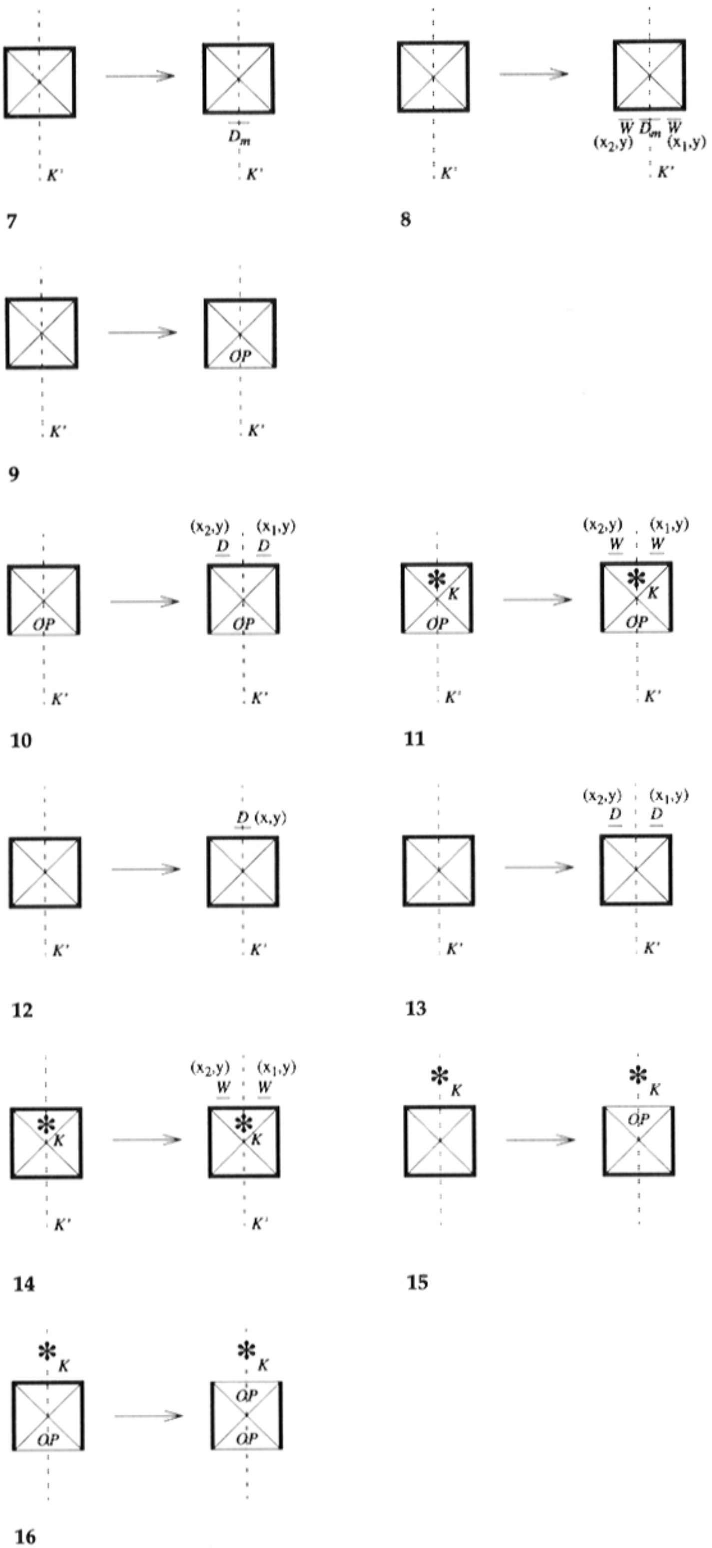

Figure 5. Stage 3: Rules for adding openings to the central room.

There are constraints. Rule 9, which produces a semi-open central room, is applicable only to a central room in a main building that is not connected to another at its rear such as the principal building. Rules 11 and 14 apply only to the principal building. Rules 15 and 16 are applicable only to central rooms in the other main buildings. This is because the rear wall of the central room in the principal building cannot be made open.

Stage 4: Generate the plan of a main building

There are seven rules in this stage. The first two shape rules, shown in figure 6, generate the plan of a main building. Rule 17 adds two rooms laterally on the main building and, at the same time, decreases the scale bar ΠΠ by 2 units. The width of the room (unless it is the central room), w', is less than the width of the central room, w.[18] The width w' is typically between 80% and 90% of w. For convenience, we may assume $w' = 0.9w$.

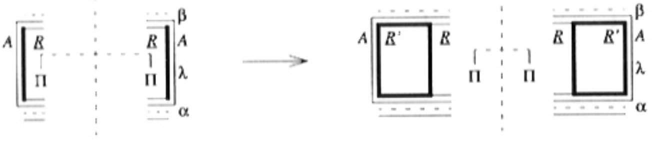

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Figure 6. Stage 4: Rules for generating rooms in a main building.

Rule 18 terminates the generation of the principal building. Two labels Z are positioned at the rear of the building. The end rooms are marked by labels E. Note that the rule is applicable only when the scale bar ΠΠ has zero length.

The next three rules refine the rooms. Rule 19 inserts an extra space within a room, by inserting a wall at the positions indicated by the label B, in each of two rooms located symmetrically about the central axis. In effect, the rule divides the rooms into two spaces. Rules 20 and 21 extend the porch across two additional rooms. In Taiwanese traditional architecture, most main buildings have five or seven rooms. There are very few cases where the porch spans more than five rooms.

The last two rules (22 and 23) change the marks on the end room to prepare for a subsequent stage in the generation. The rules are shown in figure 7.

Stage 5: Add openings to the rooms in a main building

In general, every room in a main building is connected to the central room either directly or indirectly. By indirectly, we mean that there is an opening (doorway) to an adjoining room which likewise is connected to the central room. Windows in the

(18) This is not necessarily the case for the end room in a main building, which could be as wide as the central room. The end room was used for a number of public or semipublic functions such as cooking, dining, or storage, which required a larger space.

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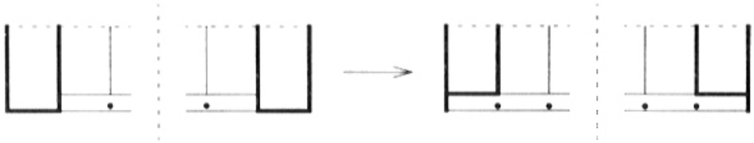

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Figure 7. Stage 4: Rules for refining rooms in a main building.

rooms had minimal openings, just enough to allow sunlight and breeze (wind); bedrooms were thus generally darker than the central room. In the following rules, a short line is used as a marker to indicate both an opening and the direction of its opening (especially in the case of doors). The parametric coordinates in the rule correspond to the center of the openings.

The shape rules, shown in figure 8, fall into two main categories, one group (rules 24 – 30), which insert placeholders for doors in partition walls, and the other group (rule 31) which inserts placeholders for windows. There is, in addition, a shape rule (rule 32) that changes a window placeholder to a door placeholder.

Rule 24 inserts two doors, one in each of the walls between the central room and an adjoining room. The width of the doors (indicated by labels D_r) is constrained by the light beam in the central room indicated by labels R. In Taiwanese traditional architecture, the width of the door (D_r) would not have been in conflict with the light beam[19] (see figure 4). That is, the light beam would not have been inside the range of the door (D_r). Moreover, the *Kè-jiā* believed that the light beam

[19] Otherwise, the Taiwanese believed that boys would not be born in the house. In fact, architecturally, it is a reasonable constraint if one considers the functions of the light beam and the door.

