Computational Considerations of Historical Architectural Analysis
– A Case Study of Chinese Traditional Architecture

Shang-chia Chiou
Department of Architecture
Carnegie Mellon University

M.S., Carnegie Mellon University, Pittsburgh, PA, U.S.A.
M. Arch., Tunghai University, Taiwan, the Republic of China
B. Arch., Tunghai University, Taiwan, the Republic of China

Submitted to
the Department of Architecture of Carnegie Mellon University
in partial fulfillment of the requirements for the degree of Doctor of Philosophy

Dissertation Advisory Committee:
Ramesh Krishnamurti, Ph.D. (Chair)
Department of Architecture, CMU

Ömer Akın, Ph.D.
Department of Architecture, CMU

Rudi Stouffs, Ph.D.
Architecture and CAAD
Swiss Federal Institute of Technology Zurich

Donald S. Sutton, Ph.D.
Department of History, CMU

Abstract

This dissertation is about the fusion of key elements from computation and historical architecture. It builds upon ideas from shape grammars and employs the analytical methodology of historical analysis. This combination can help produce a different experience, through visual and ultimately interactive explorations, of historical architecture, particularly from those cultures where drawings were not the established mode of communicating designs. Grammatical analyses can be used to differentiate between various architectural styles; explore relationships between styles; and lend themselves to computational models.

There are three parts to this dissertation. The first part is a case study of southern style Chinese vernacular architecture (the domain selected to demonstrate the claims of this dissertation) and deals with concepts from geomancy and its application to traditional architecture. The second part deals with the formal and computational considerations of historical architectural analysis. A shape grammar of vernacular dwellings is developed. This grammar is illustrated for five existing buildings. An extension to grammar for traditional temples is explored and developed.

Lastly, an aspect of shape grammar implementation is tackled. A [programming] language for describing shapes is developed and its design implementation and use described.

The main contributions of this dissertation are:

- A new approach to historical architectural analysis, illustrated by way of Chinese traditional architecture. This approach is particularly applicable to designs which have not been documented in any formal way.
- A shape description language, an interpreted programming language for the specification of shapes and rules augmented with non-geometric information.

There are other implicit contributions of the dissertation to historic preservation; the design of contemporary Chinese architecture; and the teaching of architectural history.

On the whole, this dissertation presents a new approach to the study of historical architecture, one that facilitates investigation from a number of distinct vantage points, integrated into systems of compositional rules for exploration and comparison, and amenable to computer implementation., for the primary purpose of visually and interactively exploring architectural styles.

To my parents, parents-in-law,
Miao-wan, Joseph & Matthew

Acknowledgments

I would like to express my sincere gratitude to my advisor and dissertation committee chairman, as well as mentor, Professor Dr. Krishnamurti for his invaluable instruction, and Mrs. Krishnamurti for their kindness, encouragements, and extra care about the welfare of myself and my family for past five years through my Master and Ph.D. study in CMU. It was not for Professor Krishnamurti's encouragement, guidance, and advice this work would never have been possible. I would like to thank the members of my dissertation committee. Professor Sutton's constructive suggestions and discussions on Chinese culture and traditional architecture; Professor Akin's encouragement and helpful contributions on architectural issues; and

Professor Stouffs's invaluable helps on computer programming, GRAIL kernel code, and discussions lead me to prepare this dissertation.

Financially, I would like to thank Professors Robert Woodbury, Steven Fenves, and Ulrich Flemming. They supported me during my Ph.D. study and lead me to work on the SEED project. It is so helpful for me to learn about CAAD research from this project. Particularly, the instructions from Professors Woodbury and Fenves in SEED-Config are so helpful. On the other hand, I appreciate the supporting from EDRC (Engineering Design Research Center, an NSF research center in CMU) and its excellent working environment.

I also wish to thank my former advisors, Professors Ko-li Chen and Wen-hsiung Hung in Taiwan. Professor Chen's encouragements and helps on looking for resources, and Professor Hung's constructive suggestions on traditional architecture are grateful. I thank all my friends and teachers for their encouragements, particularly Pastor and Ms. Joseph Cheng, Professor Dr. Gene T. Wang, Ms. Kathleen F. Hwang, Ms. Shu-chen Chen, Mr. Pai-hsing Hsiao, Mr. Don-yi Ou, Professor Dr. Hwa-shan Kwan, Professor Dr. Jyue-Huey Chen, Dr. Yi-Shin Deng, Ms. Hsiao-Chen You, Ms. Fang-Yi Chang, etc. I also thank my office-mates in EDRC, Ms. Sheng-Feng (Nik) Chien, Mr. Wen-Jaw (Jonah) Tsai, Mr. Mikako Harada, and Mr. James Snyder for their helps during my Ph.D. study.

I am indebted to my parents for being constant source of inspiration during my education, and to my parents-in-law for their endless supports and encouragements. I also thank my younger brother, Ji-sou, for taking good care of our parents during I was away.

I thank my wife, Miao-wan, and two kids, Joseph and Matthew, for being patient, understanding, and supportive during this difficult time.

Finally, thank you, Lord. To God be glory.

Table of Contents

List of Figures

List of Tables

The Format of
Chinese Transliteration

The following format is used in this dissertation for Chinese transliteration.

- The transliteration of Chinese corresponds to the (Hanyu) Pinyin[1] system and is italicized.

- Each Chinese character transliteration is separated by a hyphen (-) within a word (or phrase) in Chinese.[2] Usually a phase in Chinese is made up of two or more characters. For example, *fēng-shuǐ*.

- In Chinese, surnames precede given name; therefore, all the Chinese persons mentioned in this dissertation are indicated first by their surname, and then by their given name separated by a comma (,). For example, *Wáng, Jí*.

- If the English form of a Chinese person or book title is well known, it is not transliterated. For example, Liang, Ssu-ch'eng.

- All the transliterated Chinese characters in this dissertation are supplemented in the Glossary in their original writing.

We note the following comments on the translation of Chinese writings that are cited in this dissertation.

- Unless otherwise specified, all translations of cited Chinese passages are by this author.

- Where a cited Chinese passage has not been translated by this author, and where the transliteration of Chinese does not correspond to the Pinyin system, the corresponding Pinyin transliteration is provided within a matching pair of square brackets ([]).

---

1. For the reader unfamiliar with Chinese (Mandarin) pronunciation, I provide a brief introduction to the transliteration systems: (Hanyu) Pinyin and Wade-Giles, the two systems in wide use. Both are phonetic systems using the Roman alphabet. The Wade-Giles system is the older one and remains in use among scholars and on Taiwan (the Republic of China) and Hong Kong. It was first derived by Sir Thomas Francis Wade (1818-1895) in 1859 and later revised by Herbert Allen Giles (1845-1935) in 1892. Furthermore, prior to 1979 it was employed in a vast majority of English publications. In 1979, the Beijing government officially abolished the deep-rooted Wade-Giles system. Hanyu Pinyin, adopted by mainland China (the People's Republic of China) in 1958, is generally employed by newspapers, magazines as well as in many scholarly books, especially those on modern and contemporary China. Presently Pinyin has become the more popular transliteration system in use.

    Chinese characters are monosyllabic, consisting of an initial sound which is usually a consonant, and a final sound which is made up of either a simple or compound vowel. Each vowel can be modified using one of four diacritical (or tone) marks: ¯ (macron), ´ (acute accent), ˇ (inverted circumflex), and ` (grave). For example, the pronunciation for 'ba' can have four tones, namely, *bā, bá, bǎ,* and *bà.* Each tone may present different Chinese characters which share the same pronunciation and tone. The letter ü (u-dieresis) is also used when the initial sound is to be extended. In the Wade-Giles system, I indicate each distinct sound by a numerical superscript. The numbers refer to tone marks, in given order; that is, 1 ↔ ¯, 2 ↔ ´, 3 ↔ ˇ and 4 ↔ `. The superscript indicates how the immediately preceding vowel is accentuated. In the Wade-Giles system, there is a superscript 0, which reflects a shortening of the sound of the vowel it marks; that is, it serves as a neutral tone. This is, in fact, a fifth tonal form, derived from the macron form described above. For further information, see Appendix 2 of the *Learners Chinese-English Dictionary.*

2. Officially, the Pinyin system does not separate each Chinese character transliteration by a hyphen, but the Wade-Giles system does. In order to, easily, indicate different Chinese character transliteration, I use a variation of the Pinyin system which includes the hyphen.

Chapter 1:
Motivation and
Background

1.1 Introduction

This dissertation is about the fusion of key elements from computation and historical architecture. It builds upon ideas borrowed from shape grammars and uses the analytical methodology of historical analysis. This combination can produce an altogether original and different experience of historical architecture particularly from cultures where drawings were not established mode of communicating designs.

Grammars originate from linguistics where such analyses of natural language provide structural, semantic, and pragmatic descriptions of

sentences. Likewise, grammatical analyses of spatial languages can provide useful compositional and constructive descriptions of spatial forms. Here, spatial compositional rules can be used to recreate [old] designs and also to create [new] designs [within a given style]. Moreover, grammatical analyses lends itself to explorations of the relationship between different styles through transformations between the respective grammars. Perhaps, most importantly, grammatical analysis lends itself to computation; we can visually and interactively explore architectural styles.

Computation in architecture is as old as architecture itself. The constructibility of forms is (and has been) as much a concern to designers as the constructibility of buildings. We have only to look at perspectives and other such geometrical constructions, for example, gothic traceries, proportional systems and so on. These are all formal devices. We can admire Richard Meier's perspectives, Le Corbusier's *Modulor*, Rob Krier's use of proportional systems, and Frank Gehry's sculptured designs. The techniques, which these individuals use, the same techniques which we have learned, are deeply rooted in mathematics and computation.

Architectural historians have consistently promoted the view that an understanding of architectural history can help one experience and, in the end, produce better designs. The question remains though: *what does it mean and how does one experience architectural design?*

Over the past decade using computers in architectural practice and research has become fashionable. Originally, as drafting systems for producing architectural designs, with improved technology, other different uses of computers in architecture are being looked at – from the more academic studies on schematic layouts, knowledge bases for architectural cases and precedents, simulations of building performance to the visually more compelling studies involving three-dimensional modeling and virtual reality. In all of this, architectural history has only obliquely played a part. In a recent recognition of this issue, the Society of Architectural Historians has started calling for projects to be *informally* discussed in April, 1997.

One might argue that ultimately the best way to experience historical architecture is to create visual three-dimensional models. There is a problem with this: it is a tedious and time-consuming task and particularly so when

documents are not readily available. Such attempts are typically one-off and have to be redone from scratch for each design even those that belong to a particular style. An alternative approach and one that is articulated in this dissertation is that principles that lend themselves to computation ought to be extracted from studies of historical architecture and be taken into account in developing such visual experiences. This dissertation illustrates this claim through a case study of Chinese traditional architecture.

This is especially relevant from the standpoint of historical preservation and restoration – in the case of Chinese architecture, traditional artisans did not design on paper, nor were designs documented in a way that can facilitate preservation and reconstruction using modern building techniques. A similar situation occurs in many other cultures. This calls for a different kind of understanding and interpretation of the history and design of traditional architecture. In this respect this dissertation offers a significant departure from previous approaches by using the computer as a foundation for historical research.

Problem Statement

The broad problem that this dissertation tackles is: what kind of computational principles can be extracted from historical analyses and how these principles can be implemented? In the narrow sense, I consider this question in the context of Chinese traditional architecture. Even more narrowly, I focus on Chinese historical architecture in the Southern style of the *Qīng* dynasty (A.D. 1644–1911), particularly, Taiwanese traditional houses. My preliminary work when exploring this dissertation topic was on Taiwanese vernacular houses. Recent research suggests that an understanding of Taiwanese architecture easily expands to an explanation of traditional architecture for the whole of China (Dillingham and Dillingham, 1985). Furthermore, historically, the southern style traditional architecture which encompasses Taiwan, *Fú-jiàn*, and *Guǎng-dōng* is younger, and has been influenced, in its development, by the older middle and northern styles. Lastly, buildings that belong to this style are in a much better state of preservation, particularly in Taiwan, useful for collecting valuable data.

Personal Motivation

I have been a student of Chinese traditional architectural history for many years. My earlier studies and research experiences in Taiwan focused on architectural history and historic preservation of Taiwanese traditional architecture. My experiences led me to seek a different kind of understanding and interpretation of the history and design of Chinese traditional architecture. I have been a student of computational design for the past five years. For my master's project I explored hypermedia aspects, though interesting, it has its drawbacks.

Chinese architecture and its history has been explored from sociological, cultural, technological, economic context, and the underlying spatial relationships of the built environment. None, to my knowledge, has looked at Chinese traditional architecture compositionally and constructively. From my background in historical preservation and restoration this is important. In this respect my work is a significant departure from previous approaches in using the computer as a tool for historical research. The following quote from Hazel Conway (1987: 5) sums up my personal motivation:

> Studies of the past enable us to understand where we have come from, and something of the complex choices and decisions that have led to where we are today. Without that perspective our understanding is limited. We become prisoners of the present, unable to foresee alternatives, or recognize our own possibilities of choice.

According to Carr (1961), all history is 'contemporary history,' and in his words, "history consists essentially in seeing the past through the eyes of the present and in the light of its problems." We live in a world of information and computing technology – perhaps, through computers we can reach our goals more effectively – and perhaps too, 'see' the past a little more clearly. Using computational approaches to historical architecture may help us to *experience* such designs more deeply, and transfer these experiences to designs with historical contexts. I believe this to be among the important issues that concerns the 'post-modern' architect.

1.2   Background

The work described in this dissertation draws upon three main disciplines: shape grammars, architectural history, and Chinese traditional architecture.

1.2.1   Architectural History

Architectural history, like any other form of history, is concerned, though not solely, with a corpus of ascertained facts. These facts take the form of the buildings, their remains, and documents such as plans, drawings, descriptions, diaries or bills (Conway and Roenisch, 1994: 30).

However, facts do not tell us completely what happened. In his classic *What Is History*, Carr (1961: 35,164) argues that history is "a continuous process of interaction between the historian and his facts, an unending … dialogue between the events of the past and progressively emerging future ends. The historian's interpretation of the past, his selection of significant and the relevant, evolves with the progressive emergence of new goals." The past, in a certain sense, lives through the historian's interpretation.

> [Facts] are like fish swimming about in a vast and sometimes inaccessible ocean; and what the historian catches will depend, partly on chance, but mainly on what part of the ocean he chooses to fish in and what tackle he chooses to use — these two factors being, of course, determined by the kind of fish he wants to catch.
>
> Edward Hallett Carr (1961: 26)

Among architects, historians and other architectural researchers, many different opinions hold. Nikolaus Pevsner (1985: 15) draws a distinction between building and architecture: "A bicycle shed is a building; Lincoln Cathedral is a piece of architecture. Nearly everything that encloses space on a scale sufficient for a human being to move in is a building; the term architecture applies only to buildings designed with a view to aesthetic appeal." His explanation of architectural history seems to lead him to focus 'architecture' on heroic buildings. This is not surprising because "in past centuries, histories of architecture were written largely by architects, princely patrons, or court historians who wished to sharpen the distinction between

what they had achieved in contrast to the surrounding mass of vernacular buildings" (Roth, 1994: 2).

Banister Fletcher (1950: 1) in his introduction to *A History of Architecture on the Comparative Method for Students, Craftsmen & Amateurs*, wrote: "Architecture, with all its varying phases and complex developments, must have had a simple origin in the primitive efforts of mankind to provide protection against inclement weather, wild beasts, and human enemies." According to him, caves, huts, and tents were the three primitive types of human dwellings, from which man began to develop houses for himself and temples for his gods. It is immaterial whether or not Fletcher is right about the development of architecture, it is clear that human beings have always needed some way of protecting themselves.

The American architect Louis I. Kahn (1965: 305) has described "Architecture is what nature cannot make." That is, architecture is about the whole environment that humans create. In this respect, architecture includes buildings, landscape, and also the urban space. It is not surprising that some refer to the built environment as architecture.

Architectural history has attempted to understand the built environment in the context of the period in which it was created. Thus, criticisms of designs cannot be divorced from an understanding of the theories and philosophies prevailing at the time. Spiro Kostof (1995: 7) wrote: "Architecture, to state the obvious, is a social art – social both in method and purpose. It is the outcome of teamwork; and it is there to be made use of by groups of people, groups as small as the family or as large as an entire nation. Architecture is a costly act. It engages specialized talent, appropriate technology, handsome funds. Because this is so, the history of architecture partakes, in a basic way, of the study of the social, economic, and technological systems of human history."

No matter which definition one adopts, whether it reflects a total context (Kostof, 1995), or as an all-embracing subject (Conway and Roenisch, 1994), architecture spans a considerable period of history, includes all manner of buildings in all parts of the world. It is not surprising then that a wide variety of approaches to architectural historical analyses have been developed.

According to Conway and Roenisch (1994), there are three main approaches: practical, historical, and aesthetic.

> The practical aim seeks to establish what was built, when it was built and by whom, so it would include the architect, the patron and system of patronage. The historical aim seeks to establish why a building was built and its relationship to the social, economic, political, cultural and religious environment. The aesthetic aim seeks to account for visual and stylistic differences and to explain how styles change and why they do so.
>
> Hazel Conway and Rowan Roenisch (1994: 36-37)

The practical approach records historical events. The historical and aesthetic approaches tend to offer explanations for historical facts. Most approaches, however, tend to be reductionist.

With respect to the emphasis in this dissertation on computation and historical analyses, a number of studies have been undertaken. Examples of work from the past five years include De Cola, et al.(1990); Gilleard, et al., (1990); van Plet and Seebohm (1990); Seebohm (1990a; b, 1991, 1992); Stenvert (1991); Alkhoven (1992); Lindsey and Rosenblatt (1993); Mahoney (1994); Chiu (1995); Heng (1995); and Sun (1995). However, these studies offer no real paradigm for historical analysis, but, to put it simply, are applications of computer graphics, geometric modeling, or database technology for historical architectural studies. Figure 1.1 illustrates the different approaches and methodologies that have been employed in using computers for studies of historical architecture. The shaded region highlights the approach taken in this dissertation. As an example, in his dissertation, *Constructing the Past: Computer-assisted Architectural-historical Research*, Ronald Stenvert (1991) uses the computer to compare the use of the classical orders in The Netherlands in late 16th and 17th centuries. His work relies extensively on the use of vector graphics. This research is similar to studies in art history (Hamber, et al., 1989). Primarily, they use computer-aided drawing for architectural historical studies.

In the context of Chinese architecture, there are have attempts at developing software for pedagogical purposes. For example, Millet, et al. (1991) and Choi (1994, 1995) have developed systems for the retrieval – typically images – from a database (though with little historical

reconstructions of the past
(three-dimensional visualization)

hypermedia,
multimedia,
graphics,
animation.

interactive storybooks

graphics,
geometric modeling

data storage

artificial
intelligence,
object-oriented
approaches

architectural case bases

database

historical facts

architectural languages (style)

grammatical analysis

shape grammars

shape description language

grammar implementation

Figure 1.1. Approaches of computer-assisted historical architectural studies.

interpretation). Between 1991–1993, the Architecture department at the University of Hong Kong produced a self-learning program on Chinese traditional temples (Will, et al., 1995). During 1993-94, the Chinese University of Hong Kong produced a computer program for instruction into various aspects of Chinese wood frame construction in *Sòng* dynasty (A.D. 960 – 1279), *Yíng-zào Fǎ-shì* (Li and Tsou, 1994; 1995a, b). Another computer program also on Chinese traditional wood structure was developed in Taiwan (Chiu, 1995). These employ simplified geometrical models for multimedia 'slide shows.'

1.2.2 Shape Grammars

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: 247-8).

A shape grammar (Stiny, 1980a;b) is a formal system for producing shapes based on rewriting rules. 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.

Informally, shape grammars can be described as follows. One begins with an initial shape; from it and shapes produced thereof, one produces new shapes by the application of rules. Each shape rule, *lhs* → *rhs*, consists of two shapes, the left hand side and right hand side. In applying a rule, one finds a shape, in the current shape, that is similar to *lhs* and replaces it by *rhs*, under the same geometric transformation. In other words, the transformation that specifies the spatial relationship between *lhs* and the current shape is preserved in *rhs*. A shape rule may be considered analogous to a pencil and eraser. *lhs* corresponds to the 'pencil marks' that are erased from the current shape; *rhs* to those that are added to it.

Formally, a shape grammar consists of quadruple (S, L, I, R):

- S is a finite set of shapes;
- L is a finite set of symbols;
- I is a labelled shape in $(S, L)^+$ called the *initial shape*; and
- R is a finite set of shape rules of the form $a \rightarrow b$, where a is a labelled shape in $(S, L)^+$, and b is a labelled shape in $(S, L)^*$.

A rule application $u \Rightarrow v$ applies a shape rule $a \rightarrow b$ to the labelled shape u under transformation T which provides $T(a) \leq u$, and a new labelled shape v is generated based on $v \leftarrow u - T(a) + T(b)$. Thus, a language can be defined as: *Language* = {*shape* | *initial shape* $\Rightarrow^*$ *shape*}.

We consider a simple example based on the work of George Stiny (1977). The Harvard historian, Daniel Sheets Dye, in 1937, published a classic study of Chinese lattice window designs between 1000 B.C. and A.D. 1900. Among

these include the *ice-ray* (*bīng-liè-wén*) designs so called because the lattice work resembled the formation of lines in cracked ice. One can imagine an artisan at a building site, given a rectangular frame, being asked to create an ice-ray design. He begins by selecting a stick of appropriate length and attaching it to the window frame, forming two quadrilateral regions (rule 1). He may then proceed to divide one of these regions into a pentagon and a triangle (rule 2). He may further subdivide the triangle into a triangle and a quadrilateral (rule 3), and the pentagon into a pentagon and a quadrilateral (rule 4). Each subdivision is made in exactly the same way by attaching sticks of the appropriate length so that the sticks do not cross previously inserted pieces. Each stage follows the same rules. We can describe these four subdivisions as shape rules.

An example of an ice-ray (Z-shaped) design from Chengtu [*Chéng-dū*], Szechwan [*Sì-chuān*] province, A.D. 1800, is illustrated in Figure 1.2.

Thus, shape grammars are formal devices for encapsulating spatial change. By experimenting with change one can explore worlds of possibilities in which spatial forms and patterns emerge, sometimes surprisingly so.[3] In this sense, shape grammars can be viewed as design devices.

1   2   3   4
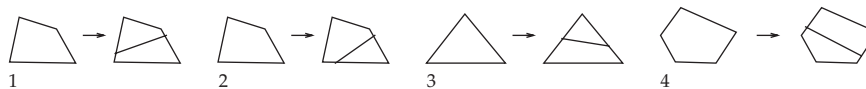
Shape Rules (Redrawn after Stiny, 1977: 94)
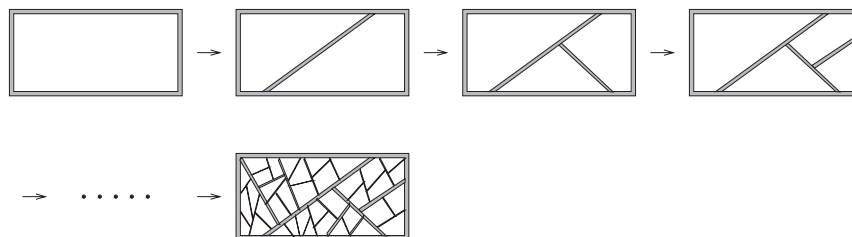
Example generation

Figure 1.2. Ice-ray design.

Shape grammars pertain to notions of style. The hallmark of style is its recognizability. By fiat, style is associated with a certain period of time; with a particular designer, community or society. Individual artifacts may be appreciated for their singular unique qualities, collectively for their shared characteristics. Shape grammars offer an appropriate language for succinct descriptions of shared spatial features and relationships. In this sense, it is merely incidental that grammars can produce new forms.

Shape grammars have a mechanical feel. By nature, design and analysis have a large element of the mechanical or routine. Otherwise, the activity would, in the main, be chaotic. The pleasure that derives from creation, explanation, appreciation or anything else lies chiefly in setting the 'framework' for that activity. Shape rules are not predefined but post-rationalized. By using a grammar to produce new forms one may get insights into the spatial workings of a style of designs. This is not dissimilar to the practice of aspiring architects, in their designs, mimicking their architectural heroes.

The formulation of a shape grammar is not necessarily separated from historic design and practice. In this dissertation, it is shown that one can produce a grammar from considerations of traditional design practice alone. From such grammars one can produce known designs; one can even create a corpora of designs for further study.

Shape grammars have been used extensively to analyze styles of American and European architecture, most notably, that of Palladian architecture (Stiny and Mitchell, 1978a, b; Gamel, 1991); Frank Lloyd Wright (Koning and Eizenberg, 1981; Rollo, 1995); the picturesque Queen Anne style of the 19th century (Flemming, 1987a; b; c); the bungalows of Buffalo (Downing and Flemming, 1981); and works of Terrangni (Flemming, 1981). Terry Knight's (1981) analysis of Japanese tea-rooms is the first to use shape grammars to

---

3.   The phenomenon of emergence or emergent forms plays an important role in understanding designs. It is formally shown in Stiny (1993, 1994) and Krishnamurti and Stouffs (1996) – using concepts from topology – that the structure of any argument from precedent to present that can be deemed to be articulately consistent or continuous must account for the emergent forms within the argument. This cannot be achieved by purely symbolic (non-geometric) means.

study Oriental architecture. Other studies on oriental architecture, such as Chinese gardens (Liu, 1993) and Korean architecture (Byun, 1989) have been developed at UCLA. In 1990, a grammar of Beijing *sì-hé-yuàn* was developed (Liou, et al., 1990). In 1995, two grammars on Taiwanese street-houses (*jiē-wū*) and academy (*shū-yuàn*) were developed (Hung, 1995; Ni, 1995). Shape grammars are considered in some detail in the books by Stiny and Gips (1978), Schmitt (1988), and Mitchell (1989).

Implementations

To date, we do not have a viable shape grammar interpreter. Gips (1975) implemented a grammar system for polygonal shapes with limited subshape matching capabilities. Krishnamurti (1982) implemented the first complete shape grammar interpreter for two dimensional shapes. His implementation was refined by Tapia (1996). Carlson (1989) implemented a single rule system based on a string grammar formalism. Heisserman (1991) developed a boundary solid grammar which has been used to show the viability of grammatical computation on 3-dimensional solids. There are drawbacks to his system: rules tend to have more global effect and less local effect; rule application relies on the characteristics of the underlying programming framework than on the spatial nature of the designs; the onus is on the user to ensure that viable solids result from rule application.