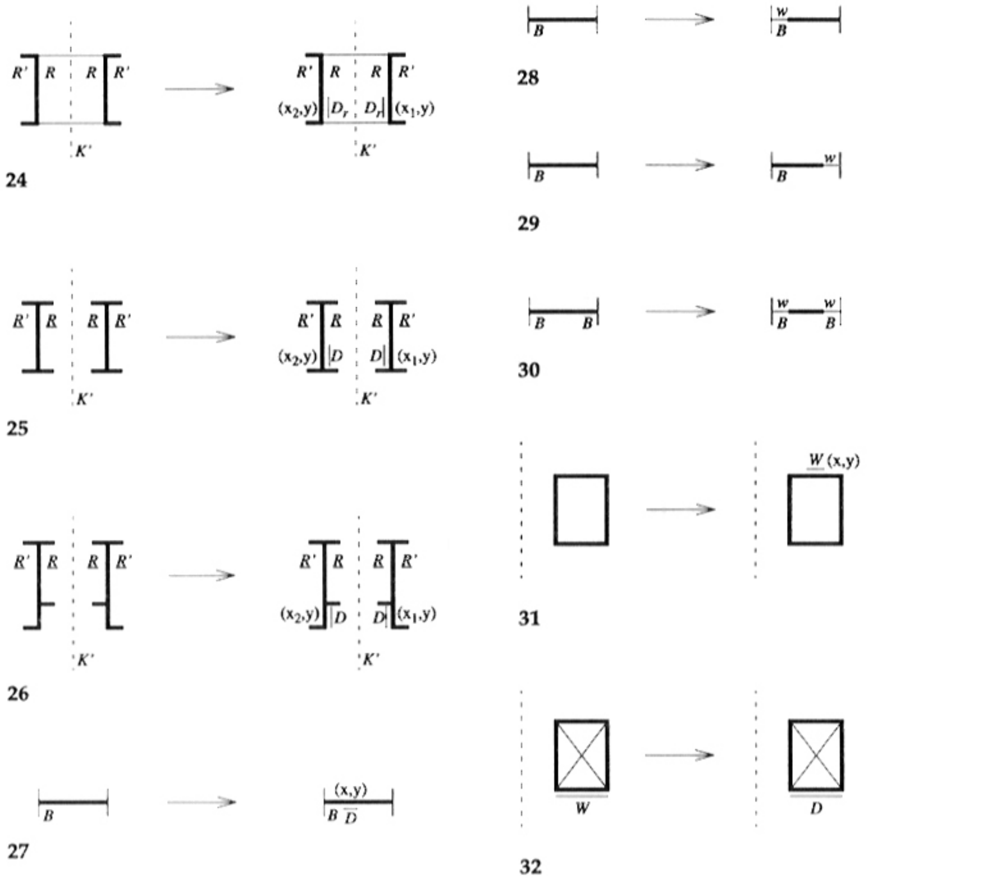


Figure 8. Stage 5: Rules for generating windows and doors in a main building.

had to extend marginally into the adjoining room (indicated by label R') in order to ensure that boys would be born in the house. This was not, however, a belief of the *Mĭn-nán* and, consequently, their dwellings did not generally reflect this.

Rule 25 adds a door to the partition wall between two rooms. The partition wall between two rooms is separated by labels $\underline{R}$ and $\underline{R}'$ on either side of the wall. Rule 26 is similar to rule 25 except that it connects to the porch as well. Rule 27 inserts a door in the wall of the extra space in a room. Rules 28 to 30 are similar to rule 27 except that these insert one or more openings with width w. Rule 31 adds windows to the front and rear walls. Note that rule 31 is applicable in a number of different ways, for example, symmetrically about the horizontal axis. Rule 32 ensures that the end room of a main building, which is usually a public or semi-public space, such as a kitchen, dining room, family room, or storage space, could be directly connected to the outside. This rule ensures that any windows generated for the end room will be converted into doors.

Stage 6: Replace doors and windows by their icons

In this stage, we replace the labels of doors and windows, D, D_m, D_r, and W, by their two-dimensional icons. Each icon is a shape; the width of the opening equals the length of the line marker associated with the label. In addition, we change the label to P.

All door and window dimensions are measured according to the scales of the opening ruler. The parameters, h, w, and u represent the length (vertical dimension) of the opening, its width, and its height measured from the ground, respectively; u represents the height of the threshold in the case of doors, and the height of the sill of the window frame. Generally, the main entrance is a two-way swing door. There are seven shape rules, all but one dealing with doors. The rules are shown in figure 9.

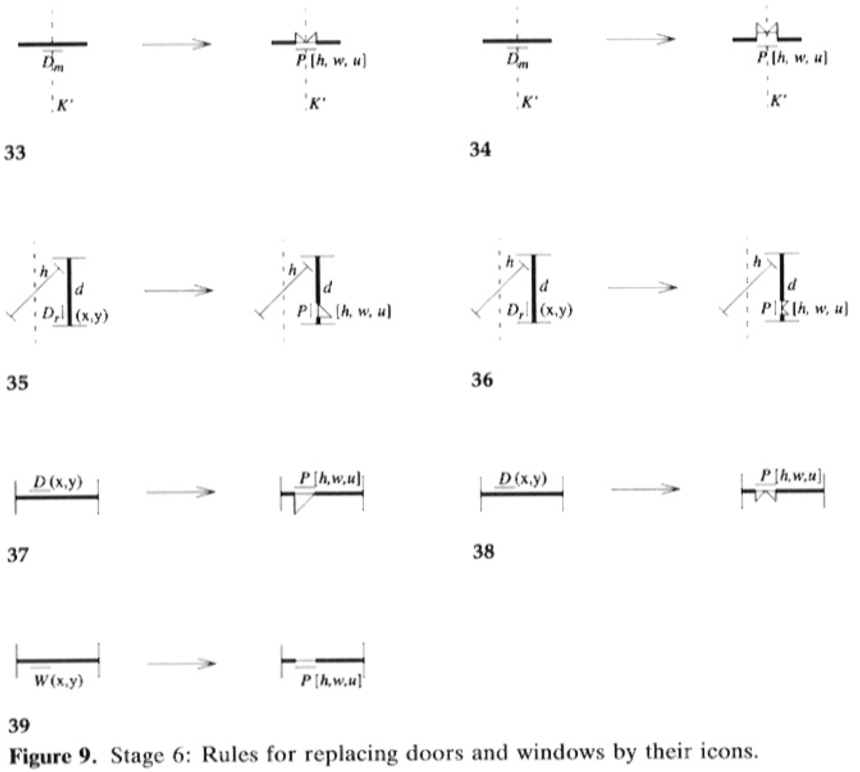


Figure 9. Stage 6: Rules for replacing doors and windows by their icons.

Rules 33 and 34 add doors to the main entrance. Rule 34 also creates a small porch (the entrance porch). The height of the door, h, must satisfy the constraints illustrated in figure 4. The depth of the entrance porch is given by the stride measure, generally, minus one stride.[20] Also, there can be no beams within the trace of the door opening. Rules 35 and 36 create a one-way or two-way door between the central room and an adjoining room. This door serves as a separation between the public and private spaces. The width, w, must satisfy the constraint that the light beam cannot be positioned inside the range of door. Again, see figure 4. Rules 37 and 38 create all other doors. In a similar fashion, rule 39 creates a window opening.

Stage 7: Generate a courtyard in front of a main building

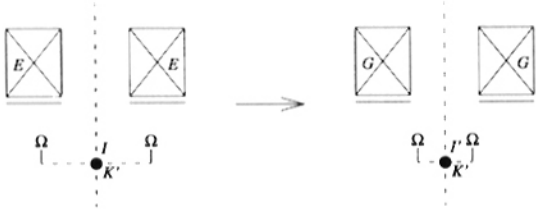
The courtyard is an open space enclosed by at least one main building and two secondary buildings.[21] The dimensions, width (w) and depth (d), were determined by an odd number of strides, using the stride measure.

[20] The depth of the entrance porch was possibly determined by the *chǐ-bái* and *cùn-bái* (Chiou and Krishnamurti, 1995).

[21] One main building with a single secondary building (forming an L-shape), can also define a courtyard. However, this case is not considered in this paper.

It was an important aspect of Taiwanese traditional architecture how the secondary buildings were connected to the main building. There were special constraints, and the following taboo that governed the nature of the joints between a main building and a secondary building, namely that the drop line of the roof of the secondary building could not fall within the range of the opening of the main building.[22]

Rules 40–42 (figure 10) mark the generation of a courtyard and secondary buildings. Rule 40 decreases, by 2 units, the scale bar ΩΩ. Rules 40 and 41 change the label, *E*, of the end room in the main building to *G*, which signifies the generation of a 'small' courtyard surrounded by secondary buildings. In a similar fashion, rule 42 changes the label *E* to *G'*, which signifies only a courtyard will be generated in front of the main building without secondary buildings connected to the front.



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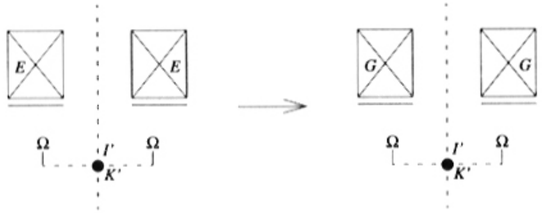

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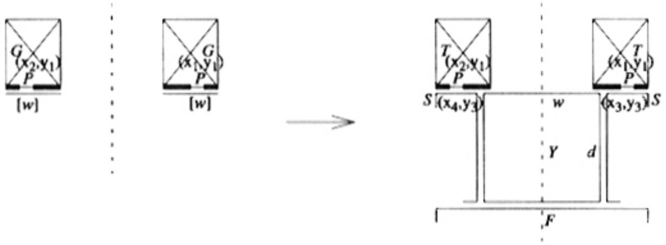
Figure 10. Stage 7: Rules that mark the generation of a courtyard and secondary buildings.

Rules 43–51 create courtyard enclosures. See figures 11 and 12. The front walls shown in rules 43–50 are variable, that is, verandahs or porches may be in front of these front walls. Rules 43 and 47 create a courtyard that connects with the two end rooms with openings to the front. The constraints on the x-coordinates x_3 and x_4 were such that these could not have values that lie within the openings *P* if the rooms had other openings. Label *Y* denotes a courtyard. Rules 44 and 48 create a courtyard that connects to two rooms adjoining the end rooms that also have openings in the front. The constraints on the x-coordinates x_3 and x_4 are the same as in rule 43. Rules 45 and 49 create a courtyard that connects to two end rooms that have no openings to the front. Rules 46 and 50 create a courtyard that connects to two rooms adjoining the end rooms that also have no openings to the front.

[22] In the view of the artisans, the opening would have served as the eye of the building. Should the drop line of the roof fall within the range of the opening (eye), resembling tears, this would have been considered inauspicious for the owner.

Rule 51, shown in figure 12 (see over), generates a 'large' courtyard; the secondary buildings enclose both the courtyard and the main building.

The last four rules, also shown in figure 12, ensure the proper termination of the courtyard generation. When the scale bar $\Phi\Phi$ equals zero, this signifies that there are no further main buildings to be generated. Rules 52 and 53 apply in this case. Rule 52 applies if a courtyard had not been generated; and rule 53 otherwise. In the latter case, we erase label F and mark the end of the buildings by labels Z'. The last two rules, 54 and 55, constrain the inner secondary buildings; in particular, rule 55 adds a small corner yard to the buildings.



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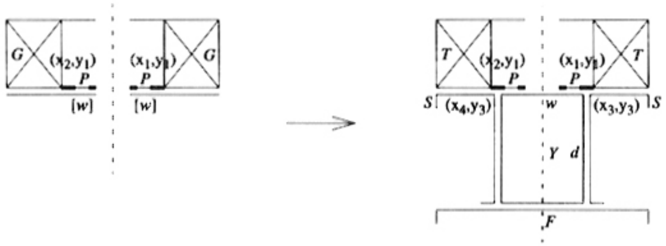

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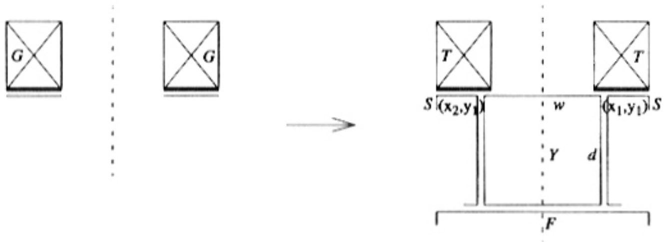

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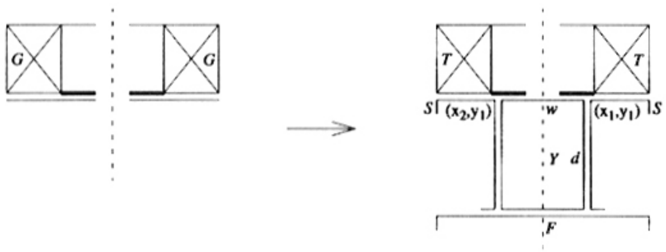

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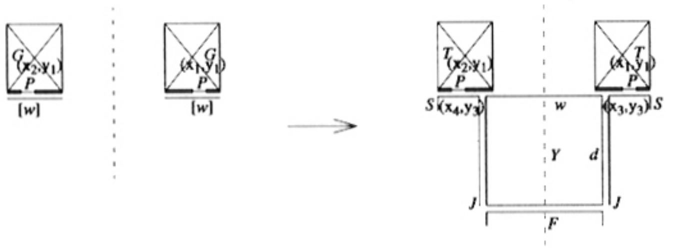
Figure 11. Stage 7: Rules for generating courtyards enclosed by inner secondary buildings.

Stage 8: Generate the plan of the secondary building

The secondary buildings (*hù-lóng*) connect to the main buildings in a direction parallel to the line of symmetry or transversely.

The dimensions of rooms in secondary buildings were not necessarily ascertained by the methods of *chǐ-bái* and/or *cùn-bái*, though, in general, these values were less than their corresponding dimensions of the central room in the main building. There were, however, other constraints that were imposed. Suppose d, w, and h were the dimensions of the central room in the main building, and d', w', and h' the corresponding dimensions of hall (or central room) in the secondary building.



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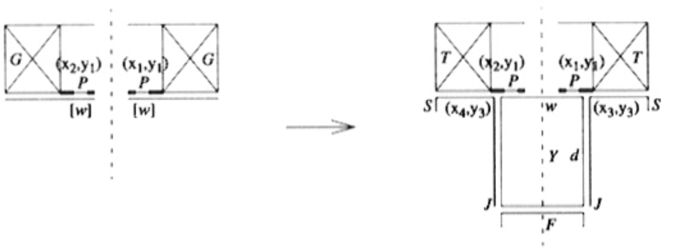

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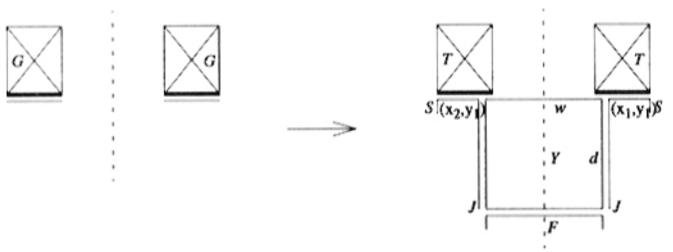

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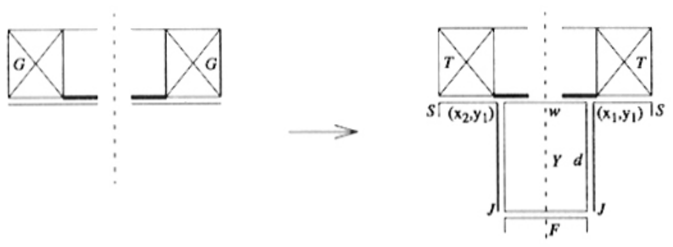

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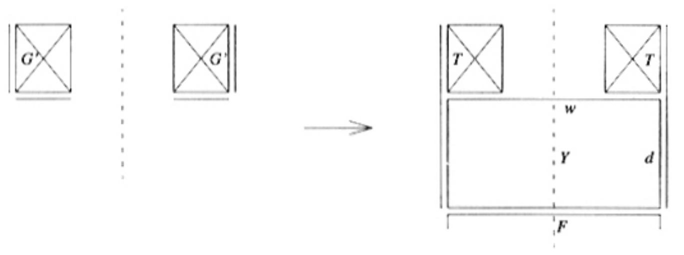
Figure 11 (continued)



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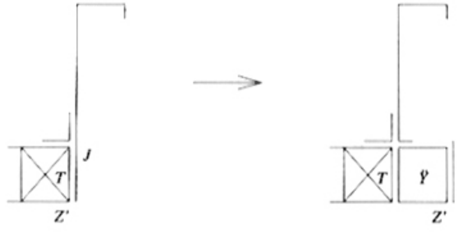

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Figure 12. Stage 7: Courtyard and terminating rules.

Then:

(a) The central room (or hall) of a secondary building was either the middle room in the building, or a room adjoining a room in the main building where the two buildings connect.

(b) The central room had the largest width among the rooms in the secondary building.

(c) The total length of the secondary building was determined by the depth of the courtyard.

(d) The number of rooms in the secondary building was bounded by the number of rooms in the main building. If it was an inner secondary building, this number usually did not exceed 4. An inner secondary building is one which encloses a courtyard, and where there are no other buildings between the two.
(e) The basic width of a room in a secondary building was based on its length and the number of rooms in the building.
(f) $h' < h$, $w' < w$, and in general, $d' < d$. Also $w' < h'$.
(g) d' could be identical to w'', the width of the end room of the main building.