1.2.3   Chinese Traditional Architecture

Chinese architecture is based on a long tradition of rigidly applied rules and regulations that were, and perhaps still are, linked to their way of life. Their system of architecture, especially their methods of design and construction make it eminently suitable for formal computational analysis.

China has a history that is documented over four thousand years with a rich cultural tradition and a large land mass. From archeological evidence, Chinese traditional architecture may be traced back at least seven thousand years (Steinhardt, 1984). The Chinese nation is made up of over fifty different nationalities, such as the *Hàn*, *Mǎn* (Manchu), *Méng* (Mongol), *Huí* (Uighur), and *Zàng* (Tibetan).

Architectural historians have classified Chinese traditional architecture, along geographically determined boundaries, into several categories, for example, the Northern style, the Southern style, and so on. See Figure 1.3. These different styles share some basic characteristics. Wong and Chung (1986) identify continuity, uniqueness of style, and diversity in architectural design as the three fundamental characteristics; according to them, traditional architecture in China "has managed to follow an unbroken line of development. Based on the needs of the people, and assimilating beneficial experiences and influences from various source, it [has] evolved independently with its own tenor from beginning to end. It is this very continuity, independence and adaptability that constitute the characteristics of the classical traditional" (Wong and Chung, 1986: 9).

Chinese architectural design was influenced by *fēng-shuǐ*, some precepts of which can be equated to modern environmental concepts, some that can be translated into computational terms. The Chinese style of architecture, especially the Northern style, followed rigid construction rules under the dictates of *zhì-shì*. Architectural codes or laws were based on rules of social hierarchy, and placed limits or constraints on the scale, color, number and size

Figure 1.3. Chinese architecture systems and regions. (Redrawn after Knapp, 1992: 21)

of spaces (rooms), types of roofs and the number and location of the beams in the central room and so on. Thus, Chinese traditional architectural design was not just an embodiment of social, cultural, and technological factors, but also incorporated highly interdependent compositional and constructional considerations. It is these latter aspects that make Chinese traditional architecture eminently suitable to grammatical analysis. It is the former aspects that endow such rules of composition with meaning.

Chinese tradition calls for the use of earth and wood (*tǔ-mù*) for construction to mean 'buildings' or 'architecture.' Traditional building materials included bamboo, wood, earth, stone, and brick; however, wood construction was the most prevalent, and earth was the chief material as mortar.

"The house is the basic cell in the organism of Chinese architecture, just as the family it houses is the microcosm of monolithic Chinese society" (Wu, 1963: 31). Chinese traditional house design had little basis in physical function (as is understood in Western architecture), but took its sources from traditional ideas of family, religion, and society, all of which hinged on a hierarchy of human relationships – man to elders, man to ancestors, man to family. If its roots are followed far enough, the Chinese house can be seen as a physical and symbolic vision of a way of life and its human relationships. As Nelson I. Wu (1963: 34) has remarked: "The dual quality of the house as a setting for ceremony and as a home, is a most important characteristic of the house as an image of human relationship."

The Chinese house fulfills its vision in a balanced, form-oriented style. The ancestral hall (central room), the focus of the family and the center of house, always occupies the important position in the middle of a building facing out into a court, its purpose the most important, its roof the highest. A room's importance and use by various persons was related to its position relative to the ancestral hall, that is, the closer the room was to the ancestral hall, the higher the status of the person using it. Circulation follows a similar, formal pattern, the path marked out, the proper human behavior recorded. The methods of growth, the details of decoration all follow in a formal, stylized manner. Besides the symbolic, formal aspect of the plan, the lack of interest which the Chinese house exhibits in physical function can be seen in

the essentially undifferentiated character of its spaces. With the exception of the ancestral hall (central room) and perhaps a kitchen, if one had been specially built, the rooms were more or less the same in size and design. The form of a room used for sleeping was practically identical with a dining room. In this similarity a very basic Chinese attitude toward space can be seen: man is adaptive and space flexible. To create a particular type of space, it is only necessary to add the required furniture in the best arrangement and begin using it. In spite of its symbolic and formal qualities, the Chinese house was never intended as a monument nor as art. The desire for physical permanence or personal remembrance which fostered a monumentality in some western or european dwellings, is missing in China. Continuity and eternity are achieved instead through the family, through a continuing line of descendants and their attentions to their ancestors (Dillingham and Dillingham, 1985).

Different Chinese building types shared quite similar architectural forms. Therefore, a plan of a *sān-hé-yuàn* (or *hé-yuàn*, courtyard) could be used for a temple, a house, an official *yá-mén*, even the imperial palace. A way to differentiate between them is through the details, e.g., doors, eaves, roof, decoration, and so on.

The basic form of the Chinese architecture is a walled enclosure surrounding several smaller buildings which in turn surround one or more courtyards. The enclosure or the wall, and the hollowness of the court give a form and a place for the unity of the family. The organization of the design is usually symmetrical in a general way: the central axis leads through the center of the front wall, the lower building, the court, and the higher building. In this arrangement, the principal building is located opposite the entrance, facing into the court; the central space within this building is usually the ancestral hall (central room, or a room with altar), the main ceremonial and guest receiving room. To either side of this room are bedrooms of the grandparents or elders and the oldest sons and wives. The rooms in the building adjacent to the street, the lowest building in importance and form, are occupied by servants or used for storage or other service functions. Sometimes if families became poor or broke up, the different buildings around the side of the court might then be occupied by three or four

separate, unrelated, nuclear families. As a family became larger, necessary growth could be accommodated by adding one or more courtyards in front or behind the original. As courts were added, the central building in the rear court usually continued to be the most important, the ancestral hall, but the other rooms along the central axis also might become rooms for receiving guests or for other social functions; they also were used to allow circulation between the front and rear courts. Besides accommodating growth, the addition of extra courts and receiving rooms fulfilled a social function in that it created a hierarchy of privacy; the more intimately one knew the family, the farther along the axis one could progress. Trades people or very brief acquaintances may not get beyond the gate, casual friends or important officials might be received in one of the outer rooms, but only intimate friends were permitted to penetrate the inner, family courts. In the larger houses which had grown loosely in a lateral direction, the original series of axial courts continued to be the ceremonial or semi-public area of the house; but the private zones moved into less formal apartments in the side areas or behind the ancestral hall (Dillingham and Dillingham, 1985).

In general, there are three spatial concepts that influence the Chinese mores of living, and the hierarchy of spaces (Kwan, 1989).

The Boundary of Human Beings Derived from Chinese Popular Religion

The Chinese believe that the world we abide in is an intermediate place where the gods and ghosts exercise their power. People wish to invite the gods into the 'inner space' of their living environment, and exorcise the ghosts to the 'outer space.' In this way, the Chinese demarcate the boundary between humans, gods, and ghosts. An example is the positioning of the 'light beam' (*dēng-liáng*) in the central room (or ancestral hall).

The Concept of "Living Breath" Derived from Fēng-shuǐ (Chinese Geomancy)

According to the *fēng-shuǐ* (Chinese geomancy), the geographical features are shaped by the '*yīn*' and '*yáng*' breaths. The place where the living breath accumulates is considered the best location for building a *yáng* house (human's house) and a *yīn* house (the grave). For keeping the living breath, the form of the *yīn* or *yáng* house should be able to "store the wind;" otherwise, the wind will blow away the breath. This concept determines not

only the axis and location of a building, but also principles of form, e.g., symmetry, back and front, the multiple secondary buildings, etc.

The "Ethic Order Concept" Derived from Confucian Ideology

A person's relationship to others is envisioned as a ripple expanding from the center to the periphery. Fei, Hsiao-tung (1943: 28) called this *chā-xù-gé-jú* (hierarchy of different orders). According to this, the ordering of spaces in a house was determined by kinship; by the left side always considered greater than the right; and by the inner spaces of having more privacy than the outer. Thus, rooms closer to the central room (or the main axis) were higher in the hierarchy. In this way we can define a space hierarchy for a *sān-hé-yuàn* (enclosure-courtyard). This is illustrated in Figure 1.4, with 1 being the highest indicating the central room or ancestral hall.
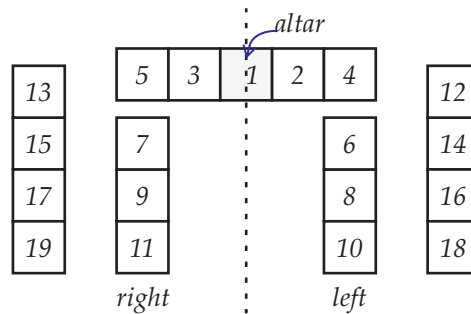
Figure 1.4. The general space hierarchy in a *sān-hé-yuàn*.

1.3   Organization of the Dissertation

This dissertation is organized in three parts.

The first part comprising Chapters 2 and 3 presents a case study of Chinese traditional architecture. In Chapter 2, I describe two theories of Chinese geomancy (*fēng-shuǐ*) that were applied to traditional design, the system of spatial organization in traditional architecture, and the design/construction processes. Chapter 3 introduces the Chinese calendar system from which and geomancy we can derive procedures for the computation of

the fortunate measurements of the central space, the orientation and propitious date for the start of construction of a traditional building.

The second part comprising Chapters 4 through 7 form the core of this dissertation. In it is presented the formal and computational considerations for historical architectural analysis. In Chapter 4, a grammar of Chinese Southern Style vernacular dwellings is developed. Chapter 5 looks at five different existing buildings in increasing order of complexity and illustrates the generation of their plans by applying the rules of the grammar. Chapter 6 takes this approach a step further and explores the extension of the grammar to temples. Chapter 7 looks at one of the issues in implementing shape grammars, that of describing shapes to a computer. A shape description language is presented and illustrated with examples from the grammar. Other examples and test results are also illustrated in this chapter.

The third part comprising Chapter 8 concludes this dissertation. In this chapter, are listed a summary of the contributions of this dissertation and an outline of possible future work.

In addition, a glossary of Chinese characters used in this dissertation is provided, and two appendices, one on the chronology of Chinese dynasties and the other on the BNF of the shape description language.

Part I
Case Study

Chapter 2:
Geomancy and
Chinese Traditional
Architecture

In many ways, *fêng-shui* [*fēng-shuǐ*] was an advantage to the Chinese people, as when, for example, it advised planting trees and bamboos as windbreak, and emphasised the value of flowing water adjacent to a house site. In other ways it developed into a grossly superstitious system. But all through, it embodied, I believe, a marked aesthetic component, which accounts for the great beauty of the siting of so many farms, houses and villages throughout China.

<div align="right">Joseph Needham (1956: 361)</div>

The Chinese have long been accustomed to take into account the cosmic aspect of nature; for instance, cities and important buildings represented ideal

images. It was natural to choose a site that looked towards the sun – namely, the south or southeast – as these directions were considered to be the best orientations both practically and spiritually. The ancient cities of Xian, Beijing, and Nanjing are good examples where the city roads ran (mostly) along north-south and east-west directions, and where the main entrances of buildings and courtyards (usually) faced south.

China, for the most part, has a prevailing southeasterly wind, cold in the winter and warm in the summer. By orienting buildings towards the south or southeast, the Chinese could take advantage of the wind and sunshine to provide for courtyards with a pleasant micro-climate. This basic idea of orientation developed into a special branch of Chinese philosophy called *fēng-shuǐ* (or geomancy).

2.1   Geomancy and Orientation

Fēng-shuǐ is the art of adapting buildings, rooms, and furniture so as to achieve maximum harmony with nature – in effect, with the local environment and climatic conditions[1]. The origin of *fēng-shuǐ* dates back to the *Hàn* dynasty (206 B.C. – A.D. 220). It was first applied by *Guō, Pú* (A.D. 276 - 324), a scholar of the *Jìn* dynasty (A.D. 265 - 420), to the design of graves (circa A.D. 300). *Wáng, Jí* (circa 11th century), another scholar of the *Sòng* dynasty, first applied its principles to house design. *Fēng-shuǐ* was almost universally considered, applied in all localities and to different building types. It is still in use today.

> 氣乘風則散，界水則止。古人聚之使不散，行之使有止，故謂之風水。
>
> Qi [*qì*] (breath), if it rides the wind, would be scattered, but it would stop at water. Ancient people would concentrate Qi [*qì*], so this was called wind and water, or Feng Shui [*fēng-shuǐ*].
>
> *The Burial Book* (*Zàng-shū*)[2]
> Translated by Lawrence Liu (1989: 29)

---

1.   Needham (1956: 395) uses the following definition for *fēng-shuǐ* which he attributes to Chatley: the art of adapting the residences of the living and the dead so as to cooperate and harmonise with the local currents of the cosmic breath.

Literally, *fēng* is invisible wind and a medium of *qì*, the universal spiritual [life] breath, and *shuǐ* is visible water which together serves to protect *qì*. The Chinese believed that each place on earth has special topographical features (natural and artificial) that indicate (and sometimes modify) the *qì*. *Fēng-shuǐ* is based on the notion that people ought to live and work in harmonious surroundings – for instance, the aforementioned *Wáng, Jí* wrote,

> … a grave, a wide river in front, a high cliff behind, with enclosing hills to the right and left, would all constitute a first class Feng Shui [*fēng-shuǐ*] position.
>
> <div align="right">Lawrence Liu (1989: 29)</div>

Joseph Needham (A.D. 1900-1995) in his classic *Science and Civilisation in China* has referred to *fēng-shuǐ* as a pseudo-science (1956: 359). Recent researches suggest that there is a correlation between principles of geomancy and environmental theories of modern architecture (Han, 1983 & 1987; Needham, 1956; Shyu, 1983). The main tenets of *fēng-shuǐ* combine the *Yì-jīng* (Canon of Changes), and five natural elements (*wǔ-xíng*): metal, wood, water, fire, and earth. Two main schools of that *fēng-shuǐ* have been developed: the earthly forms and cosmology.

2.1.1 Earthly Forms (Jiang-xi School)

The school of earthly forms in *fēng-shuǐ* – also known as the *Jiāng-xī* school – focused on the landscape. It was developed in the ninth century by *Yáng, Yún-sōng*; *Zēng, Wén-chuán*; *Lài, Wén-jùn*; *Liào, Yǔ*; and *Xiè, Zǐ-yì* in *Jiāng-xī*, a province in the southern part of China. This school of thought took into account the environment surrounding a site and basic needs of daily life such as water. For instance, four aspects were considered in determining the orientation and/or location of a site – *lóng* (dragon), *xuè* (navel or lair; literally, the dragon's lair, or the origin of *qì*), *shā* (sand or plain), and *shuǐ* (water).

---

2. Authorship of this book is credited to *Guō, Pú*, of the fourth century, although some researchers doubt the authenticity of this (Needham, 1956: 360; Han, 1983: 130-1). However, it is almost certain that this book was finished by the Northern and Southern Dynasties (*Nán-běi-cháo*, A.D. 420 - 589). *The Burial Book* (*Zàng-shū*) is believed to be the first book that describes the fundamental theories of the Chinese geomancy (see Han, 1983: 130-1).

> A site should be surrounded on three sides by higher land, like
> the crook of the elbow in a curved arm, to provide protection
> from inclement weather or an enemy. The lie of the land should
> be gently sloping and, if possible, there should be a river or
> valley nearby to allow surface water to drain easily.
>
> <div align="right">Lawrence Liu (1989: 29)</div>

Figure 2.1 illustrates this ideal site. Here *qì* specifies the topography termed *xíng-qì* (topographical breath).
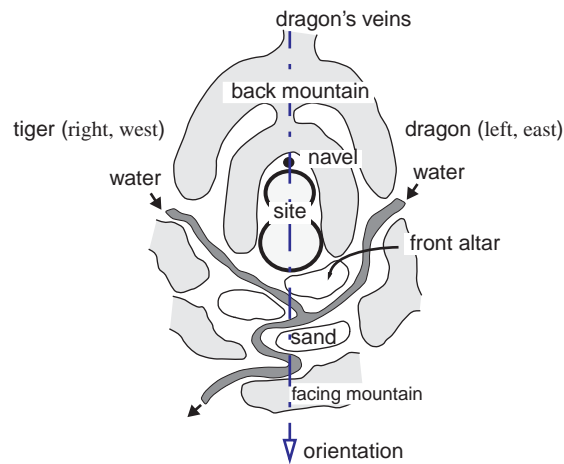
Figure 2.1. An ideal *fēng-shuǐ* site based on the school of earthly forms.
(Redrawn after Kwan, 1989: 38)

2.1.2 Cosmology (Fu-jian School)

Wáng, Jí is credited with establishing this particular school of *fēng-shuǐ*. It is also known as the *Fú-jiàn* school of *fēng-shuǐ*, because it originated from the central area of *Fú-jiàn*, a province, neighboring *Jiāng-xī*, in the southeastern part of China. Unlike the school of earthly forms which is a qualitative theory, the cosmology school is essentially computational. Geomancers of the cosmology school attempted to find rational methods to arrive at decisions that impinged on ordinary life. In the school of cosmology, *qì* is the cosmic breath, *xīng-qì* or *tiān-qì*. In order to determine *qì*, it seems, as it were, that the geomancer attempted to ascertain a cosmic order.

This form of geomancy was based on the eight-trigram and the five-stars (which are described below) whereby one determined relationships of creation and destruction from which a variety of auspicious or inauspicious situations, measurements, events etc. can be determined.

The Eight-Trigram

The eight-trigram were derived from the *hé-tú* and *luò-shū*, which are illustrated in Figure 2.2. These corresponded to numerical tables that correlated natural phenomena. The origins of *hé-tú* and *luò-shū* are still unknown, though in the *Xì-cí-zhuàn* (in Book II of the *Yì-jīng*)[3] and *Hóng-fàn-piān* (a chapter in *Shàng-shū*[4]), one find references to a myth that describes how *hé-tú* and *luò-shū* came into being. At any rate, it is obvious that these numerical tables must have existed prior to these books (circa 1000 B.C.).

---

3. *Xì-cí* (Appended Judgments) has two parts which are the fifth and the sixth wing in Book II (*The Material* — one of appendices to the original text of *Yì-jīng*) of the *Yì-jīng* (Canon of Changes). They constitute a treatise that presents many difficulties and introduce the general issues of the *Canon of Changes*. *Sī-mǎ, Qiān* (circa 145-86 B.C.), perhaps the greatest and most famous historian in China, sometimes referred to as the "father of history," called them *Dà-zhuàn* which means "great commentary" or "great treatise" (see Wilhelm, 1977: 255-261 & 280-355). *Zhū, Xī* (A.D. 1130-1200), the author of commentaries on most of the Chinese classics, and whose interpretations remained the generally accepted standard until the middle of seventeenth century, stated:
"The appended judgments are the judgments originally made by King Wên [*Wén*] and the Duke of Chou [*Zhōu*, circa 1100-256 B.C.] and appended by them to the hexagrams and their lines; they make up the present text of the book. The section before us is the commentary in which Confucius explains the appended judgments, at the same time giving a general introduction to the whole text of the complete work" (Wilhelm, 1977: 258).

4. *The Classic of History* (or *The Book of Documents*, *Shàng-shū*) is one of the *Six Classics* — the others are *The Book of Songs* (*Shī-jīng*), the *Ritual* (*Lǐ-jì*, a set of texts including the *Records of Rites*), *The Classic of Music* (*Yuè-jīng*, now lost), *The Canon of Changes* (*Yì-jīng*), and *The Spring and Autumn Annals* (*Chūn-qīu*). *The Classic of History* records the history and social activities from the late primitive period (circa 3000-circa 2100 B.C.), *Xià* (circa 2100–circa 1600 B.C.), *Shāng* (trad. 1766–1122 B.C., or circa 1600–circa 1100 B.C.), to *Zhōu* dynasty. It is a collection of documents purposedly compiled by Confucius (circa 551-circa 479 B.C.) (Schirokauer, 1991: 22-24). There are two scripts of this book, namely, the *Old Script* and the *New Script*. The *Hóng-fàn-piān* is in the *New Script of the Classic of History* (*Jīn-wén Shàng-shū*) which was appended by the latter Confucians.

4	9	2
3	5	7
8	1	6

(a) *hé-tú*   (b) *luò-shū*   (c) *magic square*
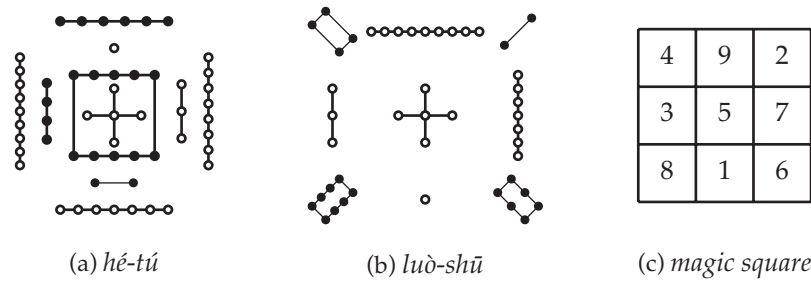
Figure 2.2. *Hé-tú* and *luò-shū*.

Hé-tú is an arrangement of the numbers 1 through 10: 1 and 6 are to the north, 2 and 7 to the south, 3 and 8 to the east, 4 and 9 to the west, with 5 and 10 placed in the center.[5] *Hé-tú* has been interpreted, at least, in the following three ways:

- The numbers 1, 3, 5, 7, and 9 are *yáng*; 2, 4, 6, 8, and 10 are *yīn*.[6]

---

5. Each direction is associated with one of the five natural elements, for instance, east is wood, west is metal, south is fire, north is water, and center is earth.

6. In the *Yì-jīng* (Canon of Changes), *yīn* and *yáng* are guiding concepts and are the two opposing principles but balancing principles in nature; the former meaning feminine, negative and death, the latter masculine, positive and living. The Chinese distinguish(ed) between the two forms of construction: *yīn* and *yáng* buildings – at the same time identifying them as dwellings of darkness (referring to such edifices as monuments, mausoleums, tombs and funeral homes -- which are erected for the dead) and dwellings of light (referring to a habitat for the living) respectively and linking the two together in a single system. There is a strong relationship between *yīn*, *yáng*, and *fēng-shuǐ*. According to Freedman (1979: 318), "It is very important to grasp the idea that in the Chinese view a building is not simply something that sits upon the ground to serve as a convenient site for human activity. It is an intervention in the universe; and that universe is composed of the physical environment and men and the relationships among men. Men are bonded to the physical environment, working good or ill upon it and being done good or ill to by it. …… Modifications in the landscape reverberate. So that, in principle, every act of construction disturbs a complex balance of forces within a system made up of nature and society, and it must be made to produce a new balance of forces lest evil follow. Chinese are frightened by the act of building -- and they are wary, too, of the tricks that carpenters and masons can play on them."

- There is a *yīn-yáng* pair for each side. The *yīn-yáng* pairs specify the rule from which all things can be generated.
- The first five natural numbers, 1-5, known as *shēng-shù* (mother numbers) generate the next five natural numbers, 6-10, termed *chéng-shù* (son numbers). Mother and son numbers are respectively *yīn* and *yáng*. These are used to interpret the eight-trigram.

Luò-shū is a three by three magic square filled with distinct numbers from one through nine with equal row and column sums. The number 1 is in the middle of the bottom row. The *yīn* numbers 2, 4, 6, and 8 are at the four corners. The *yáng* numbers 3, 5, 7, and 9 are respectively located to the west, center, east and north. The *luò-shū* implies that *yáng* leads *yīn*.

> 易有太極，是生兩儀，兩儀生四象，四象生八卦。
>
> Change (*yì*) has the universe (*tài-jí*) which produces two principles (*liǎng-yí*) which produce four bigrams (*sì-xiàng*) which, in turn, produce the eight trigrams (*bā-guà*).[7]
>
> *Xì-cí-zhuàn*, *Yì-jīng*

This concept of change is illustrated in Table 2.1. The resulting ordering on the eight-trigram is referred to [*Fú-xī*][8] *xiān-tiān bā-guà* ("eight-trigram in former heaven order").

The eight trigrams split into two groups according to the following numeric property: if the long bar is considered to represent 1 and the two short bars –1, then a trigram has a number associated with it which is obtained by multiplying the bars in the trigram. Thus, a trigram is either *yáng* (1) or *yīn* (–1). The eight trigrams fall into two equicardinal groupings:

- *yáng* group: *qián*, *zhèn*, *kǎn*, and *gèn*;
- *yīn* group: *kūn*, *xùn*, *lí*, and *duì*.

---

7. Superimposing a *yáng* on the top of a *yáng* principle is called *tài-yáng* (great *yáng*); however, a *yīn* on the top of a *yáng* principle is called *shào-yīn* (little *yīn* or *yáng* with *yīn*) which is no longer *yáng*. The eight trigrams produce sixty-four hexagrams which together with their associated commentaries constitute the core of the *Yì-jīng* (Canon of Changes).

8. *Fú-xī* was believed to have been the father of Chinese animal husbandry, marriage, calendar, and musical instruments. The construction of the eight-trigram of the *Yì-jīng* is ascribed to him (Schirokauer, 1991: 24).

The eight trigrams can be used to represent a number of different sorts such as natural phenomena, kin relationships and so on. Table 2.1 includes an interpretation of kinship within a family according to the *yīn/yáng* groupings.

Each trigram, taken in order of the generated sequence I to VIII, can be assigned, based on its *yīn/yáng* grouping and *hé-tú*, a distinct number, excluding 5 and 10, from either the mother or son numbers. The first generated trigram, *qián*, which is *yáng*, is given the largest son number 9 (which is also *yáng*). If we follow the sequence, in order, we get the values: *duì* 4, *lí* 3, *zhèn* 8, *xùn* 2, *kǎn* 7, *gèn* 6, and *kūn* 1. If we place these values into the eight-trigram in 'former heaven' order, and add 5 to the center, we find that the resulting arrangement is exactly the same as *luò-shū*. In the eight-trigram in 'former heaven' order, the trigrams on the left – *qián*, *duì*, *lí*, and *zhèn* – are *yáng*; the others, naturally, are *yīn*.