There are eleven rules in this stage, divided into two categories. The first category, shown in figure 13, comprises five shape rules that relate to the generation of rooms. Rule 56 creates a raised platform for the secondary building. Rule 57 generates the first room. This rule applies only if the secondary building has more than one room. The width of the room, w, is dependent on the length of the secondary building, the number of rooms in the building, and whether the room is the hall of the secondary building. Rule 58 applies if there is only one room in the secondary building. Rules 59 and 60 add a room. If the newly added room is the hall, its width should be the widest. There are no special constraints on the widths of two adjoining rooms, unless one of them is the hall. Rule 60 generates the end room.

The second category, shown in figure 14, consists of six shape rules: three for the creation of porches, and three for refinements to a room. Rule 61 adds a porch to a room. The depth of the porch, s, generally equals one stride less than the measure determined using the stride measure procedure (Chiou and Krishnamurti, 1995). Rule 62 extends the porch to an adjoining room. Rule 63 removes the side walls of the porch. The last three shape rules refine a room. Rule 64 modifies a room to be a semi-open space, rule 65 combines two spaces into a semi-open space, and rule 66 removes side walls.

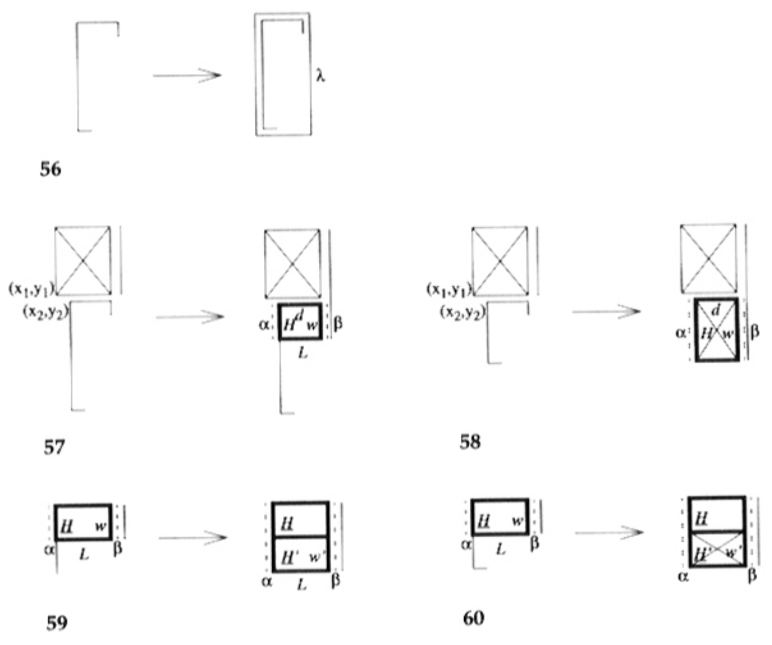

Figure 13. Stage 8: Rules for generating rooms in a secondary building.

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Figure 14. Stage 8: Rules for adding porches and refining rooms.

Stage 9: Compute the fortunate dimensions of a main building which is in front of a courtyard
This stage initializes the generation of a main building that is not principal. As in the case of the principal building, we fix upon fortunate dimensions for the building. These values are dependent on the dimensions of the previously generated main building, and the orientation of this building. The procedures to determine the dimensions of the building are similar to those described in stage 1. There are other constraints on this building, of which, perhaps, the most important is its height, which must be lower than that of the previous main building.

This stage consists of a single shape rule, which specifies the basic dimensions for the design. As stated, calculations are dependent on the orientation and the dimensions of the previous main building, say, h, d, and w. Let the corresponding dimensions for this building be h', d', and w'. We have the following constraints:

$$h' = \mathrm{f}_h(\text{orientation}, h);$$

$$w' = \mathrm{f}_w(\text{orientation}, w), \text{ and possibly } w' \leqslant h', \text{ and } w' \leqslant w;$$

$$d' = \mathrm{f}_d(\text{orientation}, d), \text{ and } d' \approx 1.3 \times h', \text{ and } d' < d.$$

For convenience, we may assume $w' = h'$, and $d' = 1.3 \times h'$.

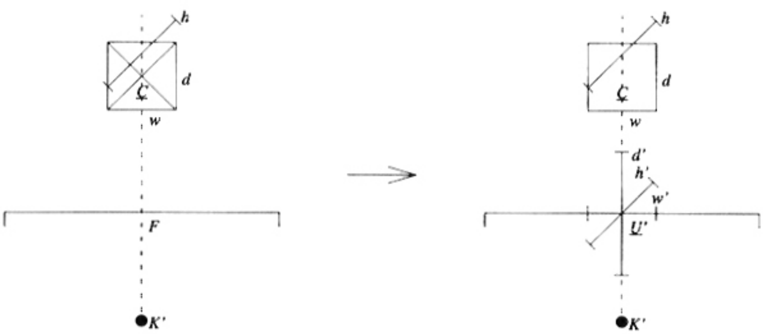

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Figure 15. Stage 9: Calculate the fortunate dimensions of a new main building.

In the shape rule shown in figure 15, the position of label $\underline{U}$ is determined from the position of $\underline{C}$.

Stage 10: Generate a main building plan which is in front of a courtyard
This stage generates a new main building in front of a generated courtyard, indicated by the label *Y*, according to the dimensions given by the application of shape rule 67. The four shape rules 68–71 shown in figure 16 each generate the central room (hall) located on the symmetrical line. In addition, the scale bar for the recording of the number of main buildings ΦΦ is decreased by a single unit.

Rule 69 generates the central room with an additional space at the rear, where d', the depth of the back space, is determined by the wall frame and the arrangement of beams. Rule 70 generates the room with a rear porch, where d', the depth

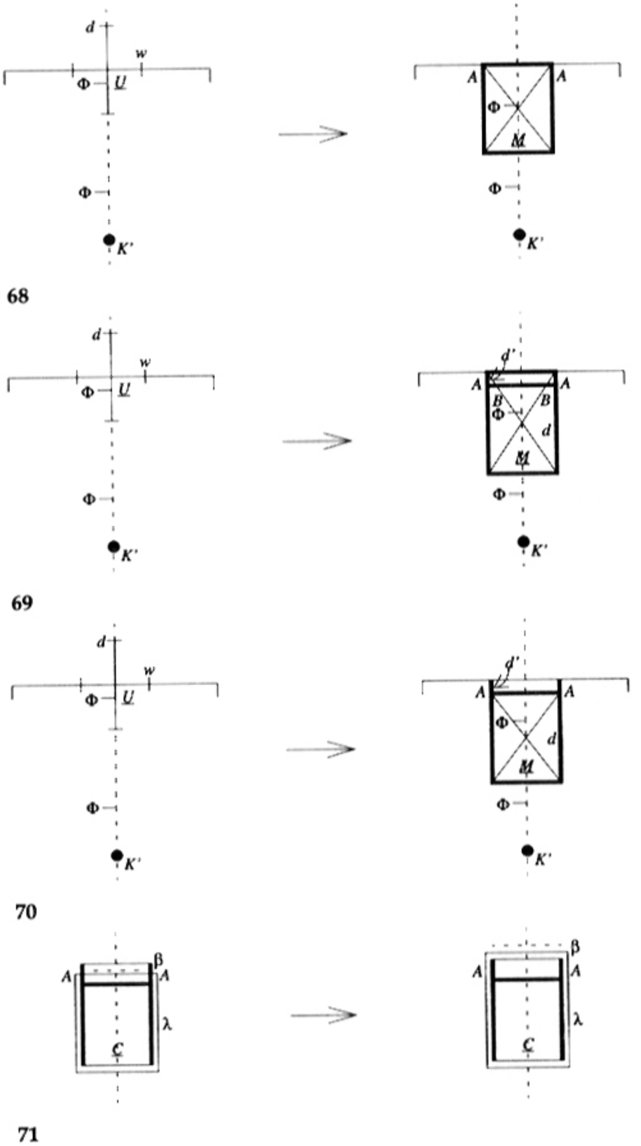

Figure 16. Stage 10: Shape rules for generating the central room of a main building.

of the rear porch, is usually one stride less than the value given by the stride measure. In each rule, label U is replaced by label M to signify the start of a new main building. Rule 71 refines the platform on which the central room is placed.

Shape rules 72, 73, and 74, given in figure 17, add two rooms to the main building. Rules 73 and 74 are terminating rules in that they can be used to generate the end rooms of the building. In rule 74, the end room is an open space.