In *fēng-shuǐ*, the sequence of the eight-trigram that is employed is [*Wén-wáng*][9] *hòu-tiān bā-guà* ("eight-trigram in later heaven order"). The 'later

change	universe							
two principles	*yáng*				*yīn*			
four bigrams	*tài-yáng*		*shào-yīn*		*shào-yáng*		*tài-yīn*	
eight trigrams	*qián*	*duì*	*lí*	*zhèn*	*xùn*	*kǎn*	*gèn*	*kūn*

natural phenomenon	heaven	lake	sun lightning	thunder	wind	moon	mountain	earth
kinship	father	youngest daughter	middle daughter	eldest son	eldest daughter	middle son	youngest son	mother

sequence	I	II	III	IV	V	VI	VII	VIII
value	9	4	3	8	2	7	6	1

Table 2.1. Change according to the *Yì-jīng*.

heaven' order can be obtained by rearranging the 'former heaven' order. It was believed that the symbols for *yīn* and *yáng* originally represented numbers. Ancient scholars have mentioned that *yáng* stood for three and *yīn* for two.[10] The *Canon of Changes* treated *yáng* as nine and *yīn* as six. Taking the latter values, the sum of each trigram can be calculated: *qián* is 27, *duì* is 24, *lí* is 24, *zhèn* is 21, *xùn* is 24, *kǎn* is 21, *gèn* is 21, and *kūn* is 18. The total sum of the eight-trigram is thus 180. Since *yīn* and *yáng* have to be balanced, 180 has to be sum-wise evenly distributed:

group 1: *qián* (27), *zhèn* (21), *kǎn* (21), *gèn* (21);

group 2: *duì* (24), *lí* (24), *xùn* (24), *kūn* (18).

Now there is only one way to divide the groups into two further subgroups while maintaining divisional balance. Figure 2.3 shows the subdivision of the groups each into two subgroups with sums of 48 and 42 respectively.
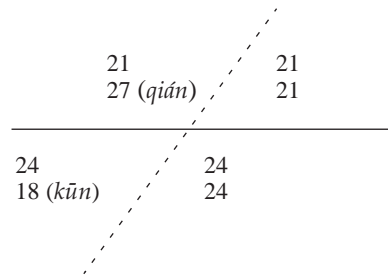
Figure 2.3. The numbers of eight-trigram for later heaven order.

According to this numerical division, it is clear that *zhèn*, *kǎn*, and *gèn* are interchangeable within an ordering; so too are *duì*, *lí*, and *xùn*. However, the 'later heaven' order is fixed in a particular fashion. There is a historical explanation for this. The 'later heaven' order was developed in the *Zhōu*

9. *Wén* (circa 1150 B.C.) who established the *Zhōu* dynasty (the Western *Zhōu*, circa 1100–771 B.C., and the Eastern *Zhōu*, 770–256 B.C.). This was after the *Shāng* dynasty, and before the first empire (*Qín* dynasty, 221–207 B.C.).

10. The earliest spatial representation for *yáng* was three short bars, not a long bar. It is interesting to note that the ancient Chinese used the first two primes, 2 and 3, to describe the essence of the universal.

dynasty. *Zhōu* originated from the northwestern part of China. Naturally, it was believed that the trigram with largest sum (27), *qián*, should be to the northwest. According to the history of the *Zhōu* dynasty, the first ancestor (or emperor) of *Zhōu* gave his eldest son lands to the east. Thus, the trigram *zhèn* (eldest son) is to the east. The trigrams *kǎn* (middle son) and *lí* (middle daughter) have to be in opposite positions. Thus far, the positions of six trigrams have been decided. The two remaining trigrams, *xùn* and *duì*, are respectively positioned to the southeast and west. It is still a mystery as to why these are so located.

The ancient geomancers of the cosmology school also incorporated the *luò-shū* magic square into the 'later heaven' order. According to the *hé-tú*, the number, 1, is to the north. This combination of the 'later heaven' order of the eight-trigram, *luò-shū*, and *hé-tú* provided the basis of the cosmology school. Figure 2.4 illustrates the two different ordering of the eight-trigram. For the purpose of this dissertation, we note that the orientation of a house or site was based on the 'twenty-four aspects,'[11] which were derived from the above combination.

        (a) former heaven order   (b) later heaven order
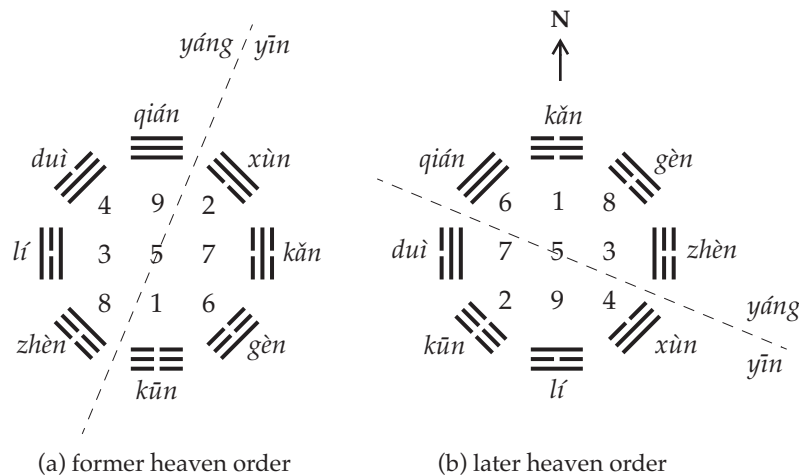
Figure 2.4. The heavenly orders of the eight-trigram.

---

11. The twenty-four aspects are related to the meteorological cycle of twenty-four fortnightly periods (see Section 3.1.2). Aspect is defined in Section 3.2. See, also, footnote 11 of Chapter 3 on page 69.

The Five Stars

The five-stars (*wǔ-xīng*), the other basic element of the cosmology school, described types of mountain forms, and had names corresponding to the five natural elements (*wǔ-xíng*), namely, metal, wood, water, fire, and earth. In fact, the terms 'five-stars' and 'five-elements' are equivalent (or synonymous). The five-elements[12] were first referenced in *The Classic of History* (*Shàng-shū*, see footnote 4 on page 25). In it is mentioned the five elements and their shapes – namely, the five-stars. It was believed that each thing can be derived from the five elements, in a manner similar to the chemical processes we know today. Alternatively, everything belonged to the five-elements. It was, therefore, believed that to bring fortune or protect *qì* one had to follow rules of producing and destroying the five-elements as illustrated in Figure 2.5. The five-elements are related to many other categories, for example, see footnote 5 on page 26.

By the late 19th and early 20th centuries, the two schools had merged. The term *fēng-shuǐ* now refers to the combined school of thought, and geomancers
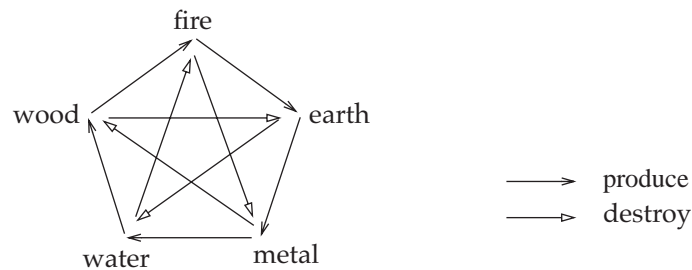
Figure 2.5. The relations among the five-elements.

12. The translation 'five elements' is misleading for it implies inertia and passivity, instead of the dynamism and self-movement that is inherently part of the Chinese conception. As Schirokauer (1991: 8) puts it: "Since the components of this concept recall the four elements of Greek philosophy, for a long time the Chinese term was translated as the 'Five Elements.' This translation is misleading, for it implies inertia and passivity rather than the dynamism and self-movement inherent in the Chinese conception. Furthermore, the translation 'Five Agents,' or 'Five Phases' more accurately reflects the Chinese view that the processes of five nature occur in regular sequence." Nonetheless, for this dissertation, I remain with the most popular translation, namely, the 'five elements.'

apply concepts from both. For further information and detail, the reader is referred to the original books on *fēng-shuǐ*, for example, *Fēng-shuǐ Jiǎng-yì* (Notebook of Chinese Geomancy), *Dì-lǐ Mì-jué* (Secrets of Geomancy), and *Bā-zhái Míng-jìng* (Book of Eight Buildings), and recent research such as Chiou (1991), Feuchtwang (1974), Han (1983, 1987), Lee (1986), Lip (1979, 1995), and Wang (1992). See also Zhang (1994) on the relationship between *fēng-shuǐ* and its application to GIS.

2.2　Modules

The late Chinese architectural historian, Professor Liang, Ssu-ch'eng (A.D. 1901-72), has characterized Chinese architecture compositionally as having three main parts: the raised platform, body (or structure), and roof (Liang, 1984: 8).

Chinese traditional dwellings, mainly, comprise two types of buildings, arranged orthogonally to the other, which I have termed the *main* and *secondary* buildings. Main buildings are placed transversely to the orientation. The spatial organization and planning of these buildings centers around the concept of a '*jiān*' (bay). This involves the use of a *jiān*, the basic area unit in a building, as a standard which may be expanded or repeated to form either individual buildings or groups of buildings.[13] The *jiān* is a rectangular space (or room) which may be enclosed by walls, or defined by columns that separate it from its adjacent spaces (or rooms). The *jiān* can be extended to form a building by extending the *jiān* along a vertical or horizontal axis. See Figure 2.6. Buildings can be grouped around courtyards to form different types of building combinations.

---

13. The concept of the *jiān* appears to date back to the *Shāng* dynasty. In excavations at *Yīn-xū*, the *Shāng* capital at *Ān-yáng*, over ten buildings having rectangular foundations were discovered. On the foundations, laid out in straight lines and set at equal intervals, were bases for columns made of large, round stones bearing copper plates. Wood ash was found on copper plates, some of which were carved in a thunder-and-cloud design. The excavations at *Ān-yáng* proved that during the *Shāng* dynasty, both *jiān* and wood framing were used in building construction. The findings also indicate the beginning of standardization in building construction (Liu, 1989: 27).
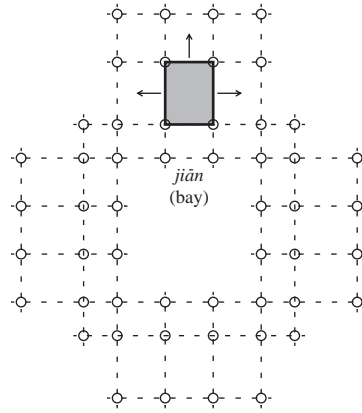
Figure 2.6. *Jiān*, the unit of spatial organization. (Redrawn after Liu, 1989: 28)

In traditional dwellings a main building has, at a minimum, three *jiān*'s.[14] Typically, each space in a main building has a unique name: the central space is *míng* (meaning light), the two rooms next to *míng* are *cì* (meaning secondary), the rooms next to *cì* are *shāo* (meaning tip or end), and the rooms next to *shāo* are *jìn* (meaning finished). See Figure 2.7. The widths of each *jiān* are not necessarily equal. In general, *míng* is at least as wide as *cì*, which in turn is at least as wide as *shāo*, which is at least as wide as *jìn*. The *míng jiān* is thus the spatial unit by which the width of a building was determined.

jìn (finished)	*shāo* (tip / end)	*cì* (secondary)	*míng* (light)	*cì* (secondary)	*shāo* (tip / end)	*jìn* (finished)
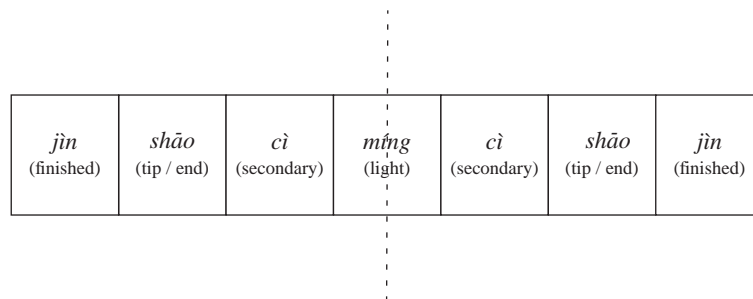
Figure 2.7. Terminology for a typical *táng-wū* (*zhèng-shēn*).

---

14. The traditional street house (*jiē-wū*), in general, had only a single *jiān* (bay).

Apart from a few exceptions, most main buildings have an odd number of *jiān*'s (bays) and number between one and nine, and never exceed eleven. Typically, nine and [on the very few occasions] eleven bays were reserved for the imperial palace.[15] There are three possible explanations why main buildings have an odd number of bays.

Firstly, most main buildings are bilaterally symmetric, and the central room (*míng*) is located on the axis of symmetry. Secondly, the Chinese believe(d) that odd is *yáng* and even is *yīn*. Thirdly, in the *Lǔ-bān-jīng* (Wu, 1986; Ruitenbeek, 1996)[16], it was defined that a building with three, five, seven or nine rooms was considered fortunate, but with one, two, four and six rooms were not.

'*Jià*,' literally meaning purlin, is the unit by which the depth of a *jiān* (and/or building) is determined. In general, most traditional buildings have an odd number of *jià*'s.[17]

In ancient China, a building's *jiān* and *jià* indicated its owner's social or political status. Table 2.2 illustrates typical values for building *jiān*'s and *jià*'s for different ranks of 'officers'[18] stipulated by the regulations during the *Qīng* dynasty (Lin, 1990: 33). For houses for common people, these values could not exceed three *jiān*'s, and in the case of temples and palaces, nine and eleven respectively (Knapp, 1990: 27).

By the *Táng* dynasty (A.D. 618-907), the Chinese had developed a modular construction system with cross-sectional measurements for each timber

---

15. Nine was considered as the limit of nature's numbers. In China, nine *jiān*'s traditionally implied a building belonging to the emperor. However, in Taiwan, there are traditional buildings with nine *jiān*'s. In the case of houses, these were mansions owned by individuals of privilege and status.

16. *Lǔ-bān* is regarded the 'first' carpenter of China and is credited with the invention of the system of measurement, described in the *Lǔ-bān-jīng*, upon which the fortunate (basic) measurements of traditional buildings were determined. See Section 3.4.

17. In the *Qīng* dynasty, a purlin (*lǐn*) was a *jià*; however, during the *Sòng* dynasty, the distance between two purlins was called a '*bù-jià*' (or step of purlins). If we assume that each step is equivalent among the different buildings, those with larger number of *jià*'s, clearly, have greater depth.

18. The (civil) officers' hierarchy was called '*pǐn*' and subdivided into seven ranks, numbered from one to nine. A mayor was usually a seventh *pǐn*.

Officer Hierarchy	Entrance Hall[a]	Principal Building[b]
dukes, princes, 1st and 2nd *pǐn*	3 *jiān*, 5 *jià*	7 *jiān*, 9 *jià*
3rd to 5th *pǐn*	3 *jiān*, 3 *jià*	5 *jiān*, 7 *jià*
6th to 9th *pǐn*	1 *jiān*, 3 *jià*	[3 *jiān*, 5 *jià*]

Table 2.2. Building *jiān*'s and *jià*'s during the *Qīng* dynasty.

a. The front-most main building which the *míng jiān* served as entrance.
b. The rear-most main building where the altar was usually located.

calculated for the desired width and depth of the *jiān* (Steinhardt, 1984). During the *Sòng* dynasty, instructions became much more precise and were recorded in the *Yíng-zào Fǎ-shì* [*Building Standards*, A.D. 1103].[19] According to Liang (1984: 16), "Ts'ai [*cái*], the standard timber for all construction, is graded into 8 classes. The depth of each ts'ai [*cái*] is divided into 15 fens [*fēn*'s]; 10 fens [*fēn*'s] gives the thickness of ts'ai [*cái*]. The proportion of every part of the building is thus measured in terms of the fen [*fēn*]." See Figure 2.8. In general, the nature of the building –house, temple, government office, official
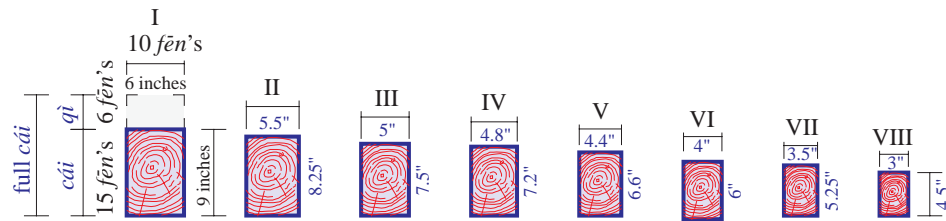
Figure 2.8. *Cái* and *fēn*. (Redrawn after Liang, 1984: 16)

19. The *Building Standards* was compiled by *Lǐ, Jiè*, superintendent of construction at the court of Emperor *Huī-zōng* (A.D. 1101-1125)of the *Sòng* dynasty. The first thirteen chapters describe the design of foundations, fortifications, stone masonry and ornamental carving, major carpentry, minor carpentry, masonry, and painted decoration. The next seventeen chapters contains definitions of terms and data for estimating the materials and labor. The last four chapters give drawings illustrating various kinds of designs in carpentry, stonework, and ornamental painting.
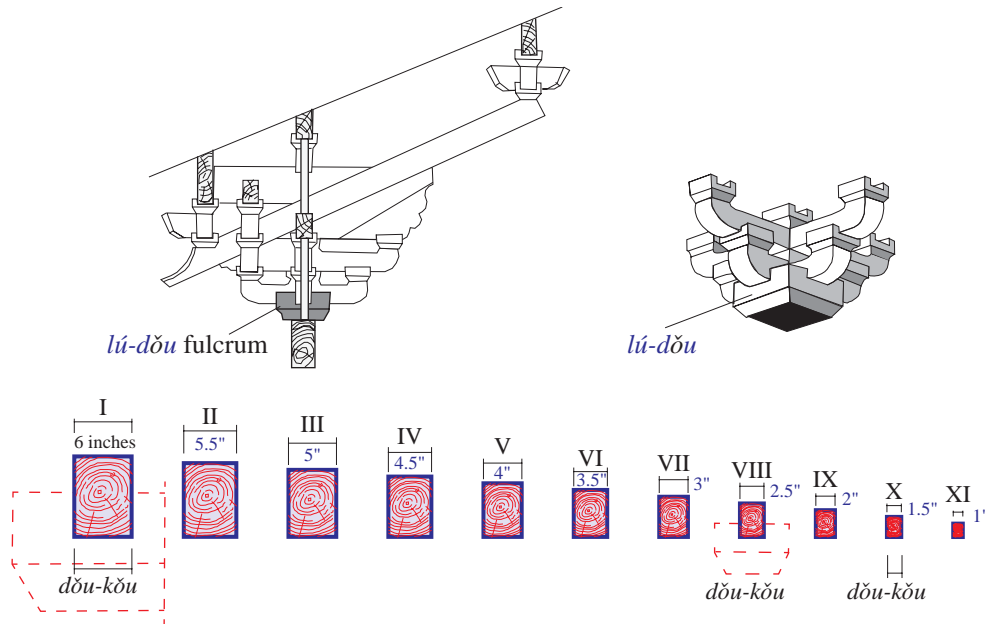
Figure 2.9. *Lú-dǒu* and *dǒu-kǒu*. (Redrawn after Liang, 1984: 13 & 19)

building (*yá-shǔ* or *yá-mén*) or palace – and its dimensional scale expressed by the number of *jiān*'s and *jià*'s would suffice in determining the necessary grade of *cái*. The width, depth, height of the building, the dimensions of every structural members, the rise and curve of the roof line would then all be measured in terms of the *fēn* of the grade of *cái* used.

During the *Qīng* dynasty, another modular system, *dǒu-kǒu*[20], was invented. According to the first chapter of *Gōng-bù Gōng-chéng Zuò-fǎ Zé-lì* [*Structural Regulations*, A.D. 1734][21], "The width and depth are determined by the collection of bearing blocks (*dǒu*) called *zǎn*. A *zǎn* equals eleven times the size of *dǒu-kǒu*." That is, given the size of *dǒu-kǒu*, say *a*, we have:

---

20. Literally, "block mouth." In an intercolumnar *dǒu-gǒng* (eaves brackets or bracket set), *dǒu-kǒu* is the opening in the *lú-dǒu* (the principal bearing block and lowest in a *dǒu-gǒng*) to receive the *gǒng* (bracket arm, a bow-shaped timber set in a bearing block that supports smaller blocks at each upraised end and at its center). Its width was the basic module in the *Qīng* dynasty. A *dǒu-kǒu* equals the width of the *gǒng*. In the *Sòng* dynasty, the width of the opening equals the thickness of the timber and equals 10 *fēn*'s. See Figure 2.9.

$z\check{a}n = 11 \times a$;

width of *míng* [*jiān*] (w_1) = $7 \times z\check{a}n = 77 \times a$;

width of *cì* [*jiān*] (w_2) = $6 \times z\check{a}n = 66 \times a$;

width of *shāo* [*jiān*] (w_3) = w_2 or $5 \times z\check{a}n = 55 \times a$.

Consequently, every detail and measurement of a building can be determined by the width of *dǒu-kǒu*.

2.3   Axial Planning

The symmetrical and orthogonal structuring of the plan and elevation was almost certainly intended as a direct representation of the Chinese cosmos. Unlike Western axial planning, the Chinese placed all main buildings and courtyards along a longitudinal axis or path in a strictly orthogonal fashion. The main buildings are separated from each other by a courtyard which functions not only as an area of traffic between buildings, but also as a place for outdoor activities. The courtyard was considered to be a major space in composition where many (important) rituals took place. It was thus regarded as an extension or addition to the buildings (Liu, 1989; Steinhardt, 1984).

The longitudinal axis is considered to be the major axis along which the main buildings are placed. See Figure 2.10. This axis also indicates the orientation of a group of buildings made up of a main building and several secondary buildings. Each building group may have precisely one courtyard; an entire dwelling though may be formed by several such courtyard groups. Each such courtyard group is called a *jìn* (or *luò*, enclosure). The front-most main building is the first *jìn*. The rear-most main building or the last *jìn* is

---

21. The *Structural Regulations* was published in A.D. 1734 by the Ministry of Construction of the *Qīng* dynasty. The first twenty-seven chapters are rules for constructing twenty-seven building types, such as halls, city gates, residences, barns, and pavilions. In the *Building Standards*, for each building type it gives general rules and ratios for designing and computation, but in the *Structural Regulations*, it detailedly specifies each building type even though the size of each structural member. The next thirteen chapters specify the dimensions of each kind of bracket sets and the sequence of assembling them. Seven chapters describe minor carpentry (doors, windows, partitions, and screens) and masonry (stone, brick, and earth). The last twenty-four chapters are rules for estimating the materials and labor.

referred to hereafter as the *principal building.* In the Southern style of Chinese traditional architecture as typified by Taiwanese traditional houses (see Section 4.1), one or two *jìn*'s were most popular; any dwelling with more than three *jìn*'s was considered to be a mansion or great house. There is a saying in Taiwan to describe one's dream of a great house, "大厝九包五，三落百二門。A mansion is nine embodying five, three *luò*'s (*jìn*'s), one hundred and twenty doors."[22]

The (secondary) buildings are placed on axes called *lù* (route), which are parallel to the major axis.[23] Some researchers treat the courtyards along the
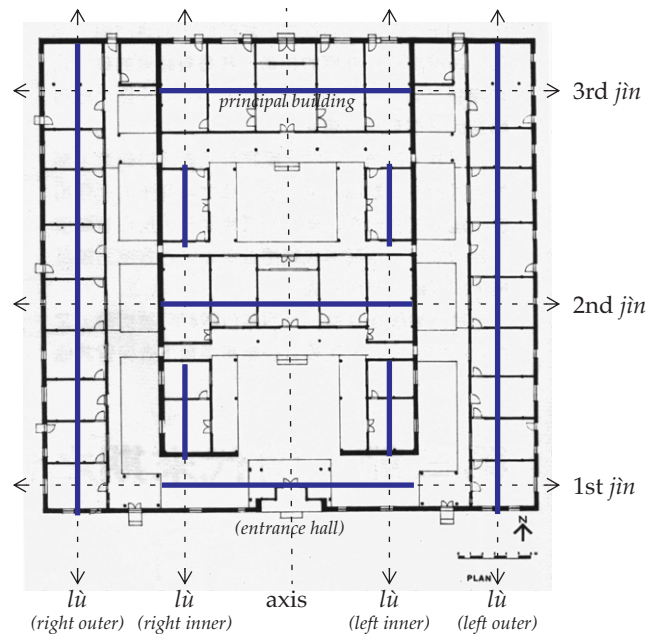
Figure 2.10. *Jìn* (enclosure) and *lù* (route). (After Lee, 1980: 180)

---

22. "Nine embodying five" has two interpretations. One interpretation is the last *jìn* (rear-most main building) has nine rooms (*jiān*) and the first one (front-most main building) has five rooms. Another interpretation is the last *jìn* has nine rooms and its outermost secondary buildings have five rooms each.