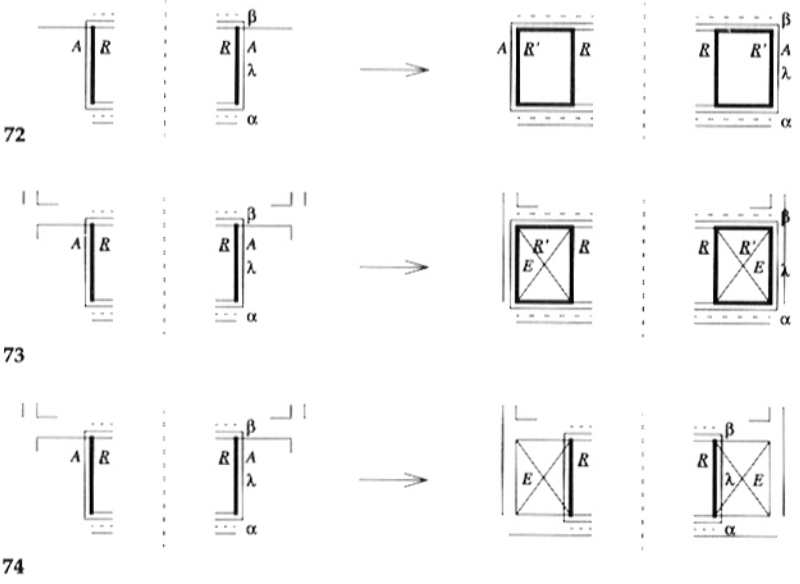

Figure 17. Stage 10: Rules for generating rooms in a main building.

Stage 11: Generate a secondary building which surrounds the front main building

The length of the secondary building is given by the sum of the depths of the front (main) buildings and of the courtyards (figure 18). Shape rules 75 and 76 add a secondary building. Rule 75 does so directly without a 'passing room';[23] rule 76 by inserting a space in front of the secondary building. Shape rule 77 creates the first room in this building.

Stage 12: Generate another kind of secondary building that is connected by a passing room to the end room of a main building

This stage generates another kind of secondary building in a direction perpendicular to the line of symmetry with a passage that connects to the main building. Traditional Taiwanese houses were usually extended in this manner or in the manner previously suggested. There is an example of such extensions in *Shè-tóu*, *Zhāng-huà*, in the central region of Taiwan, which has sixteen secondary buildings. It should be noted that the passing room was not always a feature of all secondary building extensions. Basically, there are five shape rules, which are shown in figure 19.

Rule 78 adds a passing room that will allow the secondary building to be generated inside it. Usually, $d' \leqslant d$, where d' and d are the depths of the passing room and end room in the principal building, respectively; d includes the depth of the porch. Rule 79 adds a passing room that is not aligned with the rear wall of the

[23] The 'passing room' [*guò-shuǐ*, literally, 'passing through water (rain)'] is usually a semi-open space.

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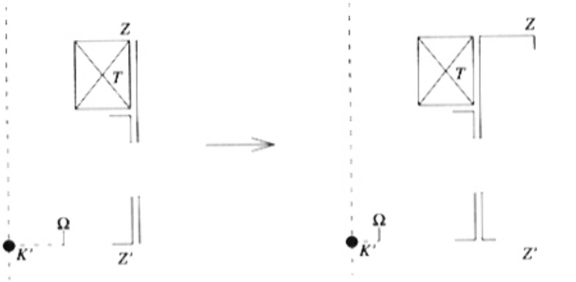

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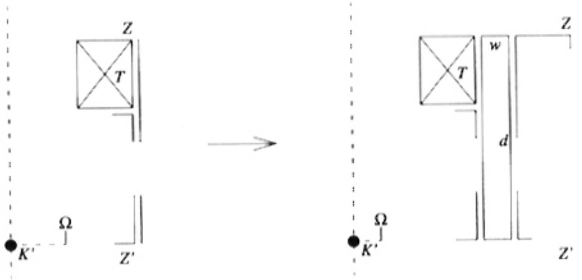

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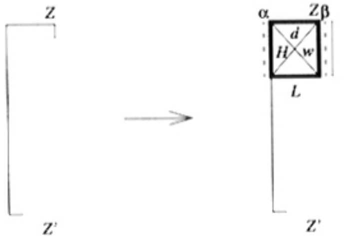

Figure 18. Stage 11: Shape rules for generating secondary buildings that surround main buildings.

main building; d' and d have the same definitions as given above with the same relationship. Rule 80 adds two passing rooms, which are located at both ends of the whole building, indicated by labels Z and Z'. Here, $d_1' \leqslant d_1$, and $d_2' \leqslant d_2$, where subscripts 1 and 2 refer to the rear and front of the house, respectively. Within this context, d and d' have the same meaning as above. Rule 81 is similar to rule 80 except that the passing room at the rear is not aligned with the rear wall of the main building. Rule 82 creates an additional passing room that connects the secondary building to the end room of the main building.

For technical reasons that are required for the shape grammar formalism, we need one additional rule in this stage. Rule 83, shown in figure 20, erases labels Z and Z' so that no further secondary buildings can be generated.

Stage 13: Add openings to the secondary buildings

The shape rules are given in figure 21. Shape rules 84, 85, and 86 add a door to the hall in the secondary building. In addition, the latter two add windows to the room. Shape rules 87–90 add doors and windows to the adjoining room. From the rules it is easy to see which doors are interior and which ones are exterior. The rules add windows to the spaces selected. Shape rule 91 adds a through door to the room connected to the main building. The last two rules specify the entrance to the secondary building. Rule 92 changes the entrance from a two-way swing door to a single swing door, and rule 93 draws it in its iconic form.

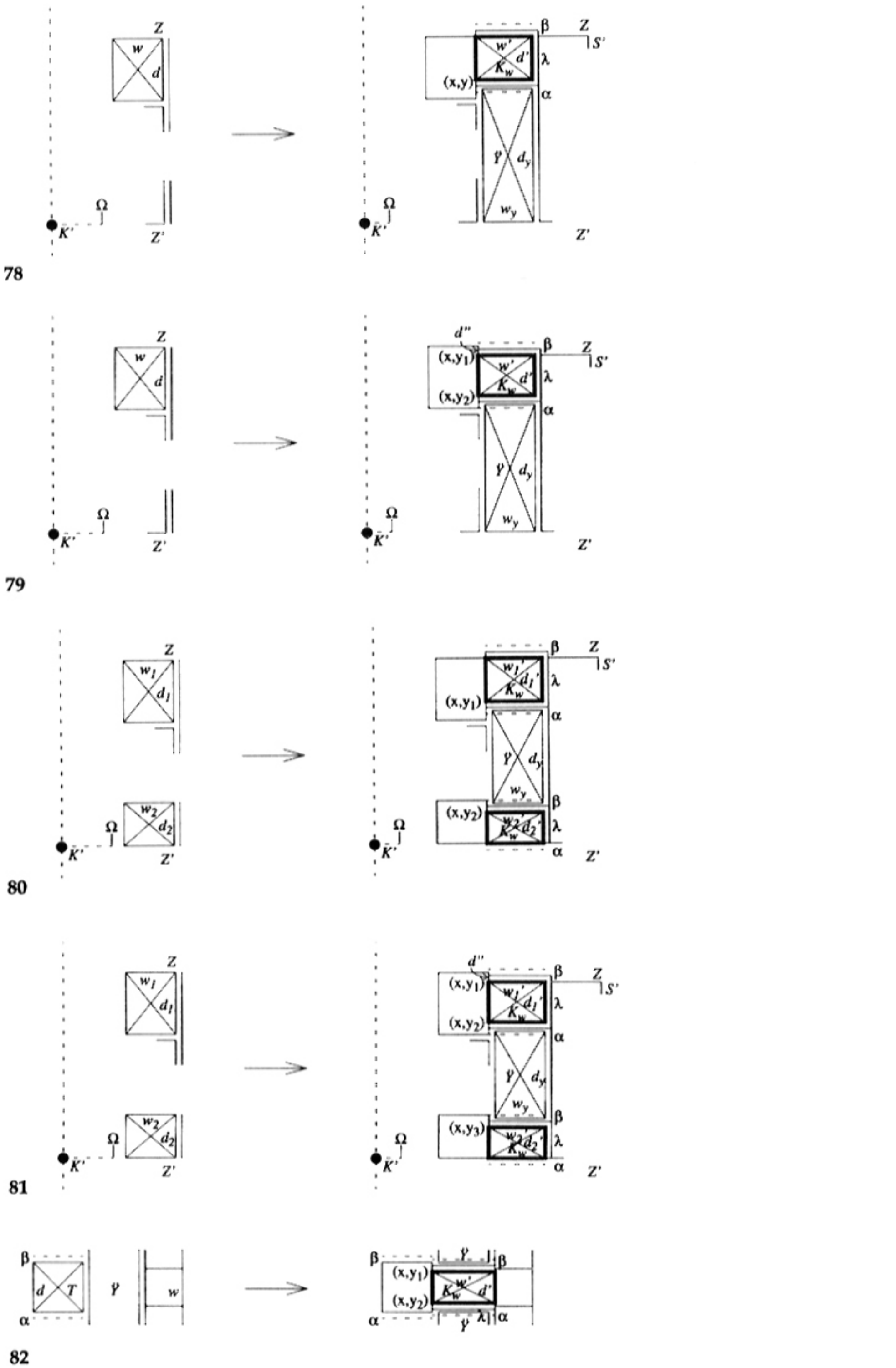

Figure 19. Stage 12: Shape rules for generating secondary buildings that connect with the main building through a passing room.