23. Some refer to *luò* as *táng* (hall) and *lù* as *héng* (transverse). Therefore, the simplest enclosure-courtyard, *sān-hé-yuàn*, a horseshoe (inverted U shape) is made up of a single *táng* (hall) and two *héng*'s (transverses).

main axis as the *zhōng-lù* or central route (Steinhardt, 1984: 14); however, this seems redundant. In each courtyard, the main building is the place of honor; in each large complex, the main axis is the most honored, and along each route, the principal courtyard ranks the highest. Usage is allocated according to seniority and rank, related closely to the prevailing family hierarchial system and social order (Steinhardt, 1984: 14). There are three basic arrangements used in Chinese axial planning. See Figure 2.11.
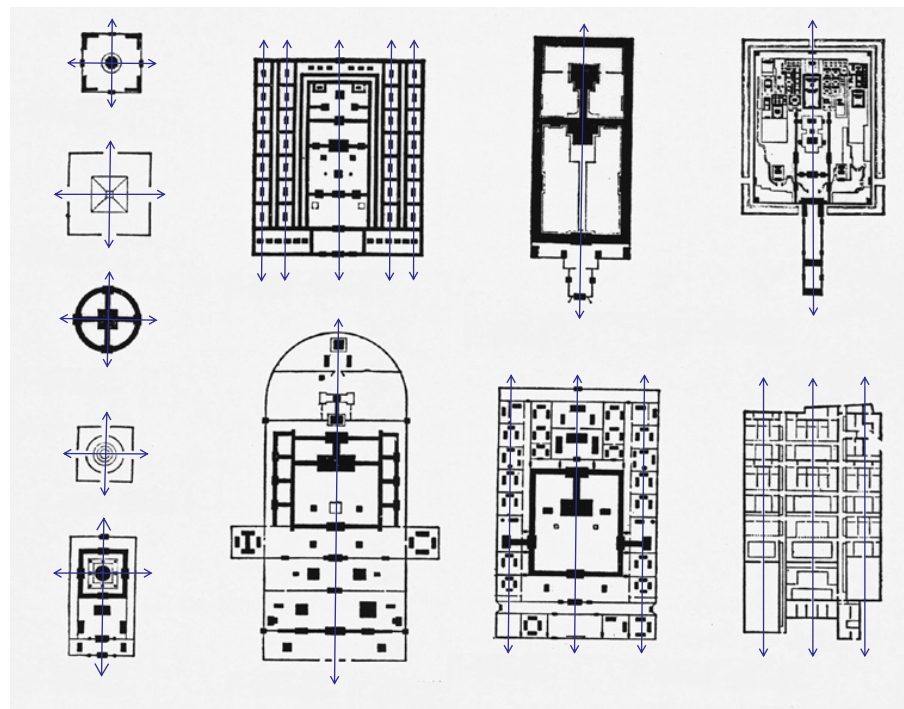
Figure 2.11. Axial planning and spatial organization. (After Liu, 1990: 13)

I.   *Central axis*

This is the most common form of arrangement where a main building [or the principal building] is placed symmetrically about the major axis. Secondary buildings are located to the left and right of this main structure, and main buildings in front and to the back of it. As a result, one or more

hé-yuàn's, horseshoe shaped enclosure courtyards, are formed. Sometimes another main building might be located to the front-most courtyard, allowing an enclosed courtyard to be formed by four buildings and the walls that connect them.[24] The most basic Chinese courtyard forms are grouped in this manner.

A variation of this arrangement, *láng-yuàn* (or verandah-courtyard), is formed by the same layout, in which the main building is placed symmetrically about the major axis with two secondary buildings to its right and left, but with covered verandahs instead of connecting these buildings directly to the main building. This composition was widely used in China beginning with the *Hàn* dynasty and endured until the *Táng* and *Sòng* dynasties. After the *Sòng* dynasty, very few structures were built using this form (Liu, 1989: 28). However, it is still one of the typical layouts for Taiwanese traditional temples.

II.   *Parallel axes*

When more rooms were needed, minor longitudinal axes are established parallel to the main axis. Thus, instead of one longitudinal extension, more than two groups of buildings were established. In order to have transport facilities and fire prevention, there were paths between each group. This type of extension was developed, during the *Táng* dynasty, for palaces, temples, official buildings, and large complex houses.

III.   *Central-building layout (double symmetrical layout)*

This type of arrangement is popular for the layout of monuments, especially after the *Hàn* dynasty. The composition, based upon perpendicular axes, places the main building at the intersection of the main and minor axes. The whole group is surrounded on all sides by minor buildings, verandahs, and other buildings to form a square or circular layout. In this way, a building group is symmetrical along both the longitudinal and latitudinal (or horizontal) axes. The Altars of Heaven (*Tiān-tán*) of the *Míng* dynasty (A.D. 1368–1644) is an example of this type of spatial planning.

---

24.   If all of the main openings faced the courtyard, it was referred to as a *sì-hé-yuàn*; otherwise, it was a *sān-hé-yuàn*. The front-most main building in a *sì-hé-yuàn* was called *dǎo-zuò* (inverted seat).

2.4 Framework

In most regions, Chinese traditional architecture relied upon wood-frame construction. Brick and stone structures were not widely adopted. The reader is referred to the literature (see for example, Needham, 1971: 65-66, and Liu, 1989: 29-30) for possible explanations on why wood construction became mainstream in Chinese traditional architecture.
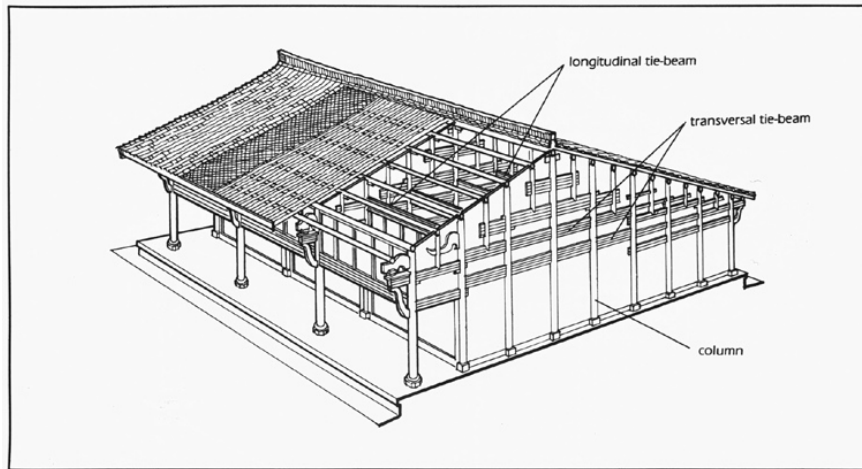
Figure 2.12. *Chuān-dǒu* wood framing system. (After Steinhardt, 1984: 12)

There were two main types of wood framing systems: *chuān-dǒu* (column-and-tie system) and *tái-liáng* (column-beam-and-strut system). *Chuān-dǒu* is the most common for dwellings in which the pillars and transverse beams are tied together (see Figure 2.12). *Tái-liáng* is a pillar-and-beam construction in which two pillars are posted onto the transverse beam directly (see Figure 2.13). *Tái-liáng* is popular in temples and palaces.

Dié-dǒu is another wood framing system similar to the *tái-liáng*, but with the transverse beam posted onto the *dǒu-gǒng*'s (eaves brackets or bracket set) which are on the top of the pillars. *Dié-dǒu* (see Figure 2.14) is more decorative than *tái-liáng*. Other minor wood framing systems such as *jǐng-gàn* and *mì-liáng píng-dǐng* (purlin-and-rafter flat roof type) are not that important to mainstream Chinese traditional architecture.

1. Architrave
2. Longitudinal tie-beam
3. Rafter
4. Purlin
5. Strut
6. Transversal tie-beam
7. Beam
8. Column
9. Bay
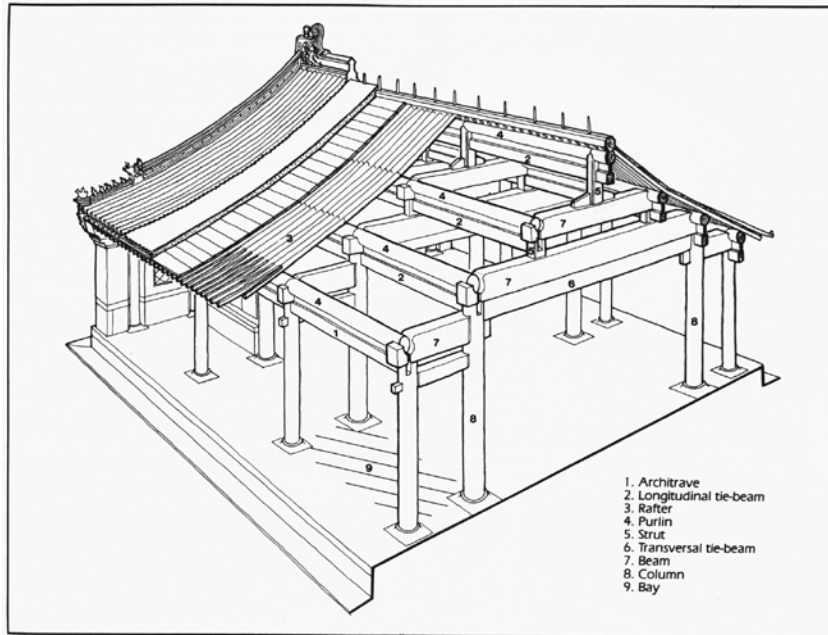
Figure 2.13. *Tái-liáng* wood framing system. (After Steinhardt, 1984: 11)

Figure 2.14. *Dié-dǒu* wood framing system. (After Lin, 1990: 64)

The *chuān-dǒu* and *tái-liáng* are used in traditional buildings with gabled roofs. The *tái-liáng* style, widespread in central, northern, northwestern, and northeastern China, is the most popular. The *chuān-dǒu* type is prevalent in eastern, southern, and southwestern China; however, even in these regions, important Buddhist and Taoist monastery halls as well as private and official residences are generally built in the *tái-liáng* method (Steinhardt, 1984: 11).

Several researchers (for example, Needham, 1971; Steinhardt, 1984; Liu, 1990; Wong and Chung, 1986) have observed a number of important architectural features found in Chinese traditional buildings (see Figure 2.15) that resulted from (or were facilitated by) the use of wood frame construction.

- The structure is divided into three identifiable parts: platform, body (the building proper), and roof.
- Roofs have concave surfaces with corners that curve upwards.
- The use of *dǒu-gǒng* (bracket set).
- The concept of *jiān* as a unit in a modular system of designing and planning. The column grids can be varied, allowing omission or shift of column supports. Other parameters such as the width of the bays and the height of the floor can also be varied to satisfy diverse functional demands.
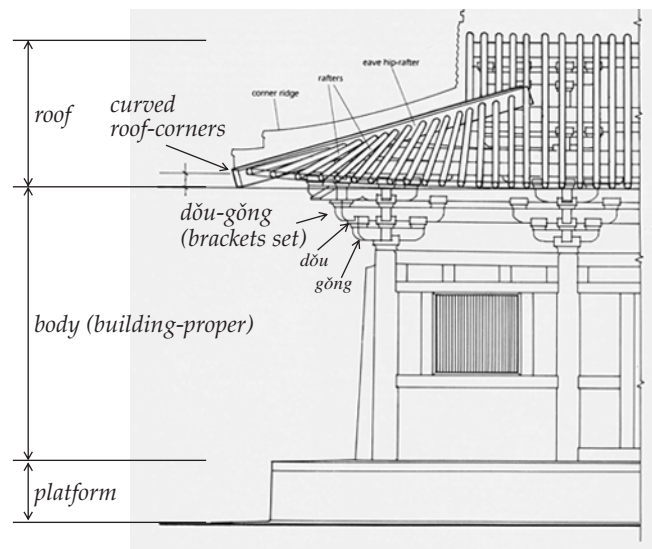
Figure 2.15. An elevation of a Chinese traditional building. (After Steinhardt, 1984: 17)

- The ease with which interior spaces can be divided.
- Paintings and color decorations (which are important aspects of Chinese traditional architecture).
- The flexibility of the structure to adapt to different climates.
- The reduction in damage due to earthquakes.
- The ease of material support.

2.5   Spatial Organization and Basic Design/Construction Process

Apart from some regions inhabited by minority nationalities, there are few examples of large single traditional buildings composed of rooms for multiple uses; typically, a single story dwelling arranged around a private courtyard prevails (Steinhardt, 1984: 14). This is known as a *hé-yuàn* (enclosure-courtyard). Traditionally, in a *hé-yuàn* the spaces bordering the enclosure have openings facing the courtyard. The axis of symmetry bisects the main central hall. All of the other spaces are developed through this central hall. Starting with the main building (*táng-wū*, also referred to as *tīng-táng*) which includes the hall, two secondary buildings (*xiāng-fáng*'s) are generated. These two secondary buildings are also basic elements of the *hé-yuàn*. It is clear that a traditional building is the combination of several *hé-yuàn*'s.

According to the literature and practice (based on field studies and information from artisans), a traditional building was planned or designed, in general, by the following process.[25]

2.5.1   Checking the site, and deciding upon the orientation and axes

Deciding upon a fortunate orientation was always the first step in the traditional design process; here, *fēng-shuǐ* played an important role. The owner would consult a geomancer[26] to check the site before the start of design and construction. The geomancer when checking the site would also

---

25. The process described here pertains to Taiwanese traditional architecture; however, there is no reason to suppose that Chinese traditional architecture did not adopt similar processes.

decide upon the orientation that best suited the owner. Typically, the geomancer would mark two points on the site. One located the central hall (*míng*) of the principal building in which the altar would be; the other located the front of the intended building layout. These two marks indicated the main axis and orientation.

In this stage, the 'master' artisan would decide upon the general layout and style, e.g., the numbers of *jìn*'s (enclosures), *lù*'s (routes), *jiān*'s (bays), and so on. This information would help the master artisan to 'design' the whole building.[27]

2.5.2 Determining the measurements of the hall (central room)

The next step was to decide upon the module and the dimensions for the height, width, and depth of the *míng jiān* (central bay or central room). The master artisan might even have followed *chǐ-bái/cùn-bái* and used the corresponding procedures described in Section 3.4.2 to compute the basic measurements for the central space.

2.5.3 Designing the main frames

The artisan usually drew a sketch of the longitudinal frames (which might include the partitions between *míng* and *cì*) of the central room. According to this sketch, the artisan made a special construction ruler (*zhàng-gāo* or *gāo-chǐ*)[28] – a stick – and marked all the details on it. Using this ruler, the artisan could design the whole building. He could also then determine how much material was needed for construction.

---

26. A geomancer could be a skilled professional with extensive knowledge of geomancy, an artisan who had learned geomancy through practice, or a god (as interpreted through a priest or spirit writing, *jī-tóng* or *fú-luán*). It was common for a god to decide his/her own temple site, orientation, artisans, and design details.

27. The master artisan (or foreman of the carpenters) was not solely hired for his technical ability but also for his honesty and reliability. The design of a traditional building was a collaborative effort by the owner and master artisan in that the customs, taboos, and fortunes of the owner played a considerable role.

28. The construction ruler (*gāo-chǐ*) was different for each building. It was analogous to a set of working drawings. In fact, artisans did not produce construction drawings. The artisan marked all the measurements for the buildings on this ruler. No one other than the artisan could understand the marks.

There were a number of issues that the artisan would have dealt with.

Yīn-yáng-biān

The roof has two parts: the *yáng* side (front roof eaves) which is higher than the *yīn* side (rear roof). In traditional architecture, the slopes of the front and rear sides of the roof, in general, were the same; as the result, the main beam was positioned 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* (or *yīn-yáng-pō*; literally, *biān* or *pō* means side or boundary). See Figure 2.16. In Taiwanese traditional houses, the pitch of the roof is approximately 0.35 (33% – 40%) and the horizontal difference between the *yīn* side and the *yáng* side is 4 to 12 *Lu Ban* inches[29] (Chiou, 1990: 117-119). In general, the pitch of the roof for temples is steeper than for houses. It was believed that a temple with steep roofs bestowed prosperity, but steep roofs for a house would drain money away and leave the owner poorer.

Figure 2.16. *Yīn-yáng-biān*. (After Lin, 1990: 96)

---

29. A *Lu Ban* foot measures approximately 29.69 cms. There are 10 *Lu Ban* inches to a *Lu Ban* foot (see Section 3.4.1).

Curving the roof

The roofs of Chinese traditional buildings were not straight, but curved. The method of curving a roof is termed, in the *Building Standards* as *jǔ-zhé* ("raise-depression"), and in the *Structural Regulations* as *jǔ-jià* ("raising the frame"). The two structures, although resulting in more or less similar forms, are quite distinct in their basic concepts. The two structures are described below.

    I.   *The jǔ-zhé structure*

This method to implement a *jǔ-zhé* is known as *zhé-wū*, literally, "bending the roof," which is described by following algorithm. The procedure is illustrated in Figure 2.17.

There are three steps.

Step 1: Determining the "rise" of the ridge

The height of the rise is called *jǔ-gāo* (*R*). *R* varies from one-fourth to one-third of the distance between the front and rear eave purlins (*B*). [The
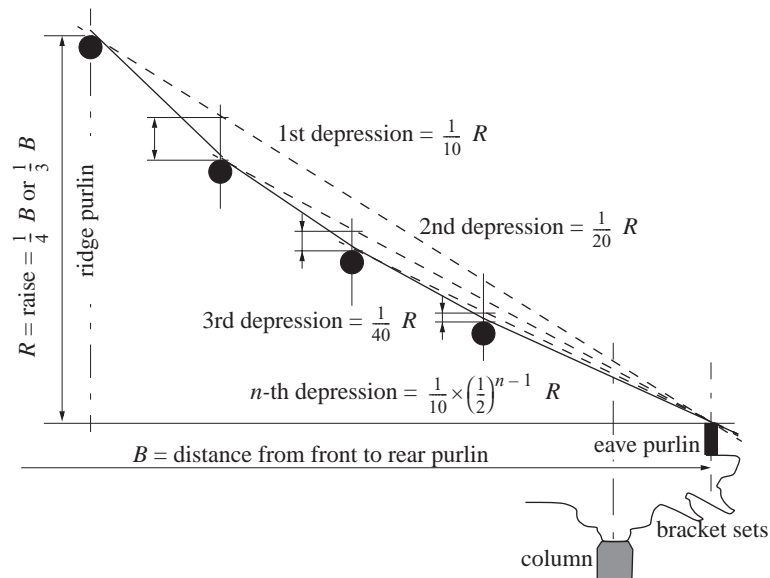
Figure 2.17. The rise and depression (from the *Building Standards*).

arrangement of the purlins are considered in the sequel.] This variation depends on the type and size of building. Thus, the slope of the roof varies from 0.5, for a small house, to 0.6$\overline{6}$, for a large hall. The curvature of the rafters are determined by a series of "depressions."

Step 2: Determining the position of the first purlin

A straight line is drawn from the ridge to the eave purlin. The first purlin is lowered in position by one-tenth of the height of the rise (*R*) off the straight line.

Step 3: Determining the position of the n-th purlin

A straight line is drawn from the most recently positioned purlin to the eave purlin, and the next purlin is lowered by half the amount of the previous depression off this new straight line.

Step 3 is repeated until all the purlins have positioned.

Thus, the second purlin is depressed by one-twentieth of the rise *R.*

In general, for the *n*-th purlin, the depression equals $\frac{1}{10} \times \left(\frac{1}{2}\right)^{n-1} \cdot R$

In this manner, the pitch and curvature of the roof is determined.

II.   *The jǔ-jià structure*

This structure was developed in the *Qīng* dynasty and its constructions defers from *jǔ-zhé* structure developed in the *Sòng* dynasty in the following manner. In the *Sòng* structure, the height of the ridge purlin is predetermined, and the curvature of the roof is determined by lowering successive purlins. However, the *Qīng* builders started from the bottom by determining the height of each purlin until eventually the height of the ridge purlin is determined. This method is illustrated in Figure 2.18.

The pitch of each section of the rafter is increased from the eave purlin upwards to the ridge purlin by gradations of between 0.5 and 0.9. Suppose the first step, *bù-jià* (that is, the distance between the two lowest purlins) be *x*. Then, the first 'rise' is 0.5*x*. The next rise for the second step is steeper than the first one. Eventually, the top section is completed by the addition of four *dǒu-kǒu*'s (called *píng-shuǐ*) to make a near vertical slope for the ridge purlin.
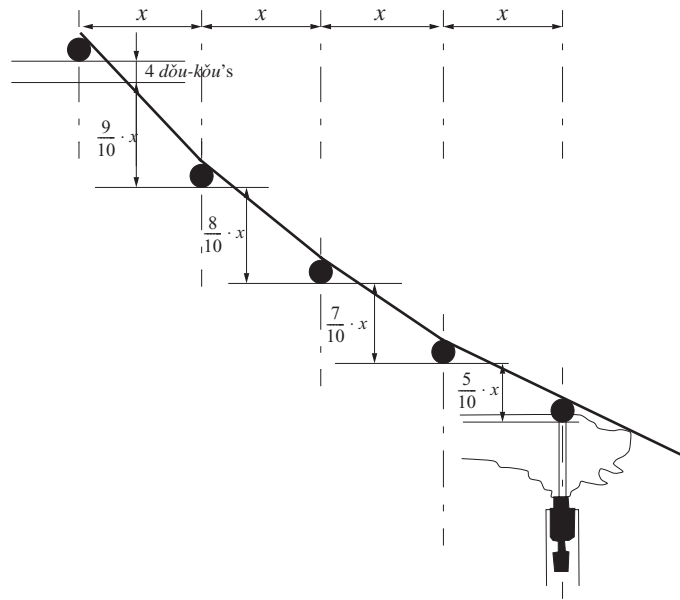
Figure 2.18. "Raising the frame" (from the *Structural Regulations*).

One may notice that the curved roofs of buildings from the *Qīng* dynasty are much steeper than those of the *Sòng* dynasty.

The arrangement of jià

The number of *jià*'s had to be odd.[30] There are four possible ways of arranging the *jià*'s (purlins). See Figure 2.19.

(i) The steps (*bù-jià*'s) were equivalent on each roof side, that is, $f_1 = f_2 = f_3$; $r_1 = r_2 = r_3$.

---

30. The number of *jià*'s, generally, was determined by the depth of the central room, or by the regulations. In Taiwanese traditional houses, it was common for the main building to have nine to thirteen *jià*'s, and each *bù-jià* (step) was approximately 2–2.5 *Lu Ban* feet. [One may find that the number of *jià*'s in Taiwanese traditional architecture exceeded the regulations. One reason for the smaller *bù-jià*, as compared to Chinese traditional architecture, was that longer timbers were not so easily obtained in Taiwan.]
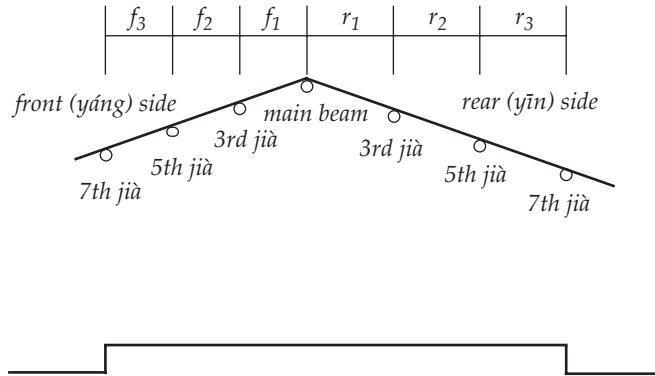
Figure 2.19. The arrangement of *jià*.

(ii) The nearer the step to the main beam, the greater its length, that is, $f_1 > f_2 > f_3$; $r_1 > r_2 > r_3$.

(iii) Corresponding steps on both sides of the roof were equivalent, that is, $f_1 = r_1$; $f_2 = r_2$; $f_3 = r_3$.

(iv) Corresponding steps on the rear side were greater than those on the front side, that is, $r_1 > f_1$; $r_2 > f_2$; $r_3 > f_3$.

Taboos on jià

There were two general taboos on the arrangement of purlins.

(i) The front-most step (e.g., f_3 in Figure 2.19) must be greater than the width of the door. In other words, there was no purlin above the trace of the door opening.

(ii) The rear-most step (r_3 in Figure 2.19) must be greater than the depth of the altar. That is, there was no purlin above the altar.

Sān-hé

Sān-hé is a restriction on the relationship between the main beam, light beam[31], and main entrance. Basically, this restriction constrains the position of the light beam and the height of the main entrance. See Figure 2.20.

In Taiwanese traditional architecture, the main beam and light beam are two holy dominants that have special meaning. 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*.[32] In addition to the *sān-hé*, there was one other restriction (taboo) on the positioning of the light beam. It was believed by some that the light beam could not be placed directly under a purlin, that is, it had to lie within a step (*bù-jià*).

In order to sketch details of the main frame, the artisan also had to decide on the framing system: *chuān-dǒu* or *tái-liáng*. He could then arrange the
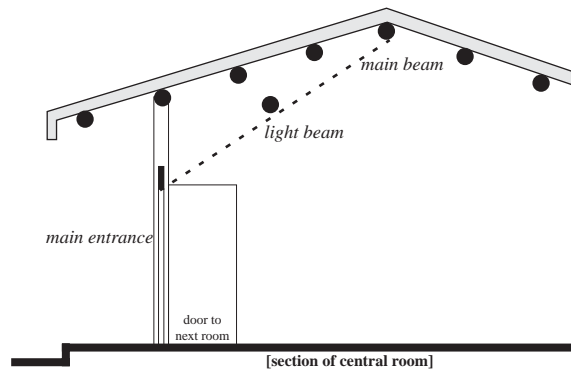
Figure 2.20. *Sān-hé*: The relation among main beam, light beam, and main entrance.

31. In Taiwanese, the pronunciation for light and boy, *dīng*, is the same. The light beam is treated as the demarcation between gods and ghosts in a house. The Taiwanese believed that the proper positioning of the light beam was important for the birth of a boy in the house.

32. 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),

道生一，一生二，二生三，三生萬物。萬物負陰而抱陽，沖氣以為和。

"Tao (*dào*) 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*)."

columns, struts, pillars, and ties (traverse beams). Generally, in Taiwanese traditional houses, the framing system *chuān-dǒu* was employed and in temples, *tái-liáng*.

2.5.4 Extending the hall to form a main building

According to the measurements of the central *jiān*, the main building could be extended by adding two more *jiān*'s to the central *jiān* laterally till the total number of *jiān* in the main building was equal to the intended *jiān*'s. Usually the width of each added *jiān* was less than the central *jiān*. The dimensions of the added rooms usually satisfied the following constraints.

(i)   Each *jiān* was no wider than the central *jiān*. The width of the chamber was between 0.8 to 0.9 times that of the *míng jiān*. Typical values for the width were between 9 and 11 *Lu Ban* feet. The width of the end room was usually equal to *míng jiān*. Table 2.3 shows a statistics of typical proportions of room widths.

(ii) With the exception of the *míng jiān*, the height of each *jiān* was determined by the adjustments on the roof which lifts up and drops

Type	*jìn* and *lù*	Cases	*cì* : *míng*	*shāo* : *cì*	*jìn* : *shāo*	*shāo* : *míng*	*jìn* : *míng*	*jìn* : *cì*
7 *jiān*'s	1 *jìn*	6	0.77	1.23	0.94	0.95	0.98	1.16
	1 *jìn* 2 *lù*'s	9	0.69	1.20	0.85	0.83	0.70	1.02
	1 *jìn* 3 *lù*'s	2	0.70	1.23	0.85	0.86	0.73	1.05
	1 *jìn* 4 *lù*'s	5	0.68	1.08	0.90	0.73	0.66	0.97
	1 *jìn* 5 *lù*'s	1	0.78	1.03	0.81	0.80	0.65	0.83
	2 *jìn*'s 2 *lù*'s	1	0.58	1.02	1.28	0.59	0.76	1.31
5 *jiān*'s	1 *jìn*	2	0.82	1.14		0.93		
	1 *jìn* 2 *lù*'s	5	0.69	1.22		0.84		
	1 *jìn* 3 *lù*'s	1	0.67	1.46		0.98		
Average			0.71	1.19	0.90	0.84	0.77	1.01

Table 2.3.   The proportions of the room widths in a main building, *Xīn-pú*, Taiwan.
(Source: Chiou 1990: 80)

down. Typically, the roof drops down at the fifth and ninth *jiān*'s, and lifts up at the third and seventh *jiān*'s. The lift and drop depends on the type of roof type selected. Figure 2.21 illustrates the roof form of a main building with five *jiān*'s.