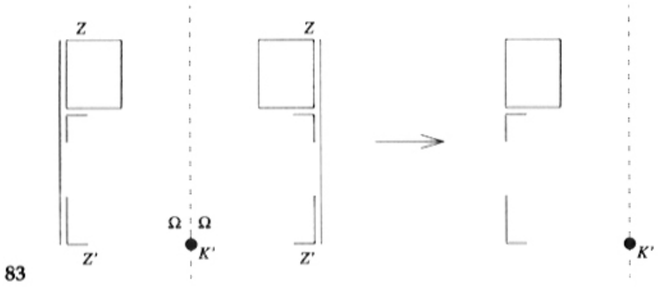

Figure 20. Stage 12: Terminating rule.

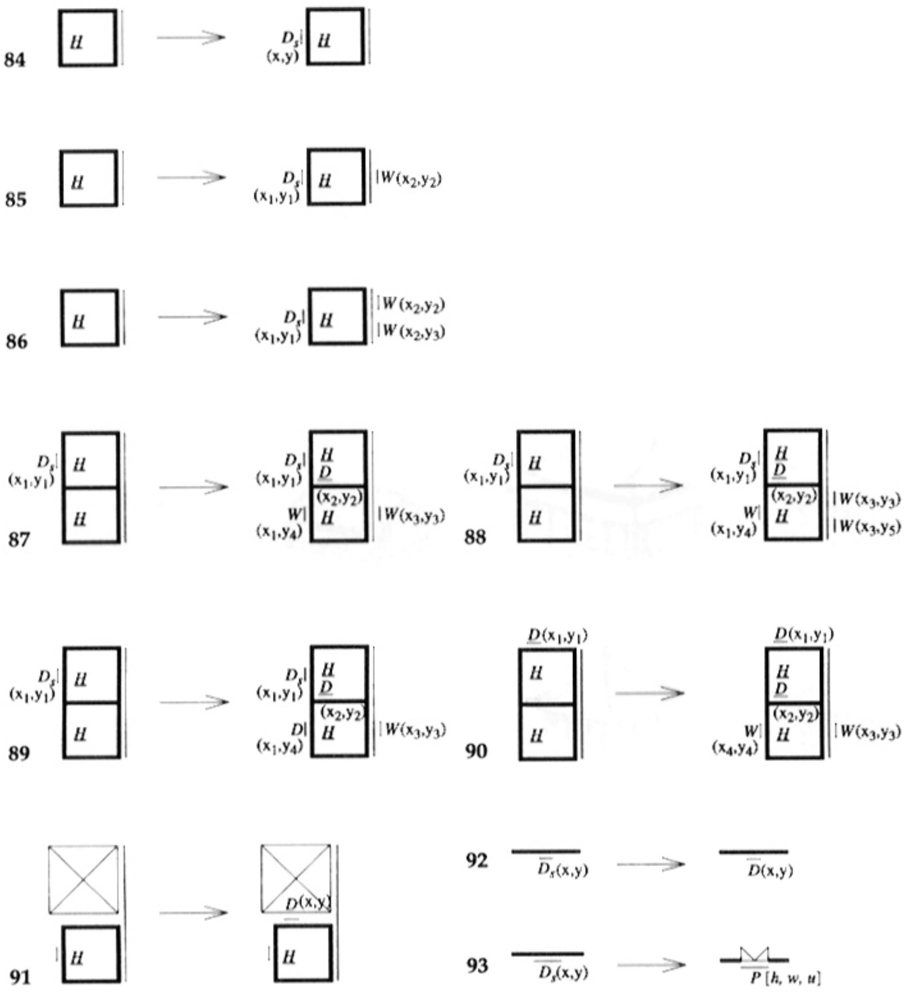

Figure 21. Stage 13: Rules to add openings to secondary building.

Stage 14: Generate platforms

The shape rules are shown in figure 22. Rule 94 adjusts the platform to the end wall. Rule 95 extrudes the platform. Rules 96 and 97 extend a platform in order to connect it to another platform.

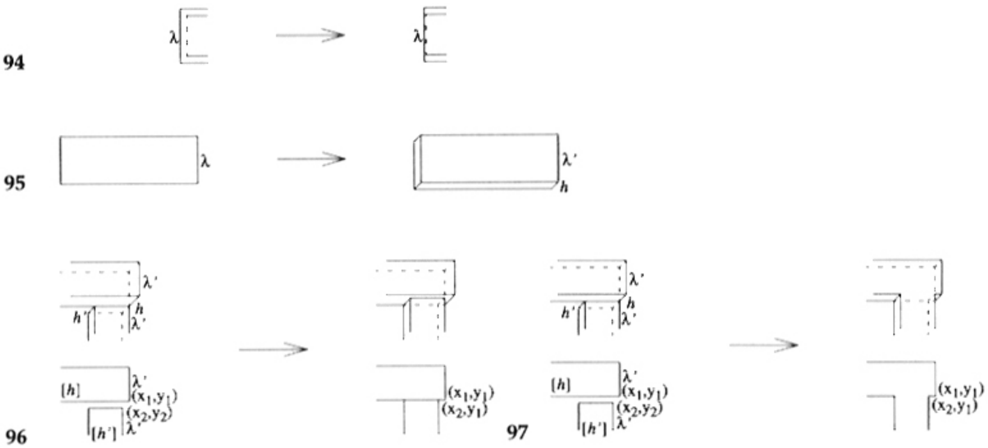

Figure 22. Stage 14: Rules for generating platforms.

Stage 15: Create roofs

The roof could be used to represent a person's social position. There are at least six roof types that were used in traditional architecture,[24] which are illustrated in figure 23. Some roofs of the same type came in different variations. In Taiwanese traditional vernacular houses, the roof took a simple form. In this stage, we present shape rules for the generation of roofs for the main and secondary buildings based on the simplest type, namely, *yìng-shān*. The slope of the roof is assumed to be approximately 0.35.

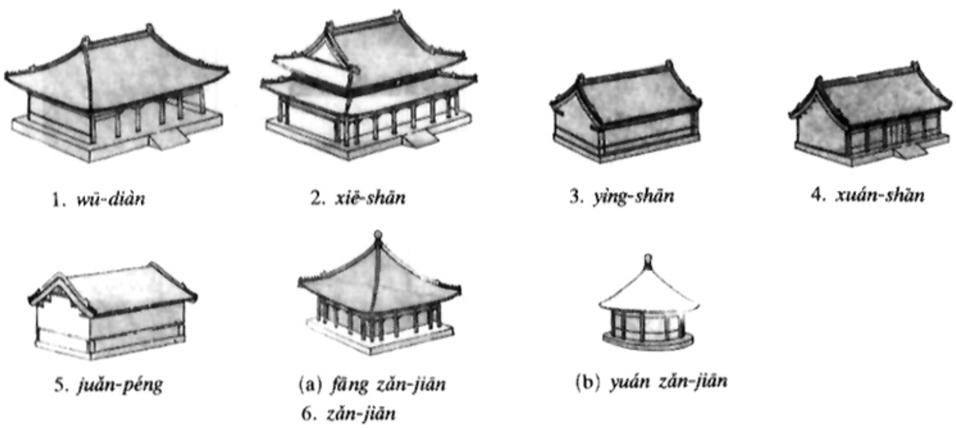

Figure 23. Various types of roofs (after Liu, 1984, page 383).

[24] *Wǔ-diàn* (four-slope roof) is only found on palaces. Vernacular houses usually used a *yìng-shān* (gabled roof with beams covered by the end walls) or *xuán-shān* (gabled roof, but the beams protrude beyond the end walls) roof; the *juǎn-péng* (curved roof) was used for auxiliary spaces such as a porch. In Taiwan, most temples use a *xiē-shān* roof (which combines the *yìng-shān* or *xuán-shān* on top and the *wǔ-diàn* at the bottom). *Fāng zǎn-jiān* [right rectangular (or polygonal) pyramid] and *yuán zǎn-jiān* (right cone) were reserved for gardens or auxiliary buildings. In the roof hierarchy, a multiroof generally has a higher status than a single roof. The roofs in figure 23 are given in their hierarchical order. That is, a *wǔ-diàn* is higher than a *xiē-shān* and so on. In Chinese architecture in general, the *yìng-shān* and *xuán-shān* roofs are considered to be of equal status, though few buildings in Taiwan use the *xuán-shān* roof.

The roof has two parts each based on the main beam. The front roof is higher than the rear roof. In traditional architecture, the slopes of the front and rear roofs were generally the same; as a result, the main beam was moved towards the front of the building, and hence, was not coincident with the center line. Where the front (*yáng*) side is higher than the rear (*yīn*) side, such roofs are called a *yīn-yáng-biān* (literally, *biān* means side or boundary). See figure 24.

Figure 24. *Yin-yáng-biān* (after Lin, 1990, page 90).

The shape rules are given in figure 25. Rule 98 extrudes a room plan to a solid (cube) based on the height (h) of the central room in the main building; d is marginally larger than the depth of the raised platform. Rule 99 creates the roof; $d' < d''$; X is $\underline{R}$ or $\underline{H}$ (both representing rooms in the main or secondary buildings). Rule 100 lifts up the roof at one end, and rule 101 drops the roof down. As before X is $\underline{R}$ or $\underline{H}$. The drop lengths n, n', and n'' are usually not the same; typically, $n \geqslant n'$, $n \geqslant n''$, with $n' \approx n''$. Rule 102 creates the roof for the passing room (indicated by the label K_w). Rule 103 determines the height of the inner secondary building. This height is less than the height of the end room in the main building, which connects to the first room of the secondary building. That is, $h_1' < h_2 < h_1$.

Rule 104 determines the height of the first outer secondary building. X is $\underline{R}$ or K_w. This height might be greater than the height of the end room, but should be less than the height of the central room in the main building, if X is $\underline{R}$. However, generally $h_2 > h_1$, if X is K_w. Rule 105 determines the height of the outer secondary building. The height of a secondary building increases from the inner to the outermost; that is, $h_2 \geqslant h_1$. Rule 106 extrudes the first room in a secondary building to height h. In order to create the roof that covers the platform as well, the depth of massing should be extended by an additional $2d$, where d has the same meaning as before.

Rules 107 and 108 connect the roofs of the main and secondary buildings. Rule 107 may be used to connect the roofs of a passing room and the secondary building. Rule 109 creates a roof solid (shown in section view).

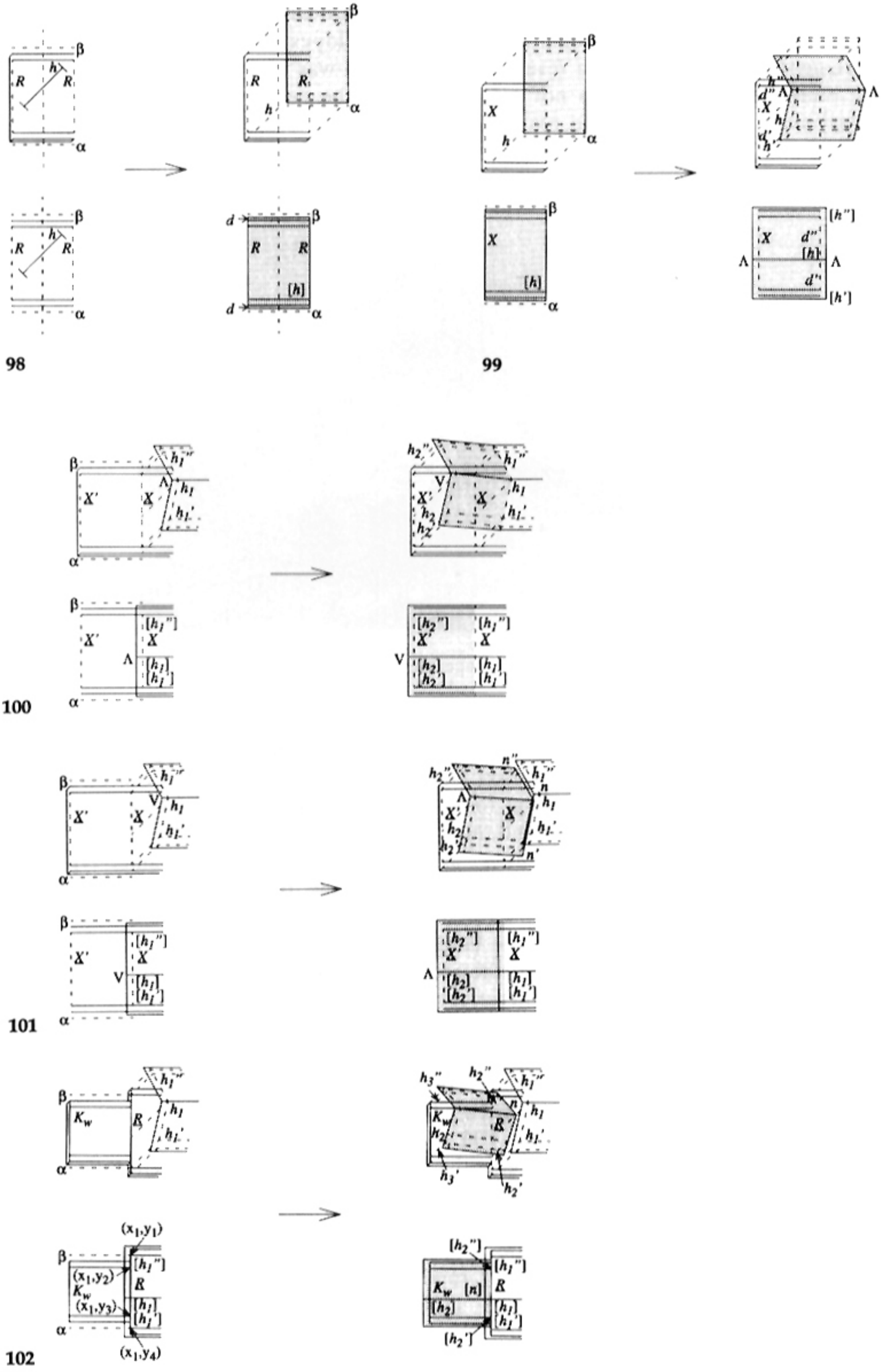

Figure 25. Stage 15: Rules for creating roofs.

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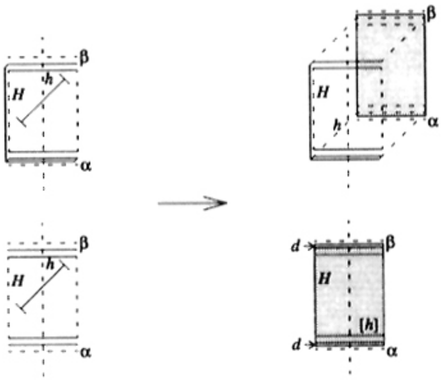

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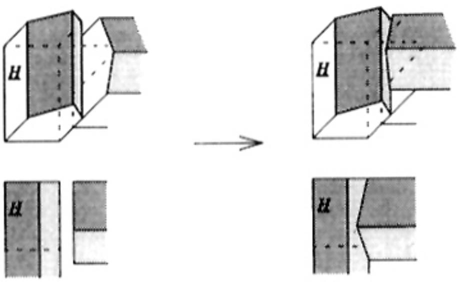

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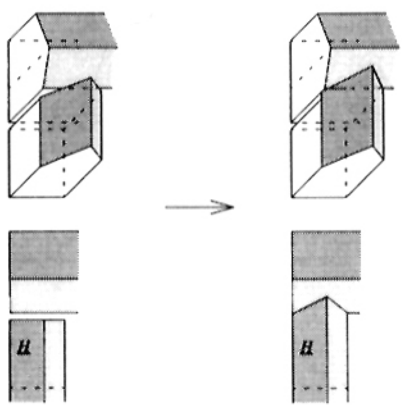

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Figure 25 (continued)

Stage 16: Modify the lines in plan to three-dimensional walls

The rules in this stage extrude the lines to three-dimensional walls that may include openings. The height and form of a wall are determined by the underside of the roof. The shape rules are given in figure 26. Rules 110 and 111 create two solid walls that intersect in plan at a point to form a corner or a T-junction, respectively. Likewise, rules 112 and 113 create a wall and an opening that intersect, in plan, at a point. In the first case, the two form a corner, and in the latter, they form a T.