Figure 2.21. The roof form of a main building with five *jiān*'s. (After Lee, 1980: 198)

2.5.5 Extending the main building group by adding a courtyard and/ or secondary buildings to form an enclosure-courtyard

We describe the organization of a *sān-hé-yuàn*.

(i) The addition of a courtyard was based on the axis. Typically, its width and depth were an odd number of strides (*bù*). A stride measures about 45 *Lu Ban* inches (or 1.336 m, see Section 3.4.1). The depth of a courtyard is between seven and eleven strides. In fact, the depth and the number of *jiān*'s of the secondary buildings that enclose the courtyard influence each other. A courtyard that is seven strides deep (31.5 *Lu Ban* feet) is enclosed by secondary buildings with three *jiān*'s.

(ii) A secondary building generally had two fewer *jiān*'s than its main building. Thus, for a main building with five *jiān*'s, the secondary building had two or three *jiān*'s; with seven *jiān*'s, the secondary had three or five *jiān*'s; and with nine *jiān*'s, the secondary building had five or seven *jiān*'s.

(iii) In general, the measurements of each *jiān* in a secondary building were smaller than corresponding measurements in its main building. The height of the secondary building depended on how its roof connected with the roof of the main building.

(iv) The depth of a secondary building was generally smaller than that of its main building; its number of *jià*'s was correspondingly less.

(v) The depth of a secondary building also depended on the width of the courtyard because the rear wall of the secondary building and the side wall of its main buildings were collinear. In addition, there was the following taboo, namely, that the drop line of the roof of a secondary building could not fall within the range of the opening of its main building.

(vi) There were two basic ways to connect the roofs of a secondary building and its main building. These are illustrated in Figure 2.22. In one instance, the roofs were separate, in the other the roof of the secondary building is extended to join the main building roof at its front third or fifth *jià*.

2.5.6 Extending the building groups

There are three ways to extend a building group into a larger building complex.

(A) Separate　　　　　**(B) Joined**
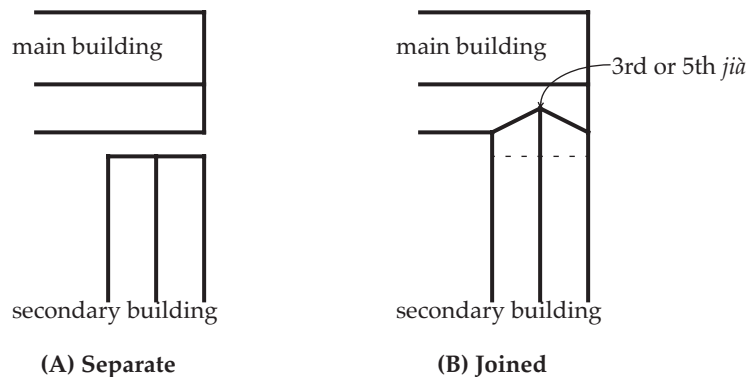
Figure 2.22. The connection between the roofs of a secondary building and its main building.

(i) *Longitudinal (or vertical) extensions.* The axis is extended and courtyards and building groups are placed alternatively along this axis, forming a series of building groups and courtyards. This type of longitudinal extension was first discovered in the palace remains of the *Shāng* dynasty.

(ii) *Latitudinal (or horizontal) extension.* New (outer secondary) buildings or building groups were added along axes parallel to the main axis.

(iii) *Two-way extensions.* As suggested, buildings complexes are extended along both the horizontal and vertical axes. The Forbidden City (*Zǐ-jìn-chéng* or Former Palace), from the *Míng* and *Qīng* dynasties, was extended in this manner.

In Taiwanese traditional architecture, a building complex was usually designed as a series of enclosure-courtyards. Subsequent extensions were lateral with symmetrical placed outer secondary buildings, the length of which did not exceed the original building group. These secondary buildings were connected to their building group through "passing rooms" (*guò-shuǐ*'s)[33] which were semi-open spaces with corridors.

Extensions were subject to the following two constraints.

(a) The dimensions of new main buildings were less than those of any existing main buildings. In other words, the rear-most *jìn* was always higher than any other building.

(b) Newly added secondary buildings were higher than any existing secondary buildings, but lower than the rear-most *jìn*.[34] It was believed that this form would protect the *qì* (life breath).

---

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

34. There are some extant traditional buildings that violate this constraint. On the whole, artisans believed that the outer secondary buildings had to be higher than inner ones.

Chapter 3:
Pre-Design Decisions in Chinese Traditional Architecture

> A calendar is only a method of combining days into periods suitable for civil life and religious or cultural observations. Some of its elements are based on those astronomical cycles which have obvious importance for man, such as the day, the month and the year; others are artificial, such as the week and the subdivisions of the day.
>
> Joseph Needham (1959: 390)

In Chinese traditional vernacular architecture, three important parameters of design – namely, the orientation of a site, a propitious date for start of construction, and the basic measurements of the main central spaces – were

derived from geomancy considerations and based on the Chinese calendar system.

3.1   The Chinese Calendar

Man has developed three basic calendars: the lunar calendar based on the phases of the moon; the solar calendar based on the apparent motion of the sun; and the lunisolar calendar. The ancient Chinese calendar was lunisolar (*yīn-yáng-lì*), and was based on the tropical year and lunar month. A tropical year measures 365.242199 days; the period of a lunar month – referred to as a *lunation* – is 29.5305879 days.

The ancient Chinese calendar was issued in the emperor's official name, became part of the ritual paraphernalia that signified his dynasty's right to rule. The imperial court was, therefore, the only proper place to apply astronomy. Officers of astronomy (i.e., calendar-makers) had two tasks: (i) to incorporate as many phenomena as possible in a correct calendar; and (ii) to observe unpredictable phenomena and interpret their political meanings so as to warm the emperor that there was something amiss in his realm, so that he could take appropriate administrative measures (Ropp, 1990: 173-174).

It has been estimated that at least 102 kinds of almanacs were known and used regularly in ancient China (*The New Encyclopedia Britannica*, Vol. 15, 1994: 426). However, calendar makers would have been punished, even put to death, for mistakes made in their almanacs. The ancient Chinese calendar depended on the location of the capital, and the emperor's decision on the starting day of a year or sexagesimal cycle.

After 1912, the Gregorian calendar[1] was adopted as the official calendar, although the *nóng-mín-lì* (farmer's or agricultural almanac) is also widely used. The farmer's almanac combines ancient Chinese *yīn-yáng-lì* (the

---

1.   The Gregorian calendar is used throughout much of the world today. It can be traced back to the Roman republican calendar, which is thought to have been introduced by the Etruscan Tarquinius Priscus (616–579 B.C.), the fifth king of Rome. A.D. 1582 was the first year of the Gregorian calendar; 10 days were to be dropped from the calendar of 1582, the day after Wednesday, October 4, 1582 (Julian calendar) become Thursday, October 15, 1582 (Gregorian calendar).

sexagesimal cycle), and general Chinese geomancy information into a single calendar (see Smith, 1992).

3.1.1 The Sexagesimal Cycle

The most ancient day-counting system in Chinese culture depended on the sexagesimal cyclical system. The *Shāng* Chinese counted days by combining the *celestial* or *heavenly stems* (*tiān-gān*) with ten elements, *jiǎ, yǐ, bǐng, dīng, wù, jǐ, gēng, xīn, rén,* and *guǐ,* and the *terrestrial* or *earthly branches* (*dì-zhī*) with twelve elements, *zǐ, chǒu, yín, mǎo, chén, sì, wǔ, wèi, shěn, yǒu, xū,* and *hài* into a system with a period of sixty elements. This day-counting system has been used for more than 3000 years. [Probably] around the year A.D. 2, during the *Hàn* dynasty, the sexagesimal cycle was adopted for counting years.

The sexagesimal cycle is shown in Table 3.1. For ease of presentation and explanation, we use the letters *A – J* to represent the celestial stems, and *a – l,* the terrestrial branches. As examples, the first element of the sexagesimal cycle, *jiǎ-zǐ,* is depicted as *A-a*; the next element, *yǐ-chǒu,* is symbolically *B-b*, and so on.

3.1.2 The Meteorological Cycle

In 1993, two American astronomers, Kevin D. Pang (Jet Propulsion Laboratory) and John A. Bangert (U.S. Naval Observatory), proved and announced that the Chinese calendar synchronized to March 5, 1953 B.C. (see *Sky & Telescope*, December, 1993). Evidence from the *Shāng* oracle bone inscriptions shows that, at least by the fourteen century B.C., the *Shāng* Chinese had established the solar year at 365.25 days and lunation at 29.53 days. Evidence also suggests that no later than the Spring and Autumn period (770-476 B.C.) of the Eastern *Zhōu* dynasty, the Chinese developed the Metonic cycle — i.e., 19 tropical years with a total of 235 lunations — about a century ahead of Meton's first calculation, around 432 B.C. (see Needham, 1959; *The New Encyclopedia Britannica*, Vol. 15, 1994: 425). During this cycle of 19 tropical years there were seven intercalations of the months. By the third century B.C., the meteorological cycle (*èr-shí-sì jié-qì*: twenty-four fortnightly periods) had been established. The twenty-four periods of the meteorological cycle are shown in Table 3.2.[2] Each period corresponds to a 15° motion of the

sun on the ecliptic.[3] It takes about 15.218 days for the sun to travel from one point to another, and 365.25 days to complete its journey in the cycle.

3.1.3   Resonance

In order to synchronize discrepancies between the tropical year and lunation, calendar-makers, in all cultures, have attached importance to certain 'resonance,' – for example, the Egyptian Sothic cycle, *octaëteris*, saros (eclipse

jiǎ	*yǐ*	*bǐng*	*dīng*	*wù*	*jǐ*	*gēng*	*xīn*	*rén*	*guǐ*
A	B	C	D	E	F	G	H	I	J

The celestial stems and their symbolic notation

zǐ	*chǒu*	*yín*	*mǎo*	*chén*	*sì*	*wǔ*	*wèi*	*shēn*	*yǒu*	*xū*	*hài*
a	b	c	d	e	f	g	h	i	j	k	l

The terrestrial branches and their symbolic notation

jiǎ-zǐ	*yǐ-chǒu*	*bǐng-yín*	*dīng-mǎo*	*wù-chén*	*jǐ-sì*	*gēng-wǔ*	*xīn-wèi*	*rén-shēn*	*guǐ-yǒu*
(A-a)	(B-b)	(C-c)	(D-d)	(E-e)	(F-f)	(G-g)	(H-h)	(I-i)	(J-j)
jiǎ-xū	*yǐ-hài*	*bǐng-zǐ*	*dīng-chǒu*	*wù-yín*	*jǐ-mǎo*	*gēng-chén*	*xīn-sì*	*rén-wǔ*	*guǐ-wèi*
(A-k)	(B-l)	(C-a)	(D-b)	(E-c)	(F-d)	(G-e)	(H-f)	(I-g)	(J-h)
jiǎ-shēn	*yǐ-yǒu*	*bǐng-xū*	*dīng-hài*	*wù-zǐ*	*jǐ-chǒu*	*gēng-yín*	*xīn-mǎo*	*rén-chén*	*guǐ-sì*
(A-i)	(B-j)	(C-k)	(D-l)	(E-a)	(F-b)	(G-c)	(H-d)	(I-e)	(J-f)
jiǎ-wǔ	*yǐ-wèi*	*bǐng-shēn*	*dīng-yǒu*	*wù-xū*	*jǐ-hài*	*gēng-zǐ*	*xīn-chǒu*	*rén-yín*	*guǐ-mǎo*
(A-g)	(B-h)	(C-i)	(D-j)	(E-k)	(F-l)	(G-a)	(H-b)	(I-c)	(J-d)
jiǎ-chén	*yǐ-sì*	*bǐng-wǔ*	*dīng-wèi*	*wù-shēn*	*jǐ-yǒu*	*gēng-xū*	*xīn-hài*	*rén-zǐ*	*guǐ-chǒu*
(A-e)	(B-f)	(C-g)	(D-h)	(E-i)	(F-j)	(G-k)	(H-l)	(I-a)	(J-b)
jiǎ-yín	*yǐ-mǎo*	*bǐng-chén*	*dīng-sì*	*wù-wǔ*	*jǐ-wèi*	*gēng-shēn*	*xīn-yǒu*	*rén-xū*	*guǐ-hài*
(A-c)	(B-d)	(C-e)	(D-f)	(E-g)	(F-h)	(G-i)	(H-j)	(I-k)	(J-l)

Table 3.1.   The sexagesimal cycle.

---

2.   For the meanings of each point, the reader is referred to Needham(1959: 402-406); Bredon and Mitrophanow (1966: 19-22); and Bodde (1991: 119-122). Bodde views these twenty-four periods as some kind of symmetric relation.

3.   The plane of Earth's yearly journey around the sun.

Period		Approximate starting date (in the solar calender)
Beginning of Spring	*lì-chūn*	February 5
Rains	*yǔ-shuǐ*	February 20
Awakening of Creatures [from hibernation]	*jīng-zhí*	March 7
Spring Equinox	*chūn-fēn*	March 22
Clear and Bright	*qīng-míng*	April 6
Grain Rain	*gǔ-yǔ*	April 21
Beginning of Summer	*lì-xià*	May 6
Lesser Fullness [of Grain]	*xiǎo-mǎn*	May 22
Grain in Ear	*máng-zhǒng*	June 7
Summer Solstice	*xià-zhì*	June 22
Lesser Heat	*xiǎo-shǔ*	July 8
Greater Heat	*dà-shǔ*	July 24
Beginning of Autumn	*lì-qīu*	August 8
End of Heat	*chù-shǔ*	August 24
White Dews	*bái-lù*	September 8
Autumn Equinox	*qīu-fēn*	September 24
Cold Dews	*hán-lù*	October 9
Descent of Hoar Frost	*shuāng-jiàng*	October 24
Beginning of Winter	*lì-dōng*	November 8
Lesser Snow	*xiǎo-xuě*	November 23
Greater Snow	*dà-xuě*	December 7
Winter Solstice	*dōng-zhì*	December 22
Lesser Cold	*xiǎo-hán*	January 6
Greater Cold	*dà-hán*	January 21

Table 3.2.   The twenty-four periods of the meteorological cycle.

cycle), the Metonic cycle, Callippic period, and the Julian period. In China, certain resonance periods have been introduced, for example, see Eberhard and Mueller (1936) on the *Sān-tǒng-lì* (*Three-Sequences Calendar*)[4] system.

---

4.   The *Three-Sequences Calendar* system was devised by *Líu, Xīn* (circa 46 B.C. - A.D. 23) and his associates in the late *Hàn* dynasty. The *Three-Sequences Calendar* "established more than a calendar system; it created a world-concept such as has been approximated perhaps only by that of Pythagoras" (Eberhard and Mueller, 1936: 197).

zhāng

A period of nineteen tropical years which is almost equivalent to 235 lunations is called *zhāng*. The 235 lunations is taken to contain 110 hollow months (*xiǎo-yuè*'s, short months) of 29 days and 125 months (*dà-yuè*'s, long months) of 30 days. This period totals 6940 days.

A *zhāng* is the same as the Metonic cycle, which consists of 12 years of 12 lunations each and 7 years each of 13 lunations. The intercalated year is called a *complete year* or *full year*. In a complete year, the *intercalated month* has the same name as one of the other months though the number of days may differ. Which month was chosen to be intercalated was subject to the following constraints (Bredon and Mitrophanow, 1966: 8):

- Spring Equinox (*chūn-fēn*) was always in the second month;
- Summer Solstice (*xià-zhì*) was always in the fifth month;
- Autumn Equinox (*qīu-fēn*) was in the eighth month;
- Winter Solstice (*dōng-zhì*) was in the eleventh month;
- The first, eleven, and twelfth months were never intercalated.

In general, intercalations are in years 3, 6, 8, 11, 14, 16, and 19 of a period.[5] Chinese New Year begins with the lunation during when the sun entered the zodiacal sign of Aquarius, between January 20 and February 19 in the Gregorian calendar.

bù

A *bù* is four periods of *zhāng*, and is the same as the Callippic period. A *bù* consists of 940 lunations equalling 76 tropical years of 365.25 days each.

huì

A *huì* equals twenty-seven periods of *zhāng* (513 tropical years) and equals 47 lunar eclipse cycles (of about 135 lunations each).

> With the Han [*Hàn*] value for the length of the lunation, the smallest number of lunations which would give a round number

---

5. Some exceptions may be found, for example, 1984 was a complete year, although it was year 5 in the period.

of days was 81 (i.e. 2932 days), and when this was combined with the lunar eclipse cycle of 135 lunations, the former being multiplied by 5 and the latter by 3, both giving 405 lunations or 11960 days, the shortest period of whole days in which the eclipse cycle could be completed was found.

Joseph Needham (1959: 407)

tǒng

Three *huì*'s (81 *zhāng*'s, 1539 tropical years) is a *tǒng*. Three *tǒng*'s (1686360 days) was found to be the smallest concordant period of 28106 sexagesimal day cycles, 57105 lunations, 4617 tropical years, and 423 eclipse cycles.

jì, suì, or dà-zhōng

A *jì* is 20 times a *bù*, that is, 1520 tropical years, or 9253 sexagesimal day cycles. This corresponds to the period of Jupiter's synodic revolution (Needham, 1959: 406-407). In other words, the sequences for sexagesimal day and month cycles repeat every 80 years.

dà-bèi, yuán, or shǒu

A *dà-bèi*, *yuán*, or *shǒu* equals three *jì*'s.

jí (grand period)

A *jí* (grand period) equals 7 *dà-bèi*'s, that is, 31920 tropical years. It was believed that after a *jí* had elapsed, "all things come to an end and return to their original state" (Needham, 1959: 406). It is exactly equal to four Julian periods.[6] Some interesting results include:

1 *jí* = 7 *dà-bèi*'s
    = 7 × 3 *jì*'s
    = 31920 tropical years
    = 399 × 80-year periods

---

6.   The Julian period (7980 tropical years) was introduced by French scholar Joseph Justus Scaliger (A.D. 1540–1609) and based on the Metonic cycle of 19 years, a 'solar cycle' (Victorinus sabbatical cycle) of 28 years, and the [Roman] Indiction cycle of 15 years. (Needham, 1959: 406-408; *The New Encyclopedia Britannica*, Vol. 15, 1994: 419-420)

= 4 Julian periods

= $4 \times 28 \times 15$ Metonic cycles

= $4 \times 19 \times 15$ solar cycles

= $4 \times 28 \times 19$ Indiction cycles.

tài-jí-shàng-yuán (world-cycle or "great year cycle")

During the *Hàn* dynasty it was thought that in exactly 138240 years all planets would repeat their motion. By combining this 'cogwheel' with the 4617-year period (three *tŏng*'s), the whole 'world cycle' can be taken to be 23639040 years. The beginning of it was known as the 'Supreme Ultimate Grand Origin' (*tài-jí-shàng-yuán*) (Needham, 1959: 408; Bodde, 1991: 123).

3.1.4 Eight-Characters

Many Chinese believed the date and time of birth characterizes a person's innate nature (*fú-yuán*, innateness, origin of fortune) by which their fate in life is decided. This date was, therefore, for that person, the provenance for the practice of Chinese geomancy for that person.[7]

The Chinese refer to the date and time of birth as *eight-characters* (*bā-zì*). The time of birth is represented by the [lunisolar] year, month, day, and the hour of birth. Each has a representation in the sexagesimal cycle. Each element of the sexagesimal cycle is a pair made up of a celestial stem and a terrestrial branch; therefore, each aspect of a date and time of birth is made up of two characters denoting the stem-branch pair. There are rules, of course, for interpreting the sexagesimal cycle to construct the description of a date and time of birth.

[Lunisolar] Year[8]

The first cycle began in 2637 B.C.[9] (*Collier's Encyclopedia*, Vol. 5, 1988:

---

7.   Fortune tellers – variants of the geomancer – would interpret a person's date and time of birth day to foretell aspects of the person such as their fate, health, wealth, marriage, and so on. A typical example, still in practice, is 'matching' the date and time of birth of grooms with those of their prospective brides.

8.   To distinguish between date and time expressed in the Chinese calendar from that of the Gregorian calendar, I prepend the word 'lunisolar.'

141). For instance, A.D. 1984 was the start of a sexagesimal cycle, that is, the [lunisolar] year 1984 corresponded to the element *A-a*.

In practice, there are two distinct modes of specifying any particular [lunisolar] year. In the *exact* mode, a [lunisolar] year starts with the 'Beginning of Spring' (*lì-chūn*), the first period of the meteorological cycle, and ends at the start of the next 'Beginning of Spring.' In 1996, the 'Beginning of Spring' began on February 4, at 9:08 p.m.; in 1997 it will begin on February 4, at 3:04 a.m. Thus, the [lunisolar] year of 1996, *C-a* (*bǐng-zǐ*), is between February 4, 1996, 9:08 p.m. and February 4, 1997, 3:03:59 a.m.[10]

In the *lunar* mode, a [lunisolar] year starts from the first day of the lunar year and ends on the eve of the year. These dates are determined by when the moon is in its 'new-moon' phase. Thus, the [lunisolar] year for 1996 started on February 19, 1996 and will end on February 6, 1997.

The ancient Chinese believed that the world would encounter great changes every 180 years, which they described as *shàng-yuán* (upper-cycle) through *zhōng-yuán* (middle-cycle) onto *xià-yuán* (lower-cycle). In *fēng-shuǐ*, this 180-year period is called *sān-yuán* (three-cycle or grand-cycle). The current sexagesimal cycle (A.D. 1984–2043) is in lower-cycle.

[Lunisolar] Month

For each [lunisolar] month, its terrestrial branch is determined by its *order*. The terrestrial branch of the first month of a [lunisolar] year is *c* (*yín*), of the second month is *d* (*mǎo*), and so on. There are two ways of determining the order depending on the mode in which the year is specified.

In the *exact* mode, a [lunisolar] month consists of two sequential fortnightly periods; respectively called the *divisional term* (*jié-qì*) and the

---

9. It is not known why the first cycle began in 2637 B.C. According to geomancers, the first cycle began on the first day of the Yellow Emperor (*Huáng-dì*, 2698 B.C.?), but this information is not reliable. *Huáng-dì* was the first of five emperors; he is credited with a long list of inventions, including the invention of government institutions. He appears in *The Classic of History* (see footnote 4 of Chapter 2 on page 25). However, the date 2637 B.C. (not 2698 B.C.) seems accurate, especially, with respect to the material discussed in this dissertation.

10. The times given here are based on Chinese standard time, though in practice the exact time is adjusted to the local time.

principal term (*zhōng-qì*). For example, the first month begins at the start of 'Beginning of Spring' (*lì-chūn*), through the 'Rains' (*yǔ-shuǐ*), and ends before the 'Awakening of Creatures [from hibernation]' (*jīng-zhí*).

In the *lunar* mode, a [lunisolar] month starts from the first day of lunation and ends on the eve of the next lunation's first, 29th or 30th day. Therefore, the first lunation of a year is also the start of the first [lunisolar] month.

For any complete year, the intercalated month is divided into two based on the 15th day. The days before and including the 15th day belong to previous month which has the same order as the intercalated month. The days after the 15th day belong to the order of the next month. Thus, the total number of months for any year is always counted as twelve.

The celestial stem for a [lunisolar] month is determined by the celestial stem of the [lunisolar] year and its order, according to the following rule: if the stem for the year is *A* (*jiǎ*) or *F* (*jǐ*), the stem for the month is counted from *C* (*bǐng*) cyclically; if the stem is *B* or *G*, the count starts from *E*; if the stem is *C* or *H,* the count starts from *G*; if the stem is *D* or *I,* the count starts from *I*; or if the stem is *E* or *J*, the count starts from *A*. This rule which is divided into five groups for determining the starting stem for first [lunisolar] month is called *wǔ-hǔ-dùn-yuè* ("five tigers escape from months"). Table 3.3 illustrates the relationship between the celestial stem for a year and the sexagesimal cycle of each month.

[Lunisolar] Day

The sexagesimal cycle for a [lunisolar] day is easily calculated. For example, the [lunisolar] day for January 1, 1996 was *D-j* (*dīng-yǒu*), and the cycle repeats every sixty days.

[Lunisolar] Hour

Each day is divided into twelve periods (*shí-chén*) each of two hours. The periods corresponds to the twelve terrestrial branches. The first period, from 11:00 pm to 0:59:59 am, is denoted as *a* (*zǐ*). The celestial stem for the [lunisolar] hour depends on the celestial stem of the [lunisolar] day. The following rule, *wǔ-hǔ-dùn-rì* ("five tigers escape from days") determines the

month	branch	month based on meteorological cycle		celestial stem for year and sexagesimal cycles for the months				
		divisional term (*jié-qì*)	principal term (*zhōng-qì*)	*A / F*	*B / G*	*C / H*	*D /I*	*E / J*
		starts	passes through	*jiǎ / jǐ*	*yǐ / gēng*	*bǐng / xīn*	*dīng / rén*	*wù / guǐ*
1	*c*	Beginning of Spring	The Rains	*C-c*	*E-c*	*G-c*	*I-c*	*A-c*
	yín	*lì-chūn*	*yǔ-shuǐ*	*bǐng-yín*	*wù-yín*	*gēng-yín*	*rén-yín*	*jiǎ-yín*
2	*d*	Awakening of Creatures [from hibernation]	Spring Equinox	*D-d*	*F-d*	*H-d*	*J-d*	*B-d*
	mǎo	*jīng-zhí*	*chūn-fēn*	*dīng-mǎo*	*jǐ-mǎo*	*xīn-mǎo*	*guǐ-mǎo*	*yǐ-mǎo*
3	*e*	Clear and Bright	Grain Rain	*E-e*	*G-e*	*I-e*	*A-e*	*C-e*
	chén	*qīng-míng*	*gǔ-yǔ*	*wù-chén*	*gēng-chén*	*rén-chén*	*jiǎ-chén*	*bǐng-chén*
4	*f*	Beginning of Summer	Lesser Fullness [of Grain]	*F-f*	*H-f*	*J-f*	*B-f*	*D-f*
	sì	*lì-xià*	*xiǎo-mǎn*	*jǐ-sì*	*xīn-sì*	*guǐ-sì*	*yǐ-sì*	*dīng-sì*
5	*g*	Grain in Ear	Summer Solstice	*G-g*	*I-g*	*A-g*	*C-g*	*E-g*
	wǔ	*máng-zhǒng*	*xià-zhì*	*gēng-wǔ*	*rén-wǔ*	*jiǎ-wǔ*	*bǐng-wǔ*	*wù-wǔ*
6	*h*	Lesser Heat	Greater Heat	*H-h*	*J-h*	*B-h*	*D-h*	*F-h*
	wèi	*xiǎo-shǔ*	*dà-shǔ*	*xīn-wèi*	*guǐ-wèi*	*yǐ-wèi*	*dīng-wèi*	*jǐ-wèi*
7	*i*	Beginning of Autumn	End of Heat	*I-i*	*A-i*	*C-i*	*E-i*	*G-i*
	shēn	*lì-qīu*	*chù-shǔ*	*rén-shēn*	*jiǎ-shēn*	*bǐng-shēn*	*wù-shēn*	*gēng-shēn*
8	*j*	White Dews	Autumn Equinox	*J-j*	*B-j*	*D-j*	*F-j*	*H-j*
	yǒu	*bái-lù*	*qīu-fēn*	*guǐ-yǒu*	*yǐ-yǒu*	*dīng-yǒu*	*jǐ-yǒu*	*xīn-yǒu*
9	*k*	Cold Dews	Descent of Hoar Frost	*A-k*	*C-k*	*E-k*	*G-k*	*I-k*
	xū	*hán-lù*	*shuāng-jiàng*	*jiǎ-xū*	*bǐng-xū*	*wù-xū*	*gēng-xū*	*rén-xū*
10	*l*	Beginning of Winner	Lesser Snow	*B-l*	*D-l*	*F-l*	*H-l*	*J-l*
	hài	*lì-dōng*	*xiǎo-xuě*	*yǐ-hài*	*dīng-hài*	*jǐ-hài*	*xīn-hài*	*guǐ-hài*
11	*a*	Greater Snow	Winter Solstice	*C-a*	*E-a*	*G-a*	*I-a*	*A-a*
	zǐ	*dà-xuě*	*dōng-zhì*	*bǐng-zǐ*	*wù-zǐ*	*gēng-zǐ*	*rén-zǐ*	*jiǎ-zǐ*
12	*b*	Lesser Cold	Greater Cold	*D-b*	*F-b*	*H-b*	*J-b*	*B-b*
	chǒu	*xiǎo-hán*	*dà-hán*	*dīng-chǒu*	*jǐ-chǒu*	*xīn-chǒu*	*guǐ-chǒu*	*yǐ-chǒu*

Table 3.3.   Five tigers escape from months: rule describing the relationship between the celestial stem of a year and sexagesimal cycles for the months.

celestial stem: if the stem for the day is *A* (*jiǎ*) or *F* (*jǐ*), the stem for the hour is counted from *A* (*jiǎ*) cyclically; if the stem is *B* or *G*, the count starts from *C*; if the stem is *C* or *H*, the count starts from *E*; if the stem is *D* or *I*, the count starts from *G*; or if the stem is *E* or *J*, the count starts from *I*. This rule is illustrated in Table 3.4.

terrestrial branch	time period	celestial stem for day and sexagesimal cycles for hours				
		A / F	B / G	C / H	D /I	E / J
		jiǎ /jǐ	*yǐ / gēng*	*bǐng / xīn*	*dīng / rén*	*wù / guǐ*
a zǐ	00:00 pm – 00:59:59 am	A-a *jiǎ-zǐ*	C-a *bǐng-zǐ*	E-a *wù-zǐ*	G-a *gēng-zǐ*	I-a *rén-zǐ*
b chǒu	01:00 am – 02:59:59 am	B-b *yǐ-chǒu*	D-b *dīng-chǒu*	F-b *jǐ-chǒu*	H-b *xīn-chǒu*	J-b *guǐ-chǒu*
c yín	03:00 am – 04:59:59 am	C-c *bǐng-yín*	E-c *wù-yín*	G-c *gēng-yín*	I-c *rén-yín*	A-c *jiǎ-yín*
d mǎo	05:00 am – 06:59:59 am	D-d *dīng-mǎo*	F-d *jǐ-mǎo*	H-d *xīn-mǎo*	J-d *guǐ-mǎo*	B-d *yǐ-mǎo*
e chén	07:00 am – 08:59:59 am	E-e *wù-chén*	G-e *gēng-chén*	I-e *rén-chén*	A-e *jiǎ-chén*	C-e *bǐng-chén*
f sì	09:00 am – 10:59:59 am	F-f *jǐ-sì*	H-f *xīn-sì*	J-f *guǐ-sì*	B-f *yǐ-sì*	D-f *dīng-sì*
g wǔ	11:00 am – 12:59:59 pm	G-g *gēng-wǔ*	I-g *rén-wǔ*	A-g *jiǎ-wǔ*	C-g *bǐng-wǔ*	E-g *wù-wǔ*
h wèi	01:00 pm – 02:59:59 pm	H-h *xīn-wèi*	J-h *guǐ-wèi*	B-h *yǐ-wèi*	D-h *dīng-wèi*	F-h *jǐ-wèi*
i shēn	03:00 pm – 04:59:59 pm	I-i *rén-shēn*	A-i *jiǎ-shēn*	C-i *bǐng-shēn*	E-i *wù-shēn*	G-i *gēng-shēn*
j yǒu	05:00 pm – 06:59:59 pm	J-j *guǐ-yǒu*	B-j *yǐ-yǒu*	D-j *dīng-yǒu*	F-j *jǐ-yǒu*	H-j *xīn-yǒu*
k xū	07:00 pm – 08:59:59 pm	A-k *jiǎ-xū*	C-k *bǐng-xū*	E-k *wù-xū*	G-k *gēng-xū*	I-k *rén-xū*
l hài	09:00 pm – 10:59:59 pm	B-l *yǐ-hài*	D-l *dīng-hài*	F-l *jǐ-hài*	H-l *xīn-hài*	J-l *guǐ-hài*
a zǐ	11:00 pm – 11:59:59 am	C-a *bǐng-zǐ*	E-a *wù-zǐ*	G-a *gēng-zǐ*	I-a *rén-zǐ*	A-a *jiǎ-zǐ*

Table 3.4.   Five tigers escape from days: the rule that describes the relationship between the celestial stem of a day and the sexagesimal cycle for the hours.

3.2   Auspicious Orientation

There are a number of ways for determining an auspicious orientation for a new building. We consider one theory, developed in *fēng-shuǐ*, known as 'eight buildings' (*bā-zhái*). The theory of eight-buildings, attributed to have been derived from the eight-trigram and magic square, was a branch of the *Fú-jiàn* School, developed during the *Qīng* dynasty.

From the arrangement of the eight-trigram, we can associate eight octants, each consisting of three *aspects*.[11] Each octant, associated with a number in the magic square, represents a *building* (*gōng* or *zhái*). The eight-buildings were divided into two categories, namely, east and west. Buildings 1, 3, 4, and 9 belong to the east, and buildings 2, 3, 6, and 7 belong to the west. Usually, the category name is associated with a building, thus, 'east building 1.'

The most important feature of the theory of eight-buildings is the determination, from the eight-characters, of the innate characteristics of a person (*fú-yuán*, innateness, origin of fortune). Based on this, an auspicious orientation can be suggested. There are four steps in the process: (i) finding the three-cycle of a person's year of birth; (ii) finding the sexagesimal cycle of the person's year of birth; (iii) finding the person's origin of fortune in the 'eight-buildings;' and finally, (iv) suggesting an auspicious orientation. In the following formulae, we suppose the year to be denoted by y.[12]

Step 1: The three-cycle of the year of birth

The following formula can be used for determining the three-cycle of the year of birth. Let r_1 be the index of the three-cycle. Then,

$$\begin{aligned} r_1 &= \lfloor ((y - 1 + 2367) \bmod 180)/60 \rfloor && \text{if } y > 0 \\ &= \lfloor ((y + 2367) \bmod 180)/60 \rfloor && \text{otherwise} \end{aligned} \quad [1]$$

The three-cycle is in upper-, middle-, or lower-cycle depending on whether r_1 equals 0, 1, or 2 respectively.

Step 2: The index of the sexagesimal cycle of the year of birth

Let r_2 be the index of the sexagesimal cycle, (1-60), for the year of birth.

$$\begin{aligned} r_2 &= \lfloor (y - 1 + 2367) \bmod 60 + 1 \rfloor && \text{if } y > 0 \\ &= \lfloor (y + 2367) \bmod 60 + 1 \rfloor && \text{otherwise} \end{aligned} \quad [2]$$

---

11. Here, aspect is diametrically opposite to orientation. In *fēng-shuǐ*, a building or site is always the *subject*. That is, references to any direction such as left or right side is with respect to the building, and not the viewer. For the same reason, an aspect is the location, termed *zuò-shān* (sitting mountain) where the subject sits, and faces the orientation, termed *cháo-shān* (facing mountain).

12. y is negative if it denotes a year before Christ; and positive, otherwise.

From the result, r_2, we can easily obtain the indices of the celestial stem, (1-10), and terrestrial branch, (1-12), for the year y.

$$\text{celestial stem} = (r_2 - 1) \bmod 10 + 1 \qquad [3]$$

$$\text{terrestrial branch} = (r_2 - 1) \bmod 12 + 1 \qquad [4]$$

Step 3: The origin of fortune in the eight-buildings

The origin of fortune in the eight-buildings is the key to suggesting an auspicious orientation. It is represented as a trigram associated with a number from the magic square. The basic method for finding the origin of fortune is called *yě-mǎ-tiào-jiàn* ("wild horse jumping ravine"). In essence, it is a counting process from a certain point on a circle combining the terrestrial branches, magic square, and the eight-trigram in later heaven order until the count equals the index, r_2, for year y. Figure 3.1 shows the counting circle.

The following are the rules for counting this index:

- Always skip the terrestrial branches, l, a, and b.

- For males count in a counterclockwise direction; for females, the count is clockwise.
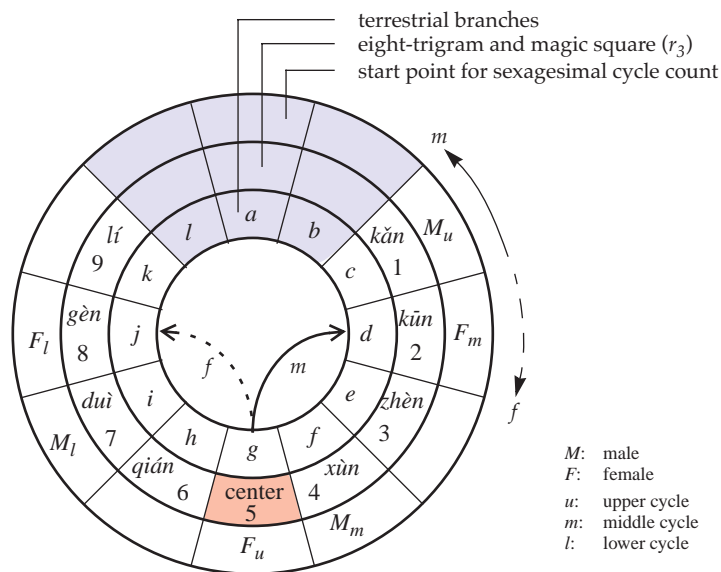
Figure 3.1. A counting circle for finding the origin of fortune.

- For males, the start point for the count is *c*, *f*, or *i*, if the three-cycle index of the birth year, r_1, is in upper-, middle-, or lower-cycle respectively. Likewise, for females, the count starts at *g*, *d*, or *j* respectively.
- If the origin of fortune falls in the center, 5, for males, the position is taken to be *kūn* (2); and for females, *gèn* (8).

Equivalently, we can determine the origin of fortune, r_3, using the following formula.

$$r_3 = (9 - r_2 + (1 + 3 \times r_1) + 1) \bmod 9 \qquad \text{if male}$$
$$= (r_2 + (5 - 3 \times r_1) - 1) \bmod 9 \qquad \text{if female} \qquad [5]$$

Step 4: Auspicious orientation

Geomancers classified the *nine-stars* – the seven stars of the Great Bear constellation and two other smaller stars near Polaris – into eight 'fortune classes' which were assigned to the trigrams. Of these, I_1: *shēng-qì* (vitality), is considered as the most fortunate. Three others in decreasing rank of good fortune are: I_6: *yán-nián* (longevity); I_2: *tiān-yī* (heavenly doctor); and I_8: *fú-wèi* (essence). The remaining are unconsidered as ill-fortunate – I_3: *huò-hài* (disaster); I_4: *lìu-shà* (six goblins); I_5: *wǔ-guǐ* (five ghosts); and I_7: *jué-mìng* (death). Table 3.5 illustrates the eight fortune classes and their relationship to the nine-stars.

For different origins of fortune, the arrangement of the fortune classes changes. Table 3.6 shows the different arrangements based on distinct origins of fortune. The fortune classes indicating good fortune are highlighted. It is

Nine Stars	*tān-láng*	*jù-mén*	*lù-cún*	*wén-qǔ*	*lián-zhēn*	*wǔ-qǔ*	*pò-jūn*	*zǔo-fǔ*	*yòu-bì*
Five Elements	wood	earth	earth	water	fire	metal	metal	water	earth

Categories	*shēng-qì*	*tiān-yī*	*huò-hài*	*lìu-shà*	*wǔ-guǐ*	*yán-nián*	*jué-mìng*	*fú-wèi*
Fortunate	$good_1$	$good_3$	bad	bad	bad	$good_2$	bad	$good_4$
Symbol	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8

Table 3.5. The eight fortune classes and the nine-stars.

trigram / origin of fortune (& r_3)		N	NE	E	SE	S	SW	W	NW
		kǎn	*gèn*	*zhèn*	*xùn*	*lí*	*kūn*	*duì*	*qián*
kǎn	east 1	I_8	I_5	I_2	I_1	I_6	I_7	I_3	I_4
gèn	west 8	I_5	I_8	I_4	I_7	I_3	I_1	I_6	I_2
zhèn	east 3	I_2	I_4	I_8	I_6	I_1	I_3	I_7	I_5
xùn	east 4	I_1	I_7	I_6	I_8	I_2	I_5	I_4	I_3
lí	east 9	I_6	I_3	I_1	I_2	I_8	I_4	I_5	I_7
kūn	west 2	I_7	I_1	I_3	I_5	I_4	I_8	I_2	I_6
duì	west 7	I_3	I_6	I_7	I_4	I_5	I_2	I_8	I_1
qián	west 6	I_4	I_2	I_5	I_3	I_7	I_6	I_1	I_8

Table 3.6. The distinct origins of fortune and the arrangements of the eight fortune classes.

interesting to note for all origins of fortune with its aspect in an 'east building' – that is, with r_3 = 1, 3, 4, and 9 – the aspects north, east, southeast, and south are considered to be fortunate. Likewise, for origins of fortune with its aspect in a 'west building,' – that is, with r_3 = 2, 6, 7, and 8 – the aspects northeast, southwest, west, and northwest are fortunate.

Each origin of fortune contains three aspects. These are known as the *twenty-four aspects*, and are shown in Figure 3.2. The twenty-four aspects are identified by the celestial stems (*A–D, G–J*), terrestrial branches (*a–l*), and four trigrams: *qián, kūn, xùn*, and *gèn*. In Chinese traditional architecture, the basic measurements of a building are calculated from the aspect of the building (see Section 3.4).

3.3   Propitious Construction Date

The Chinese refer to a fortunate day as "propitious date on the ecliptic," and believe that special events that took place on such days would bring good fortunes to one's family. This expression implies, at least, that the propitious date is based on the lunar calendar. We discuss two different methods in *fēng-shuǐ* for determining propitious construction date: one based on a person's month of birth, the other based on the aspect of the site (building).
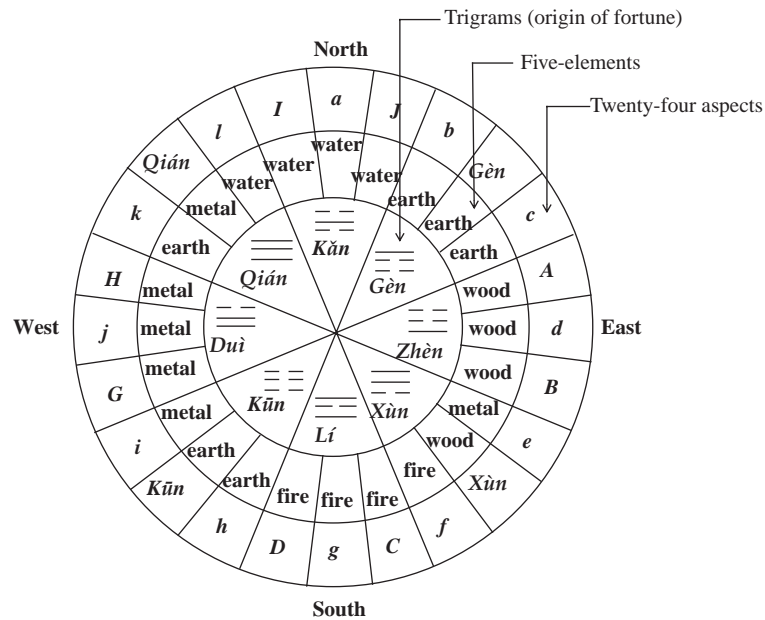
Figure 3.2. Twenty-four aspects and innateness positions.

3.3.1 Propitious date from a person's month of birth

This method, taken from the *Yáng-zhái Shí-shū* (Ten Books of Buildings for *Yáng*), is based on the concept of the "five gods of innateness," – namely, *qīng-lóng* (azure dragon), *míng-xǐ* (happiness), *cāng-kù* (warehouse), *dào-zéi* (robbery), and *bái-hǔ* (white tiger). Each god controls two celestial stems: dragon controls celestial stems *A* and *B*; happiness, *C* and *D*; warehouse, *E* and *F*; robbery, *G* and *H*; and tiger controls *I* and *J*.

The process is relatively simple and straightforward. There are six steps: (i) selecting the intended year for starting construction; (ii) finding the terrestrial branch of the owner's month of birth; (iii) finding the positions of the five gods; (iv) finding the possible month for construction; (v) checking whether the possible month is fortunate; (vi) finding the fortunate day for construction.

Step 1: Intended year for starting construction

The owner usually decided when to start new construction. This intended year (for starting construction) would then be converted to the sexagesimal cycle.

Step 2: The terrestrial branch of owner's month of birth

This obtained by converting the owner's month of birth using equations [2] and [4].

Step 3: The position of the five gods

In *fēng-shuǐ*, the position (terrestrial branch) of the five gods of innateness bears a relationship to the terrestrial branch of the owner's month of birth month. This position, as indicated in Table 3.7, is obtained by shifting through 5 places from the terrestrial branch.

terrestrial branch of the month of birth	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*
position of the five gods	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*a*	*b*	*c*	*d*	*e*

Table 3.7.   Position of the 'five gods' of innateness.

Step 4: The possible month for construction

The terrestrial branch, in the sexagesimal cycle, for the possible month for starting construction in the intended year has to be identical to the position of the five gods.

Step 5: Check if the possible month is fortunate

To check whether the possible month is fortunate or not depends on beliefs (associated with the five gods). For instance, dragon, happiness, and warehouse were considered gods of fortune, the other two not. It was, therefore, believed that a month was fortunate for construction if its celestial stem in the sexagesimal cycle was controlled by one of the three gods of fortune. That is, if the celestial stem was *A*, *B*, *C*, *D*, *E*, or *F*.

If the possible month is not considered fortunate, the geomancer may suggest that the owner postpone construction until a fortunate month can be found by repeating steps 1 through 5.

Step 6: Fortunate day for construction

In the *Ten Books of Buildings for Yáng*, the following [lunisolar] days were considered suitable and fortunate for construction: *A-a* (1), *B-b* (2), *D-d* (4), *E-e* (5), *G-g* (7), *H-h* (8), *F-d* (16), *H-f* (18), *A-i* (21), *D-j* (34), *F-l* (36), *H-b* (38), *C-g* (43), *D-h* (44), *I-a* (49), *J-b* (50), *A-c* (51), *B-d* (52), *F-h* (56), *G-i* (57).[13] These twenty days were fixed. There were, of course, other details given in the book about unfortunate days and about determining fortunate days for other types of construction event, but a description of these details is not within the scope of this dissertation.

3.3.2 Propitious construction date based on aspect

The *Zhái-jīng* (Canon of Buildings) lists, for each month, the aspects that are consonant with the breath of life (*shēng-qì*), breath of death (*sǐ-qì*), and those that conflict with breath of earth (*chōng tǔ-qì*). It was believed that construction could only start in those months for which an aspect of *shēng-qì* coincided with the given aspect. Table 3.8 summaries the various aspects for each month. Figure 3.3 depicts the fortunate months for starting construction for each aspect.

lunar month	1	2	3	4	5	6	7	8	9	10	11	12
shēng-qì	a, J	b, gèn	c, A	d, B	e, xùn	f, C	g, d	h, kūn	i, G	j, H	k, qián	l, I
sǐ-qì	g, d	h, kūn	i, G	j, H	k, qián	l, I	a, J	b, gèn	c, A	d, B	e, xùn	f, C
chōng tǔ-qì	d, h	kūn	l, I	H, k	qián	c, A	J, b	gèn	f, C	B, e	xùn	i, G

Table 3.8. The aspects controlled by the different breath of *qì* for each month.

---

13. The numbers in the parenthesis are indices to the sexagesimal cycle.
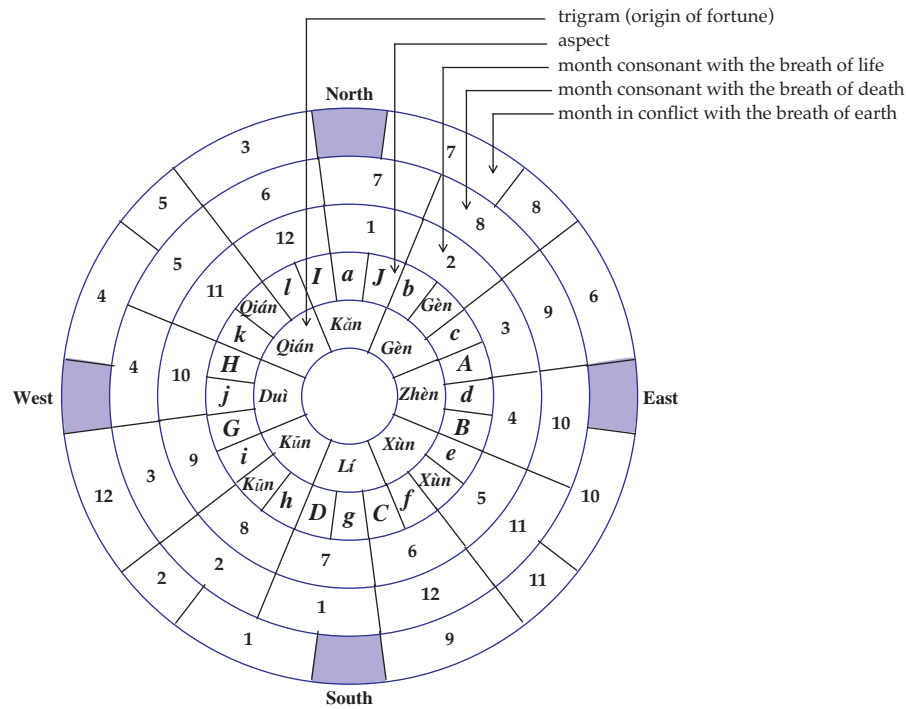
Figure 3.3. The fortunate months for starting construction for each aspect.

3.4 Measurements of the Central Spaces

There were five measurement systems used in Taiwanese/Chinese traditional buildings, which are described in the first part of this section. In the second part, I give the procedure for calculating measurements for the major spaces, namely, the central rooms (spaces of bays), which are termed the *fortunate dimensions*.

3.4.1 Rulers

It was important, in the design of traditional vernacular buildings, to employ 'good' dimensions (or measurements).[14] Equally important were the instruments or rulers that were used to measure off these dimensions. In Taiwanese traditional architecture, there were, at least, five kinds of rulers (or

measuring systems) used in design and construction: the *Lu Ban* ruler and [the newer] opening and worship rulers, stride, and step measures.

Lu Ban Ruler

The *Lu Ban* ruler (*Lǔ-bān-chǐ*) was the first general ruler for artisans. *Lu Ban* was said to be the first carpenter in China, and he invented the ruler that bears his name. A *Lu Ban* ruler has two units, nominally, 'feet' and 'inches.' Each *Lu Ban* foot is divided into 10 *Lu Ban* inches. In the metric system, a *Lu Ban* foot measures 29.69 cms. The *Lu Ban* ruler is also referred to as the Artisan's or Carpenter's ruler. The units or intervals of the other ruler systems employed in Taiwanese traditional architecture are all measured in *Lu Ban* units. For convenience we use the symbols ' and " to denote *Lu Ban* feet and inches respectively. For example, the measurement 1' 4.4" represents a distance equal to 1 *Lu Ban* foot and 4.4 *Lu Ban* inches.

Opening Ruler[15]

The opening ruler (*Mén-guāng-chǐ*[16]) is used for measuring houses (buildings for *yáng*), especially openings and furniture. Figure 3.4 shows an opening ruler.[17] The basic scale for an opening ruler equals 1' 4.4" in length,

---

14. The Chinese word for 'scale' and 'dimension' is the same, namely, *chǐ-cùn* or *chǐ-dù*. Physical dimensions employed in Taiwanese traditional architecture are sometimes referred to, in the literature, as scales. These are not scales in the sense that they correspond to measurements determined by a proportional system; but, are, instead, simply, absolute numbers that have particular associations with states of fortune. The choice of the ruler, and hence the particular association of a state of fortune for a given dimension, is determined by the design context where the dimension is required.