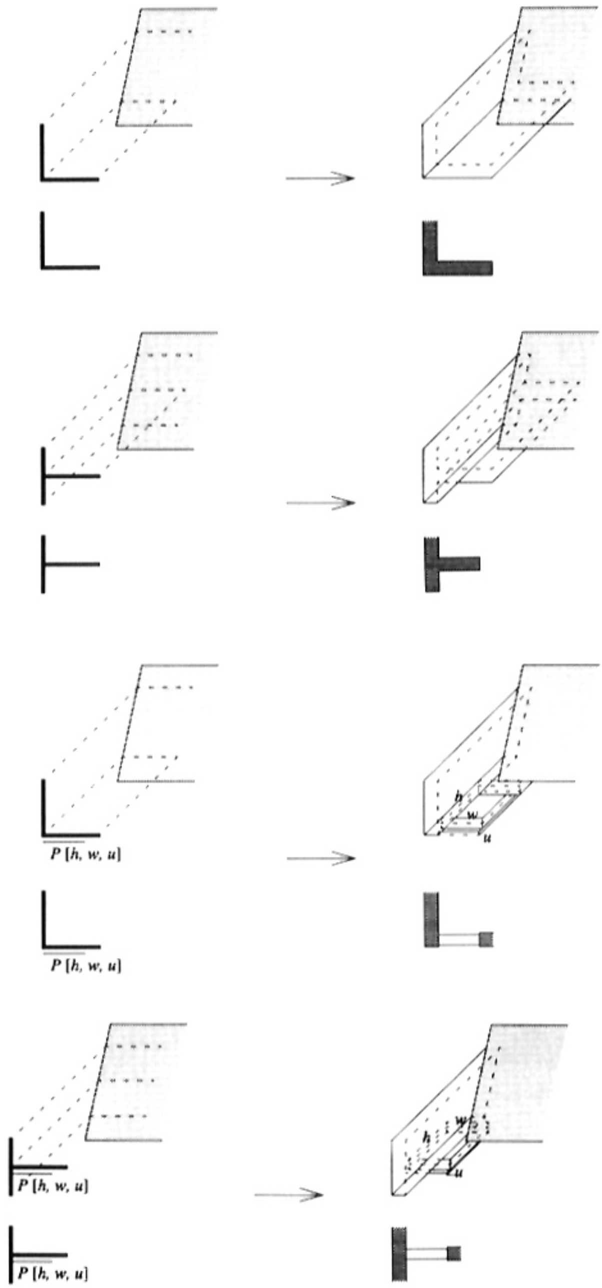

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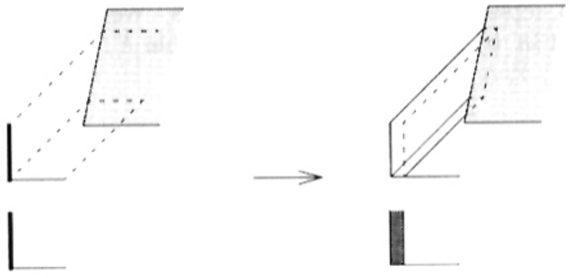
Figure 26. Stage 16: Rules to transform lines to three-dimensional walls.



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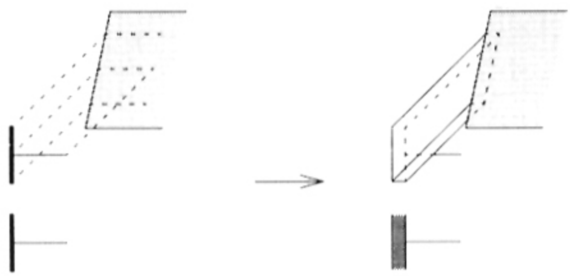

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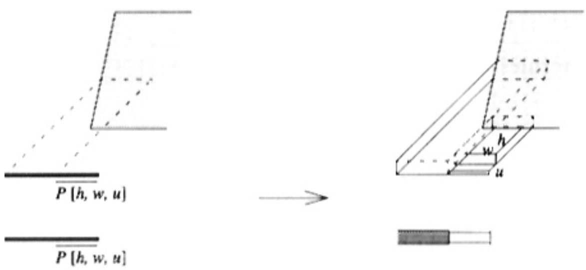

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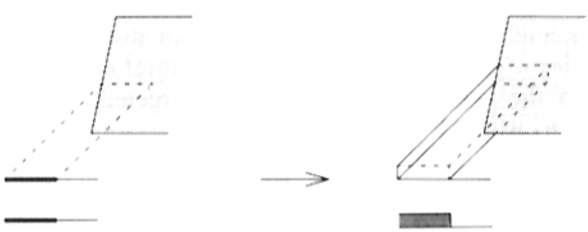

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Figure 26 (continued)

Similarly, rules 114 and 115 deal with the situation when a wall intersects, in plan, an opening of a room, at a point. Rules 116 and 117 deal with the cases when, in plan, a wall and an opening are collinear.

Stage 17: Termination

These rules are necessary for the shape grammar formalism, but the reader may ignore this stage. This stage consists of rules that erase the labels and markers that were used in plan generation and their three-dimensional model. Notationally, the symbol $s_{\varnothing}$ denotes the empty shape.

There are basically four shape rules in this stage, the first three of which are given in figure 27. The fourth shown below is a shape rule schema that erases labels.

It takes a labeled point and replaces it by the empty shape. We obtain eighteen shape rules, numbered 121 – 138, by substituting for the variable X, the labels A, $\mathring{A}$, B, $\underline{C}$, $\underline{R}$, $\underline{H}$, K_w, E, T, S, S', Y, $\ddot{Y}$, Λ, V, λ', I, and I';

$$(0,0)\colon X \rightarrow s_{\varnothing}.$$

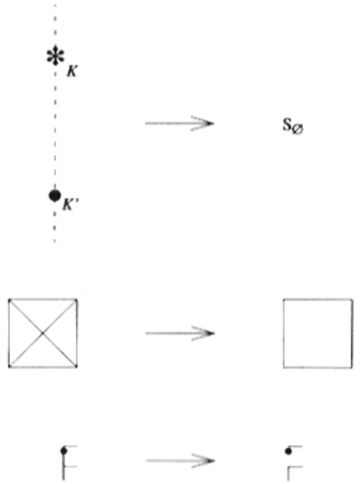

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Figure 27. Stage 17: Termination rules.

Remarks

The shape grammar developed in this paper exemplifies a particular class of buildings within Taiwanese architecture. There were, of course, some assumptions that were made during the development of the grammar.

(1) Bilateral symmetry is considered to be a basic feature even though there are extant traditional dwellings which do not possess this property.

(2) The analysis is restricted to plans of rural farmhouses. Urban sites are typically limiting, with narrow widths and long depths; however, urban dwellings followed much the same traditional rules of design and construction as rural enclosure courtyard houses. Thus, although the urban dwellings are not targeted as such, it is possible to generate urban plans with the grammar.

(3) Only roofs of the *yìng-shān* ('firm mountain') type are considered.(25) Other roof types are possible—for example, it is easy to modify the shape rules to handle the *yàn-wěi* ('swallow tail') roof profile. The *yàn-wěi* is similar to the *yìng-shān*, the differences being the ridgepole of the *yàn-wěi* is more extended at the end, and the roof is curved. The name, swallow tail, derives from its appearance.

(4) Plans are generated from the rear-most main building. This is in accordance with known practice, in which buildings were developed from and around the location of the key brick. This is reflected in the shape rules. Other shape rules were likewise determined from an understanding of the practices in traditional design and construction. We were not concerned with specific artisans or specific buildings; rather, with general considerations of design. In this sense, the grammar is an abstraction of Taiwanese traditional vernacular house designs.

(25) Although most dwellings in Taiwan have *yìng-shān* flush gables, there are some that have roofs with a limited overhang (*xuán-shān*) at the gable end (Knapp, 1986, page 104). Also see footnote (24).

The idea that the Taiwanese artisans should have designed grammatically is not far-fetched. Traditional design and construction took place at one and the same time. Each artisan, before the start of a construction, almost certainly must have had a clear image of the entire building. The rules described in this paper offer a partial explanation on how such designs could have been constructed without recourse to a priori hard descriptions of the design details.

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