15. Also known as the "fortunate ruler for *yáng*."

16. It is also as known as *Mén-gōng-chǐ* or *Wén-gōng-chǐ*. Literally, *mén-gōng* is translated as "god of doors;" it implies the ruler was given by the god of doors to bring good fortune. We prefer the term *Mén-guāng-chǐ* which means to "make light." It should be noted that to allow light through doors is to honor one's ancestors or family. In fact, *mén-guāng* and *mén-gōng* have almost the same Taiwanese (Hokkien) pronunciation. [The ancient Chinese (*Hàn* language) pronunciation is preserved much more in Taiwanese than in Mandarin.]

17. According to Figure 3.4, this ruler has to be read from right to left since the rightmost character signifies 'wealth,' which is the first character on the ruler. See footnote 18.

Figure 3.4. Opening ruler (*Mén-guāng-chǐ*). (After Lin, 1990: 34)

measuring a total of 42.76 cms, and is divided into eight equal intervals. Each interval is identified with a Chinese character which signifies a state of fortune. The characters represent 'wealth' (money), 'ill-health' (sickness), 'separation' (to live apart from one's family or community), 'rightness,' 'officer,' 'robbery,' 'harm' (misfortune), and 'luck' (good fortune).[18] As one might expect, any dimensional measurements that fell within the 'wealth,' 'rightness,' 'officer,' and 'luck' intervals bode well for the owner and his house; though, in some cases, dimensions that fall within 'rightness' and 'officer' intervals may not: for example, measurements within 'officer' intervals used as dimensions for the bedroom door were considered fortunate,[19] but were not considered so for the dimensions of the entrance to the house.[20] For longer measurements, the basic scale is repeated. The opening ruler is still in use today for dimensioning doors, windows, tables, etc. Architects still use the fortunate ruler to decide upon measurements for modern Taiwanese buildings.

Worship Ruler[21]

The worship ruler (*Dīng-lán-chǐ* [22]) was used for tombs and buildings associated with the dead. Figure 3.5 illustrates a worship ruler.[23] Though

---

18. The eight characters are *cái, bìng, lí, yì, guān, jié, hài,* and *běn*. Most of these characters translate into words that need no further explanation. The Chinese word *guān* translates to officer; but, it embraces bureaucrats, civil servants, military officers, and in general, individuals who had influence and were empowered to govern. In feudal times, people aspired to becoming 'officers.'

19. In this case, it implies that the artisan wishes that a boy, who will rise to be an official of the government, will be born in this house.

20. If entrances were designed according to 'officer' units, it implied that accusations would be brought forward against members of the household.

21. Also referred to as the "fortunate ruler for *yīn*."

Figure 3.5. Worship ruler (*Dīng-lán-chǐ*). (After Lin, 1990: 34)

this ruler was not used for dimensioning houses, certain parts of the house may be designed according to the interval scales of a worship ruler, for instance, the "table of worship." The basic scale of the worship ruler measures 1' 2.8" in length totalling 38.01 cms. The scale is divided into ten equal intervals, each associated with a Chinese character, namely, 'wealth,' 'loss,' 'prosperity,' 'death,' 'officer,' 'rightness,' 'suffering,' 'vigor,' 'harm,' and 'birth.'[24] It is evident that dimensions selected in 'wealth,' 'prosperity,' 'officer,' 'rightness,' 'vigor,' and 'birth' intervals were considered fortunate. As with the opening ruler, larger dimensions are obtained by additive repetitions of the basic scale.

Stride Measure (*bù-fǎ*)

Stride (or pace, *bù*) measures were used in determining larger scales in a house, e.g., the open space (courtyard) and semi-open space (porch). Stride measures are based on the length of a stride, which equals 4' 5" (or 1.336 m, about 2 *paces*). Generally, dimensions measured in odd number of strides – namely, 1, 3, 5, 7, and 11 – were considered good. Another reason for the popularity of odd stride measures is that odd is *yáng*. In fact, each stride

---

22. *Dīng-lán-chǐ* is said to bear the name of *Dīng, Lán* who was a famous dutiful son in the *Hàn* dynasty. His story, *kē-mù-shì-qīn*, is described in "the twenty-four stories of Chinese dutifulness," *èr-shí-sì-xiào*. It is one of worship. *Dīng, Lán* lost his parents when he was little. He made statues of his parents and worshipped them as though they were alive. He protected this memory even at the cost of his own marriage. To use this ruler is to invoke the memory of *Dīng, Lán* and the strength of his worship.

23. According to Figure 3.5, the left-most is the first character, 'richness.'

24. The ten characters are *cái, shī, xìng, sǐ, guān, yì, kǔ, wàng, hài*, and *dīng*. See footnote 18.

measure has a distinct meaning in Chinese geomancy (see for example, Lu, 1985: 52; Luo, 1985: 15).

Step Measure (*tà-fǎ*)

Step (*tà*) measures were used for determining heights of platforms.[25] The step measure is based on the concept of stairs. A step measure equals 3.5" (or 10.4 cms). Six steps form a cycle, and each step has its own meaning. The first step signifies heaven (*tiān*), the second earth (*dì*), the third human beings (*rén*), the fourth wealth (*fù*), the fifth honor (*guì*), and the sixth poverty (*pín*). It is obvious that poverty (*pín*) is not considered fortunate.[26]

Each of these different rulers was employed for specific purposes. The ruler systems not only helped in determining fortunate dimensions for a building, but also provided an effective way of keeping designs modular. Furthermore, dimensional scales related to material sizes. Rulers, thus, provided a means of constraining house plans, and at the same time, lent support, to the artisans, as a guideline for good designs.

3.4.2 The Fortunate Dimensions

It was [and still is] believed that properly determined orientations, heights, widths, and depths brought good fortune. Ascertaining the orientation of the building was the responsibility of a geomancer;[27] the rest were tasks for the

---

25. This is not universally true of all Taiwanese traditional buildings. Some artisans used the concept of *yīn* and *yáng* to determine the height of platform, that is, measures in an odd number of steps were considered good for a house (or "building for *yáng*").

26. This is not universal. Another research finds a step measure equals 6 *Lu Ban* inches (or 17.814 cms) in a different area (Jiang, 1992: 91). In this case, a half of step (3 *Lu Ban* inches) is treated as an *unit*, and any measurement must be either greater than or less than the multiple of units; otherwise, it is not considered fortunate. See footnote 25 above.

27. A person proficient in the art and practice of *fēng-shuǐ* (see Section 2.1). The geomancer played a much more vital and influential role than merely determining the orientation of the building. The geomancer was involved in virtually every stage of design and construction, ranging from site selection and orientation, to ground breaking (*dòng-tǔ*) through to working on the main frames and main beam to eventually thanking the ground (*xiè-tǔ*), serving both as a prominent player and in a consultative capacity.

artisans.[28]

It turns out, in Taiwanese traditional architecture, that almost all measurements are directly related to the three basic dimensions of the central space. These numbers are referred to as the *fortunate dimensions* or *fortunate measurements*.

The orientation of a building is the direction of the main building in the enclosure-courtyard (*hé-yuàn*). The remaining dimensions are the height, width, and depth of the building. The *height* of a building is the distance between the lower part of the main beam in the central space (or room) to the ground, the *width* is the distance between the two partition supports in the central space, and the *depth* is the interior distance from the front entrance to the rear wall in the central space. The dimensions were all measured in *Lu Ban* units. The design and ornamentation of a building depended on its fortunate dimensions. Once the fortunate numbers were decided, these became the measures by which all other dimensions and measurements of the building were calculated. Moreover, from the fortunate numbers, one could estimate the amount of material required for construction.

A fortunate measure has two parts: a fortunate *Lu Ban* foot measure and a fortunate *Lu Ban* inch measure. In many instances, only the fortunate inch measures were calculated. We can describe the process for obtaining the fortunate numbers in the following four steps: (i) constraining the height of the building; (ii) determining the attributes of the building; (iii) estimating fortunate numbers for the height, width, and depth; and (iv) deciding upon an actual height, width, and depth. The four steps are illustrated by the flowchart in Figure 3.6.

Step 1: Constraining the height of the building

Once an orientation for the new building had been decided upon, the geomancer would mark the site at two places. One marked the location of the

---

28. In this respect, a good artisan was not only skillful at construction but was also capable of design. Most artisans learned their trade from their fathers or through apprenticeship to other artisans. Thus, design methods were handed down through oral instruction; many of the design concepts were related to *fēng-shuǐ* and taboos. The ability to calculate fortunate dimensions distinguished artisans from others, who, at best, were simply skilled workers or laborers.
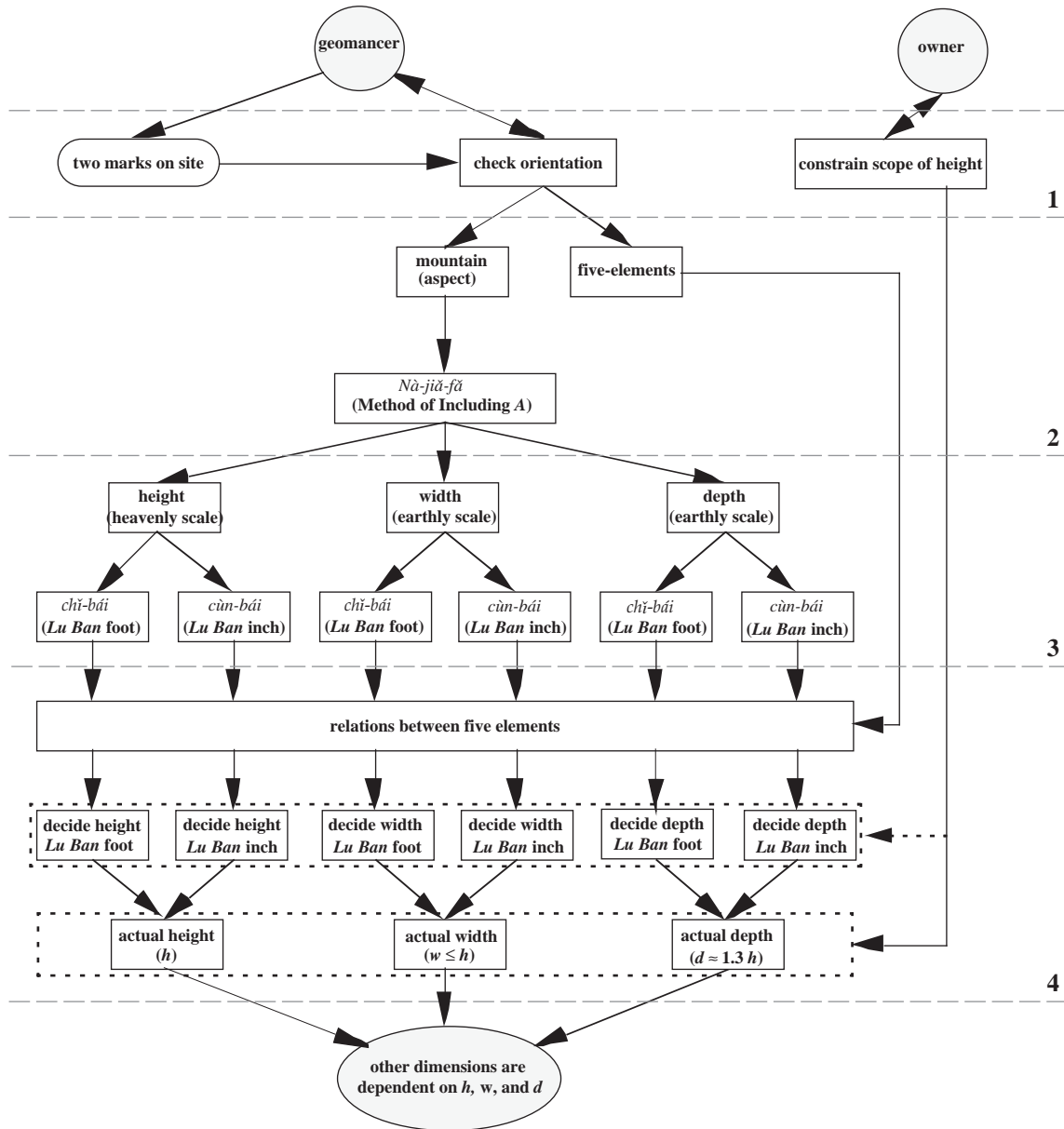
Figure 3.6. The flowchart for determining the fortunate dimensions of a building.

key brick (*hé-zhuān*),[29] and the other the front of the building. These two marks defined the orientation for the building. From the owner's brief, the artisans would have known the dimensional scale of the building. This information and orientation would have sufficed to determine a range on the height of the building.[30] In general, the width did not exceed the height;[31] the depth of the building was approximately 30 percent longer than the height. With a given orientation and range on heights, the artisans would use the eight-trigram (*bā-guà*) to find the attributes of the building.

Step 2: Finding the attributes of the building from the eight-trigram

An eight-trigram (*bā-guà*) is a simplified diagram of eight separate trigrams indicating the relationship between attributes and orientation. In actuality, an eight-trigram is an arrangement of certain cabalistic signs consisting of various combinations of straight lines arranged in a circular or tabular form. It is created from the two primary forms (*liǎng-yí*), a continuous straight line called *yáng-yí* (symbol of the male principle) and a broken line called *yīn-yí* (symbol of the female principle). Each trigram in the table is associated with a direction: *qián* (south), *duì* (southeast), *lí* (east), *zhèn* (northeast), *xùn* (southwest), *kǎn* (west), *gèn* (northwest), and *kūn* (north)[32]. A representation of the eight-trigram is given in Figure 3.2.[33]

The eight-trigram is divided into twenty-four aspects comprising:

---

29. The *key brick* signified the 'center' of the building. Many Chinese believed that the location of the center of the building was the source of good fortune (or *qì*, breath) and had been protected by the Gods. The altar or "table of worship" was often placed directly above. So too was the location of the main beam [on which is drawn an eight-trigram] in the central room.

30. The maximum length in which materials were available imposed an additional constraint on height. Another consideration for height was the social implications for the owner; the higher the building the more expensive to build and hence, the more prestigious. In general, the height was approximately 10 – 15 *Lu Ban* feet for vernacular houses.

31. Some artisans set the width to equal the height. This is because they did not want the posts (columns) to crash into another wall in the event of their falling. Other artisans did not impose such constraints.

32. This layout is based on the *Yì-jīng* (Canon of Changes) and as known as "eight-trigram in former heaven order," *xiān-tiān bā-guà* (Feuchtwang, 1974: 71-80; Williams, 1976: 148-151; Lin, 1990: 14-15). See, also, Section 2.1.2.

- the first and the last four elements of the "celestial stems" (*tiān-gān*, heavenly stems) made up from eight of the following ten elements, *jiǎ*, *yǐ*, *bǐng*, *dīng*, (*wù*), (*jǐ*), *gēng*, *xīn*, *rén*, and *guǐ*;
- the "terrestrial branches" (*dì-zhī*, earthly branches) with twelve elements, *zǐ*, *chǒu*, *yín*, *mǎo*, *chén*, *sì*, *wǔ*, *wèi*, *shēn*, *yǒu*, *xū*, and *hài*;
- four trigrams from the eight-trigram: *qián, kūn, xùn*, and *gèn*.

Each *aspect* is termed a *mountain* (*zuò-shān*).[34] Associated with each mountain is one of the five elements: metal (*jīn*), wood (*mù*), water (*shuǐ*), fire (*huǒ*), and earth (*tǔ*). The attributes of the selected element are used in the final step in deciding the actual height, width, and depth of the building. The information of the mountain is then transferred to a 'real' trigram for estimating fortunate numbers for the height and depth of the building. The method of transferring a mountain to a real trigram is what we term the *Method of Including A* [35] (or *nà-jiǎ-fǎ*). Every real trigram has one or more mountains (see Table 3.9).[36]

Step 3: Estimating fortunate numbers for the building's height, width, and depth

The fortunate dimensions belong to one of two ('heavenly' or 'earthly') dimensions. The height is determined in 'heavenly' dimensions (*tiān-fù*); widths and depths are determined in 'earthly' dimensions (*dì-mǔ*). For each dimension, there are two groups of fortunate numbers. One group consists of measurements in *Lu Ban* feet, and the other are measurements in *Lu Ban* inches. Each of these fortunate numbers are determined according to different methods: *chǐ-bái* (or "Instructions for Measuring in *Lu Ban* feet") and *cùn-bái* (or "Instructions for Measuring in *Lu Ban* inches"). These methods are

---

33. The eight-trigram in Figure 3.2 is based on a translation, from the original Chinese, of an artisan's notes into a convenient form for determining the fortunate dimensions (Chiou, 1990: 65). This layout of eight-trigram, called "eight -trigrams in later heaven order," *hòu-tiān bā-guà* (see Section 2.1).

34. The concept of mountain comes from *fēng-shuǐ*. A possible meaning for the word 'mountain' or *zuò-shān* might be "sitting on a location facing a certain direction." Contrarily, *cháo-shān* is the faced location or direction, namely, orientation. See Figure 2.1, and also footnote 11 on page 69.

35. For convenience, we refer to the mountain '*jiǎ*' by the letter '*A*.' *Jiǎ* is the first element of the celestial stems. See Table 3.1.

36. Note that, in Table 3.9, each mountain is associated with a letter. The coding scheme is identical to that in Table 3.1.

shown respectively in Tables 3.10 and 3.11. The *chǐ-bái* is an arithmetic table,[37] which includes nine stars and the five elements. The *cùn-bái* is also an arithmetic table, but includes seven colors and the five elements.

Both methods are applied similarly, though the start points for each may vary. For example, suppose the building's real trigram is *zhèn*. From Table 3.9, the possible aspects (mountains or *zuò-shān*'s) are *gēng* (*G*), *hài* (*k*), *mǎo* (*d*), and *wèi* (*h*). For each of these aspects we can estimate the orientation from Figure 3.2. For example, for the aspect *gēng*, the orientation is East North-East by East (note: its mountain, *zuò-shān*, is West South-West by West). Its element group is metal. All of this information is used in step 4. The *Lu Ban* feet measurement for the building's height would then be estimated starting from the second star;[38] the estimates for width and depth would start at the eighth star.[39] For the height, the fortunate measurements are 1, 5, (7), (8), 9, 10, 14, (16), (17), 18, …, etc. These numbers are obtained by counting, from left to right, along the row corresponding to "fortune,"

---

37. In fact, it was handed down by oral instruction. I have transferred it to an arithmetic table in order to be able to compute the fortunate numbers.
38. From the row corresponding to "heavenly scale" in Table 3.10.
39. From the row corresponding to "earthly scale" in Table 3.10.

	I	II	III	IV	V	VI	VII	VIII	IX
Nine Stars	*tān-láng* (α)	*jù-mén* (β)	*lù-cún* (γ)	*wén-qǔ* (δ)	*lián-zhēn* (ε)	*wǔ-qǔ* (ζ)	*pò-jūn* (η)	*zǔo-fǔ* (θ)	*yòu-bì* (ι)
Five Elements	wood	earth	earth	water	fire	metal	metal	metal	water
Fortune	good	good	bad	bad	bad	good	bad	fair	fair
Heavenly Dimension	*duì*	*zhèn*	*kūn*	*kǎn*	*xùn*	*gèn*	*lí*		*qián*
Earthly Dimension		*qián*	*duì*	*gèn*	*lí*	*kǎn*	*kūn*	*zhèn*	*xùn*

Table 3.10.   *Chǐ-bái* (or Instructions for Measuring in *Lu Ban* feet).

	I	II	III	IV	V	VI	VII	VIII	IX
Seven Colors	white	black	dark	green	yellow	white	red	white	purple
Five Elements	water	earth	wood	wood	earth	metal	metal	earth	fire
Fortune	good	bad	bad	bad/fair	bad	good	bad	good	fair
Heavenly Dimension		*kǎn*	*kūn*	*qián*	*xùn*	*gèn*	*zhèn*	*lí*	*duì*
Earthly Dimension	*qián*	*lí*	*Zhèn*	*duì*	*kǎn*	*kūn*	*xùn*	*gèn*	

Table 3.11.   *Cùn-bái* (or Instructions for Measuring in *Lu Ban* inches).

starting from the selected column in the "heavenly dimension" row. The measurements within parentheses signify values that are associated with the fortune value 'fair.' To obtain higher measurements, we wrap the last column onto the first and continue the count as above. In other words, the table is repeated in a periodic manner.

For the width and depth, a similar procedure to the one above is followed with the count, instead, starting from the selected column in the "earthly dimension" row. In this case, the fortunate numbers are (1), (2), 3, 4, 8, (10), (11), 12, 13, 17, …, etc.

Each measurement, so obtained, is associated with one of the five elements. The artisan would use, from step 1, the constrained range on the height of the building, from step 2, the attributes of the selected element, the groups of fortunate measurements and the attributes of each corresponding

associated element, to decide upon the actual height, width, and depth. This is described in the next and final step.

Step 4: Deciding the actual height, width, and depth

Once possible fortunate measurements in both *Lu Ban* feet and inches have been determined, the artisans would check whether these numbers fell within the allowable range for the height of the building. A further check would be to see whether the elements associated with these numbers 'fit' with the elements associated with the orientation of the building. For example, suppose the attribute of the orientation is denoted as *A*, and a possible fortunate number belongs to *B*. Both *A* and *B* must correspond to one of the five elements. For the number to be compatible with the orientation, one of the following conditions must hold.

- A is identical to *B*; or
- *B* produces *A*, or *A* destroys *B*.

The production/destruction relationship between the five elements is shown in Figure 2.5. After checking all the possible fortunate numbers, an actual height was chosen that fell within its previously determined range. The width and depth are chosen from the possible fortunate numbers that satisfy the relationship between height and depth, and height and width also described earlier. The chosen height and depth act as a scale or guideline from which all other measurements pertaining to the building are determined.

We can speculate on the reasons why such an involved procedure was devised in the first place. One may have been that the procedure formed part of the artisans professional training. Another was that one could then distinguish between an artisan-designer and an artisan-worker by their ability to calculate fortunate dimensions.[40]

This procedure was not always used in its entirety for several reasons. Long enough timber was not always readily found; in this case, artisans would have settled on fortunate *Lu Ban* inch measurements. Cost of construction was another factor. Lastly, some believed that only for temples and palaces for the gods was it required that the fortunate measurements be determined in both feet and inches.

Of all the fortunate dimensions, the height of building was the most important measurement. In cases where the procedure was not fully followed through, artisans set the width to equal the height and the depth to 1.3 times the height.

3.5   Lu-Ban: A Computer Implementation

Even today, in Chinese modern architecture, among orthodox Chinese, the choices for a good site, its orientation, and construction date are still regarded as important. Many Chinese believe that good choices for a building are harbingers of good fortune for their family. In this respect, the auspicious orientation for a building and its construction date were primarily issues of geomancy; these became sources of important rituals in Chinese life[41]. Furthermore, the orientation of a building determined its basic measurements, which I have previously termed the fortunate dimensions.

A graphical interface, *Lu-Ban*, to determine auspicious orientations, construction dates, and fortunate dimensions has been implemented. The program is written in C and TCL/TK, an X-window based tool-kit. The entry port for *Lu-Ban* is shown in Figure 3.7.

---

40. Any skill that elevated artisans socially would have been considered worthwhile. Socially, artisans were held in low esteem in Taiwan. Sometimes they had to compete with other artisan-groups. It was a harsh social system in which an artisan-group might not have been permitted to build for several years after failing a competition. On the other hand, an artisan group's social position could be elevated by winning competitions. In some circumstances artisan-groups neither won nor lost. There are buildings in Taiwan extant that were built by two groups of artisans. One group usually built the left part of a building, the other the right part. There were a number of ways artisans tried to elevate their social position. One way was becoming adept at calculating the fortunate dimensions which required knowledge of *fēng-shuǐ*. Other ways included the use of 'magic' or 'sorcery' during the construction of a building through the use of charms (Knapp, 1989: 146-147 & 1990: 65-67). By employing such procedures, artisans proceeded to make the design process mystical, thereby engendering further respect for their skills.

41. For instance, the start of construction was celebrated by a ceremony known as *dòng-tǔ* (literally translated as "breaking ground" or "stirring the ground"). For further information about this ritual ceremony, the reader is referred to Knapp (1990: 61-65) for details. See, also, footnote 29 on page 83 and footnote 40 above.
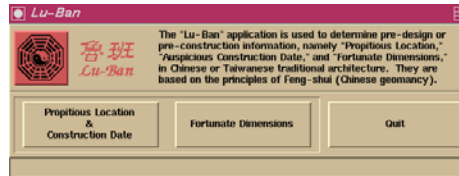
Figure 3.7. The entry port for *Lu-Ban*.

3.5.1 Auspicious Orientation and Construction Date

The interface is shown in Figure 3.8. The interface consists of four 'folders' each of which can be toggled to open or shut – the two bottom pictures illustrate the interface for the two different methods for selecting an auspicious construction date. The folders are arranged so that the information in any folder is constrained by the information inputted (and/or displayed) in the folder above. The interface was designed using a consistent display/interaction metaphor. Displayed information is centered in its field. An input field is triggered as such whenever the mouse moves over it; the field is then displayed as a right justified entry box. The basic colors used in the design of the interface are traditional Chinese colors – shades of firebrick red[42], ochre, yellow, and white. The background is the color of stone, the foreground dark brown almost black and highlights in red. Headers for display fields are indicated by a lighter shade of the background.

The first folder requires input of relevant information about a person – that is, gender, date and time of birth. Date information can be given using either the solar (Gregorian) or lunar (Chinese) calendars. The program automatically converts solar to lunisolar dates and vice versa. The conversion is driven by a mathematical table stored in a data file.[43] My current implementation specifies this table for the years between 1877 and

---

42. To the Chinese people, red signifies good or happy events while white indicates sad events such as deaths and funerals. I use paler shades of red to indicate fortunate situations that rank lower down the scale.

2031. The lunisolar year is given by the lunar mode calculations based on the phases of the moon and is described on page 65. The information displayed in this folder can be toggled between solar and lunisolar dates. Conversion of either information form to the sexagesimal cycle system is automatic.

The second folder, which is display-only, shows the eight-characters description of the date and time of birth, the index of the three-cycle, the person's origin of fortune, and the category of the eight-buildings corresponding to the person's year of birth.

The third folder displays the eight-buildings as well as the fortune classes with their associated aspects, which are colored in shades of red. The information displayed depends on the person's origin of fortune. For different values, the arrangement of fortune classes changes. The user is free to set the aspect – that is, the orientation – for their intended building.

The last folder lets the user select the method for computing the auspicious construction date.

3.5.2 Fortunate Dimensions

The interface for choosing fortunate dimensions is given in Figure 3.9. The interface consists of two 'windows,' one for a compass and the other for the fortunate dimensions. The compass can be moved to any orientation in any direction. The compass is linked to the previous interface in that any orientation set on the compass automatically sets the aspect for the building and vice versa. These values can be manually overridden by unlocking the connection. The compass can also be set through keyboard input by specifying its location, facing or orientation.

The fortunate dimensions' window consists of three folders.

The first folder is for setting constraints – namely, ranges for the fortunate height, depth, and width. The range for height is specified by minimum and maximum values. Ranges for depth and width can be set in two ways: either as a factor of the height, or by minimum and maximum values. Default

---

43. The table stores for each solar year, the number of days of each lunisolar month, the intercalated month (if any), the solar date for the Chinese New Year and the sexagesimal cycle index for that day.

input in lunar date

(*left*) construction date based on the
Ten Books of Buildings for Yáng

arrangement of the fortune
classes and aspects
(see inset below)

fortunate months   ill-fortuned months

(*right*) Chinese form of the interface
showing construction date based
on the *Cannon of Buildings*

Figure 3.8. Interface for the auspicious orientation and construction date.
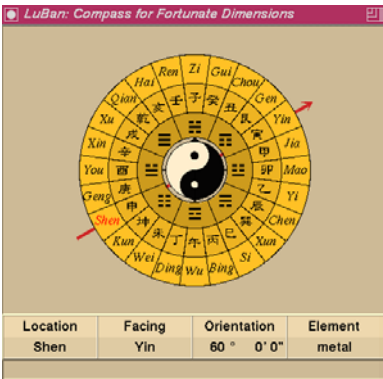
compass for setting the orientation

(*above*) illustrating the worship ruler (Chinese form)

(*left*) interface illustrating the opening ruler

Figure 3.9. The interface for the fortunate dimensions.

ranges for the height, depth, and width are based on commonly found values for Taiwanese traditional vernacular houses.

The second folder displays possible fortunate dimensions – these values are automatically computed for the set ranges and selected orientation using the procedures described in Section 3.4.2.

The third folder converts given dimensions into units used by other measurement systems, namely, stride, step, centimeters, and the opening and worship rulers (see Section 3.4.1). This folder can be locked or unlocked. If locked, it converts and displays the selected fortunate dimension (height, depth, or width). If unlocked, the conversion corresponds to values that are selected on the rulers. This is so that the user can find other fortunate measurements, such as door or window openings, that are not tied to the fortunate dimensions of the building. Both the opening and worship rulers are illustrated in Figure 3.9.

Lu-Ban is designed for user interaction in both English and Chinese. By toggling the eight-trigram icon on the top left hand corner of the interface switches the display language. See illustrations in Figures 3.8 and 3.9.

Part II
Formal and
Computational
Considerations

Chapter 4:
The Grammar of
Southern Style Chinese
Vernacular Dwellings

One day the owner of the neighbouring garden brought a carpenter to the site and told him to build-up a house. They stopped on a spot where the ground sloped gently downwards. The carpenter has a look at the trees, the ground, the environments, and the town in the valley. Then he proceeded to extract from his cummerbund some pegs, paced off the distances, and marked them with the pegs. [Note that there is no question of *what type* of house is to be built–there is a self-evident accepted model.] Thus he came to his *main* task [italics added]. He asked the owner which trees might be sacrificed, moved his pegs for a few feet, nodded and seemed satisfied. He found that the new house would not obstruct the view from the neighbouring

structures … [and then he goes on to examine light, sun, water, and so on].

<div align="right">Amos Rapoport (1969: 5)</div>

4.1   Vernacular Dwellings

According to Rapoport, the most successful way of describing *vernacular* is in terms of process – of how a building is 'designed,' and of how it is 'built.' He (1969: 5) remarks that "the vernacular design process is one of models and adjustments or variations, and there is more individual variability and differentiation than in primitive buildings; it is the *individual specimens* that are modified, not the *type*."

Taiwanese vernacular architecture is a branch of Chinese vernacular architecture, though with its own marked peculiarities. Owing, chiefly, to the geographical and climatic conditions and to its own history, Taiwanese architecture diversified from mainstream Chinese architecture. Chinese architecture is typified by the Northern style whereas Taiwanese architecture belongs entirely to the Southern style. In one sense, these can be distinguished by a special construction and design system that has its origins in the immigrant roots of Taiwanese architecture.

The ancestors of most present-day Taiwanese came to the island between a hundred and three hundred years ago, mainly, from the provinces of *Fú-jiàn* and *Guǎng-dōng*, two provinces in the southeastern part of mainland China. See Figure 4.1. The immigrants to this 'new world' formed neighborhoods fashioned according to the mores of their own hometown [on the mainland]. They preserved their religion, customs, languages, and architectural styles in their new neighborhood. Initially, there were three main ethnic immigrant groups in Taiwan.[1] Prior to 1895, when after Japanese occupation Taiwan was made a colony of Japan, these groups had engaged in inter-group rivalry and conflict.[2] People built homes; the wealthy engaged famous artisans[3] to build theirs so that they could pride themselves on a great house, and thereby become leaders in their neighborhoods.

In the case of Chinese (and 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 for architecture.

Chinese/Taiwanese traditional dwellings were made up of 'main' (*zhèng-shēn*[4]) and 'secondary' (*hù-lóng*[5]) buildings. The main buildings were transverse to the axis of symmetry; secondary buildings 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 my purpose, in this dissertation, I 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

---

1. The three groups are *Quán-zhōu*, *Zhāng-zhōu*, and *Kè-jiā*. *Quán-zhōu* and *Zhāng-zhōu* are also referred to as *Mǐn-nán* because they came from the southern part of *Fú-jiàn*. *Mǐn* is another name for *Fú-jiàn*; *nán* is south in Mandarin pronunciation. *Kè-jiā* has two special meanings. In Chinese, *Kè-jiā* refers to the region in the Western part of *Fú-jiàn* and the Northern part of *Guǎng-dōng*. In Taiwanese, *Kè-jiā* also means guests. Because the [people of] *Mǐn-nán* migrated to Taiwan earlier than the [people of] *Kè-jiā*, the former referred to these latter 'new' immigrants as guests. Most *Kè-jiā* came from *Guǎng-dōng*, though some of them came from the mountains of *Fú-jiàn*. In fact, in China, the people from this area are still called *Kè-jiā*.

2. The groups clashed with each other for many reasons, e.g., land, water, business, and so on. In the main, the *Mǐn-nán* fought the *Kè-jiā*; the *Quán-zhōu* fought the *Zhāng-zhōu*. On occasions, the *Mǐn-nán* and *Kè-jiā* grouped together against the aboriginal (the *Gāo-shān-zú* who lived in the mountains except Yami, and the *Píng-pǔ-zú* who lived in the valleys). The chief reason for these inter-group conflicts appears to have been for social and economic advantages in their new world. In Taiwan, there is a saying that describes this early period of Taiwan history: "三年一小亂，五年一大亂。Three years makes a small rebellion, and five years makes a great rebellion." This observation is key to an understanding of the diversification of Taiwanese architecture.

3. Typically, highly skilled carpenters and masons generally from the same hometown as the owner.

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 *cuò-shēn* (meaning: the body of a building).
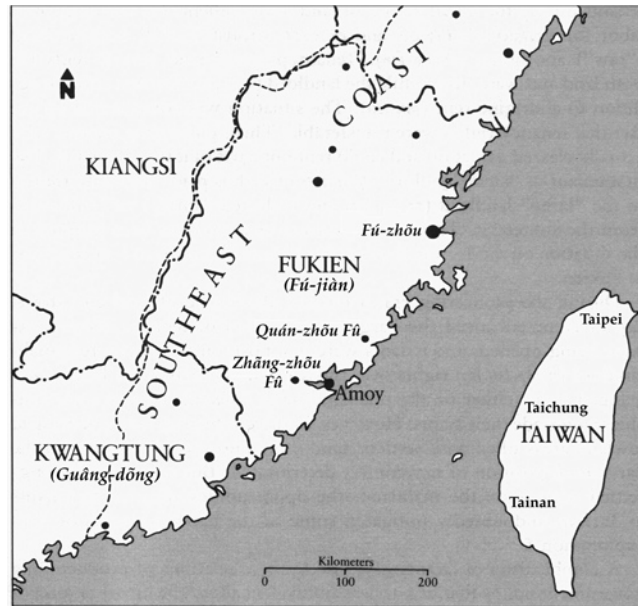
Figure 4.1.   Southeast coast of China and Taiwan, circa 1800.
(After Sangren, 1987: 27)

central hall. Starting with the main building (*zhèng-shēn*) which includes the hall, two secondary buildings (*hù-lóng*'s) were generated. The secondary buildings 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 (see footnote 24 of Chapter 2 on page 40). An example of *hé-yuàn* is shown in Figure 4.2. The number of spaces in a main building ranged from one through nine, and never exceed eleven; typically, it was seven; nine and eleven were reserved for the imperial palace. Each space in a main building had a unique name: *míng* (light), *àn* (dark), *shāo* (tip or end), *cì* (secondary), and *jìn* (finished). This concept is universal to Chinese architecture, though the terminology was not; for instance, artisans in Taiwan did not use this terminology.

---

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).

Figure 4.2. *Zhèng-shēn* (*táng-wū*) and *hù-lóng* (*xiāng-fáng*): *Huáng* family residence,
Shēn-kēng, Taipei. (After Lin, 1990: 24)

The number of main buildings, 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 main buildings 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. See Figure 2.10.

The *jiān*'s (bays) were dimensioned according to the scale defined by the fortunate dimensions of the central bay in a building (see Section 3.4.2). In plan, these dimensions had to be no larger than those for the central bay and in section, no higher.

4.2   Assumptions

The shape of a house is of the highest importance. If the shape is unfavourable, the house will be hard to live in definitively. Whether a house is favourable or unfavourable, unlucky or

> lucky, can be told by the eye. As a rule, a house is favourable if it is square and straight, plain and neat, and pleasing to the eye. If it is too high and large, or too small and tumbledown, so as to be displeasing to the eye, then it is unfavourable.
>
> *Bā-zhái Zào-fú Zhōu-shū* (1: 4b)
> Translated by Klaas Ruitenbeek (1996: 38)

Because Chinese/Taiwanese artisans designed according to established rules and regulations, it seems natural to that any description of their design process has all the hallmarks of a grammar. Traditional design and construction took place at one and the same time. Each artisan, before the start of a construction would, almost certainly, have had a clear image of the entire building. The rules described in this dissertation suggest a partial explanation on how such designs could have been constructed, without recourse to *a priori* hard descriptions of specific design details.

The shape grammar developed in this chapter exemplifies a particular class of buildings within Chinese architecture, namely, Taiwanese traditional vernacular dwellings, and those buildings were built [and *designed* also] by artisans. The rules are basically derived from an understanding of the practices in traditional design and construction process. There are, of course, some assumptions that I made during the development of the grammar.

Firstly, bilateral symmetry is considered to be a basic feature even though there are extant traditional dwellings which do not possess this property.

Secondly, 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.

Thirdly, only roofs of the *yìng-shān* (firm mountain) type are considered.[6] 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

---

6.   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: 104). Also see footnote 20 on page 134.

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.

Lastly, 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*[7]. 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.

4.3 The Grammar

The grammar is given as a sequence of seventeen stages, each comprising one or more shape rules. The initial shape is the location of the key brick and nominally, assigned to be the origin of the coordinate system in which the shapes are defined (see Figure 4.3).

<div align="center">(0,0)✳</div>

<div align="center">Figure 4.3. Initial shape.</div>

Stage 1: Establish the fortunate numbers

The initial shape consists of a single point which is identified by the asterisk (∗), and notionally, represents the key brick, the location which the geomancer marks as fortunate for the owner. Figure 4.4 shows a geomancer and his assistance choosing a building site and determining auspicious orientation for a new building which was depicted on a wood-block print in *Qīng*

---

7.   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 footnote 29 of Chapter 3 on page 83.

Figure 4.4. Choosing a building site and auspicious orientation. (After Knapp, 1990: 58)

dynasty. The key brick may be removed after construction but this rarely happens.

The two rules in this stage are shown in Figure 4.5.

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 (see Section 3.2), the start date of construction and so on.[8] [In practice,] to ensure

8.   All of these factors were considered by the geomancer who traditionally provided this information to the owner and artisans on red sheets of paper.   See, also, footnote 42 of Chapter 3 on page 89.
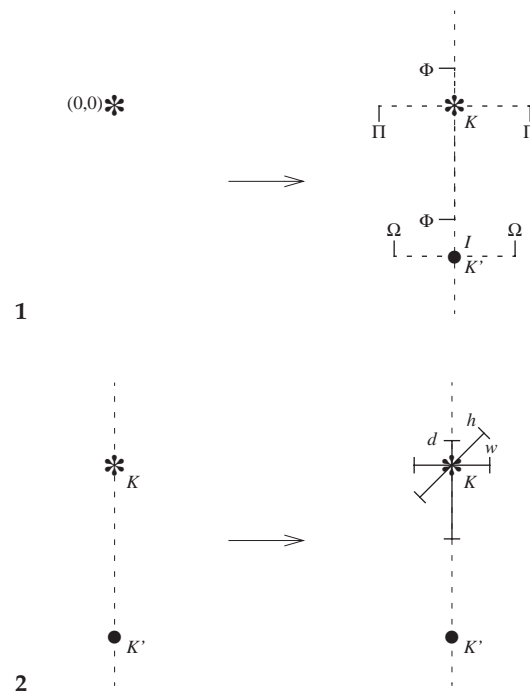
Figure 4.5. (Stage 1) Establishing the fortunate numbers.

that the orientation is easily determined, a second mark [typically, a stick] is placed at the front of the site.

[In practice,] with this line, scales[9] of intentions can also be defined.[10] 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 dash line of a certain length. The parameters are ΦΦ, the number of main buildings

---

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

10. 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.

(*jìn*'s) which, in general, does not exceed five; $\Pi\Pi$, the number of bays (spaces or rooms, *jiān*'s) in a building and does not exceed nine; $\Omega\Omega$, the number of secondary buildings (*lù*'s) which is arbitrary.

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* (see Section 3.4.2). 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[11]:

$h = f_h$(orientation, $\Phi\Phi$)
$w = f_w$(orientation) and possibly $w \leq h$
$d = f_d$(orientation) 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 (see Section 3.4.2). It was not the case for widths and depths; about 70-80% of 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 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 shown in Figure 4.6.

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.

---

11. Each dimension x is associated with a function f_x that returns a value for x.
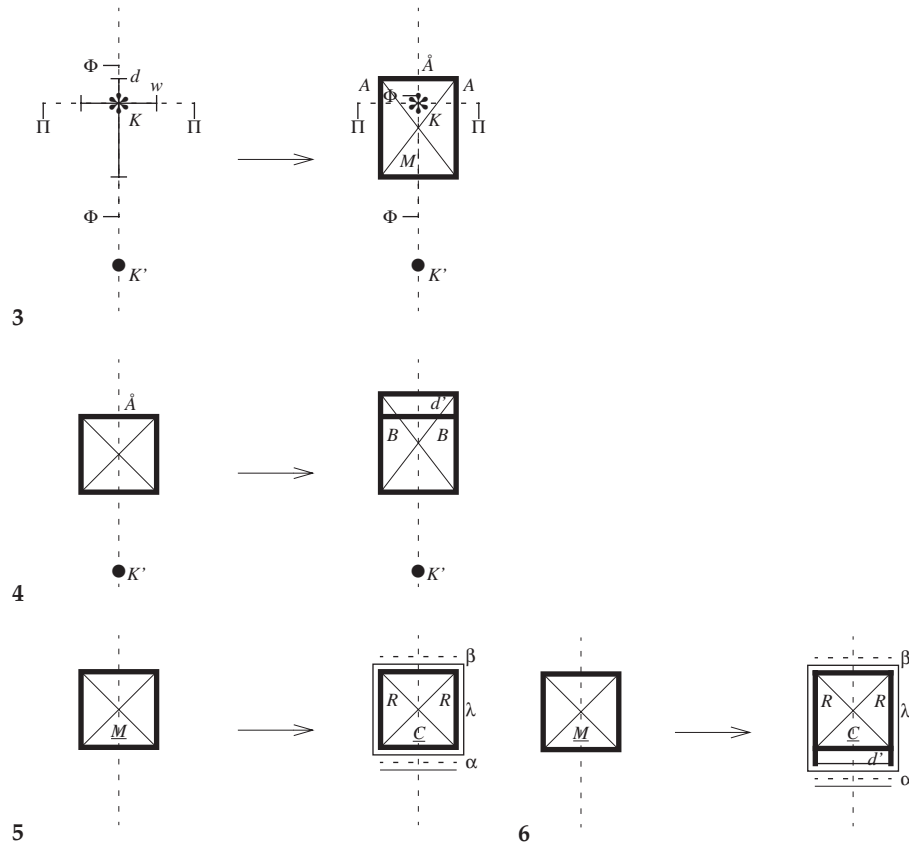
Figure 4.6. (Stage 2) Generating the central room in a main building.

Occasionally, one finds an additional space within the central room.[12] 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

---

12. 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.

raised platform[13], and associate the label, λ, with it. Labels α and β respectively identify the positions for the front and rear roofs to be specified by a later rule. The label, $\underline{M}$, associated with a main building is replaced, at the same position, by $\underline{C}$.[14] 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 (see footnote 31 of Chapter 2 on page 51). In order to protect these two important features, the artisan traditionally positioned the upper frame of the main entrance, the main beam and light beam on a straight line, namely, *sān-hé* (see Figure 2.20, and, also, footnote 32 of Chapter 2 on page 51). 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 4.7. The shape rules are divided into three groups. The first group, comprising rules 7 through 9, create openings in the front wall of the central room. The second

---

13. 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*), public space, prior to entering the chambers (*shì*'s), private space.

14. 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, $\{M, M', M'', M'^3, \dots\}$. 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''.

group comprising rules 10 through 15 create openings in the rear wall. Shape rule 16 creates openings in both walls.
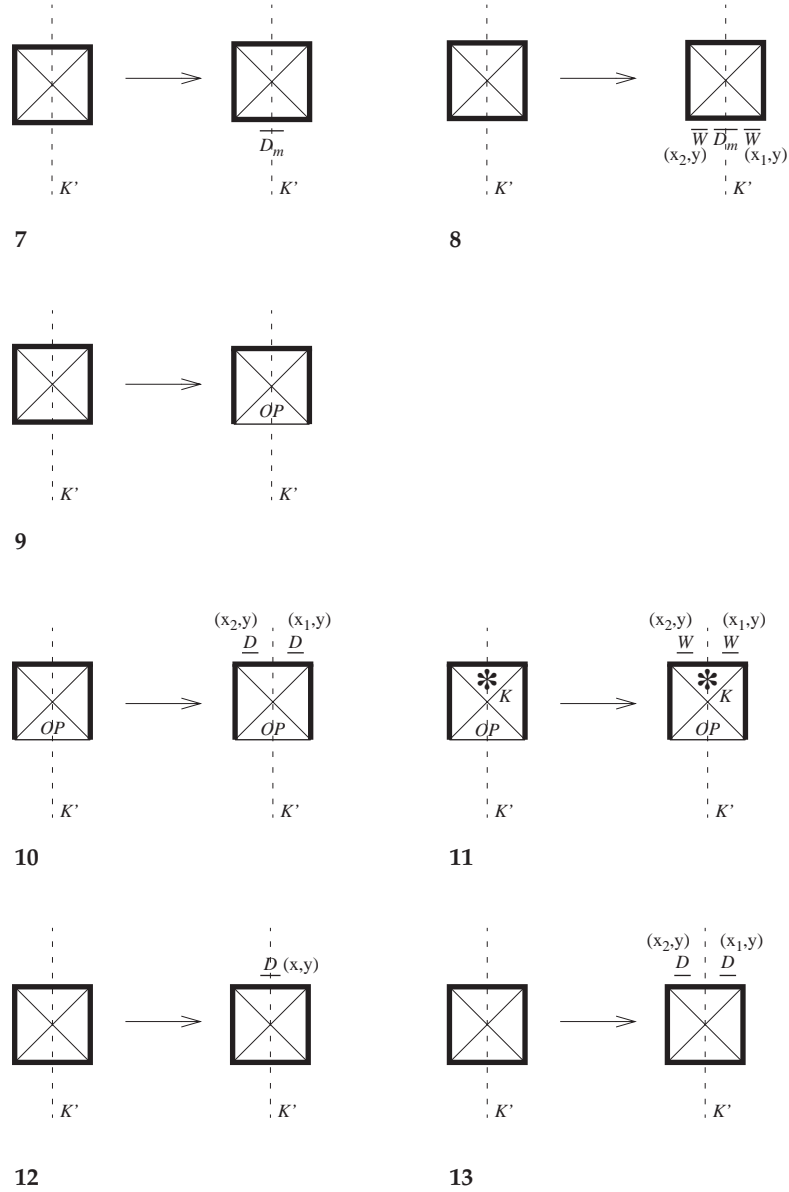

Figure 4.7. (Stage 3) Rules for adding openings to the central room.

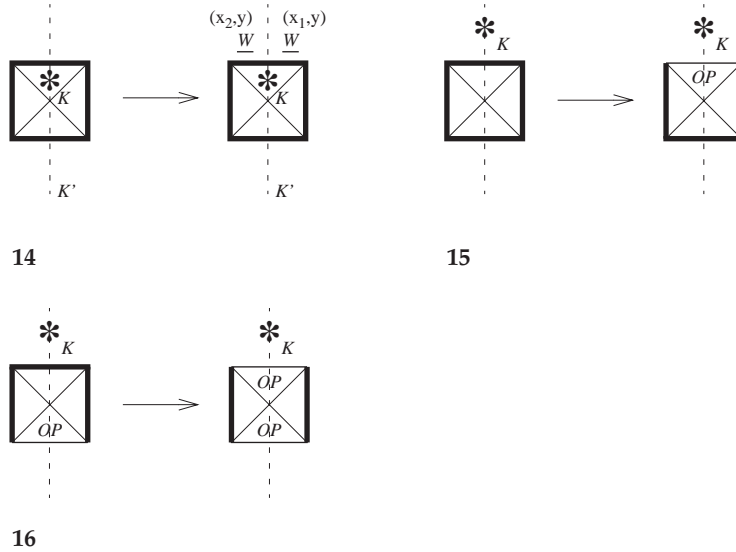**14**   **15**

16

Figure 4.7 (continued).

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 only applicable 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 4.8, 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.[15] The width w' is typically between 80-90% of w. For convenience, we may assume $w' \approx 0.9w$.

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
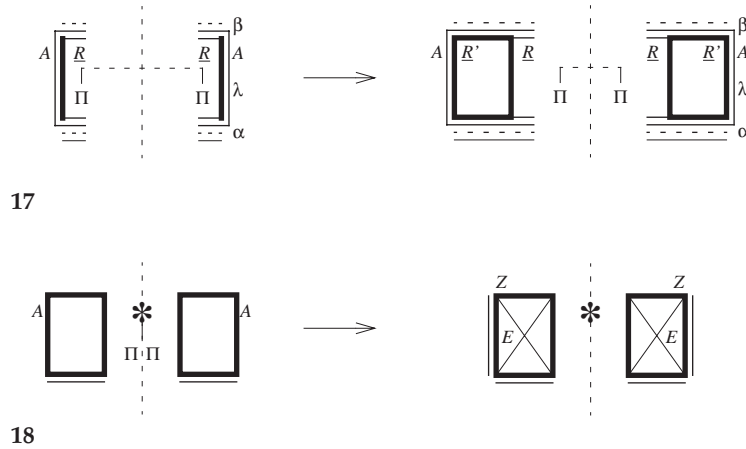
Figure 4.8. (Stage 4) Rules for generating rooms in a main building.

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 4.9.

---

15. 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 semi-public functions such as the kitchen, dining, or storage, which required a larger space.
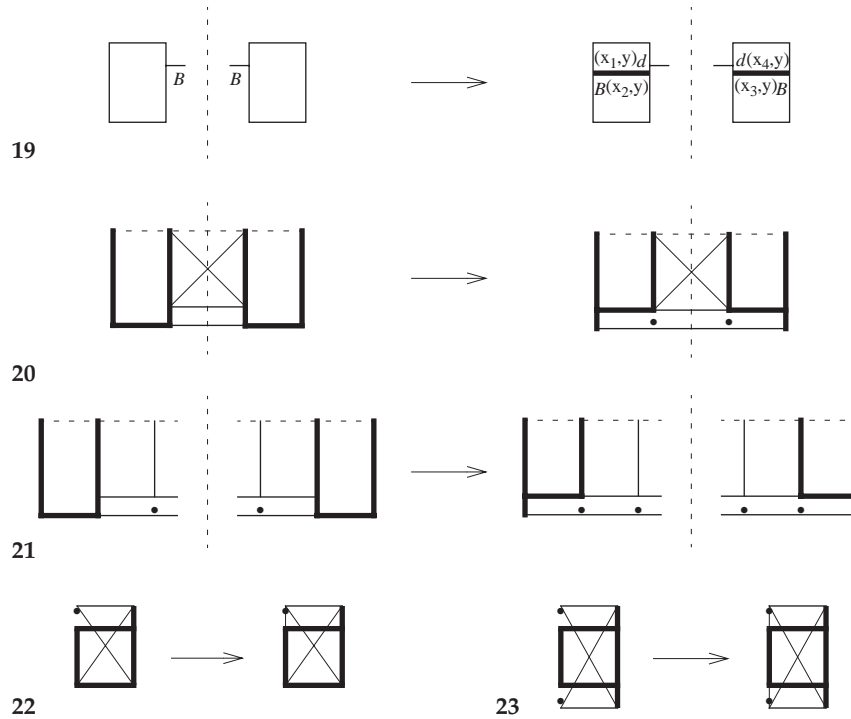
19

20

21

22

23

Figure 4.9. (Stage 4) Rules for refining rooms in a main building.

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 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 4.10, fall into two main categories, one group (rules 24-30), which insert placeholders for doors in partition walls,
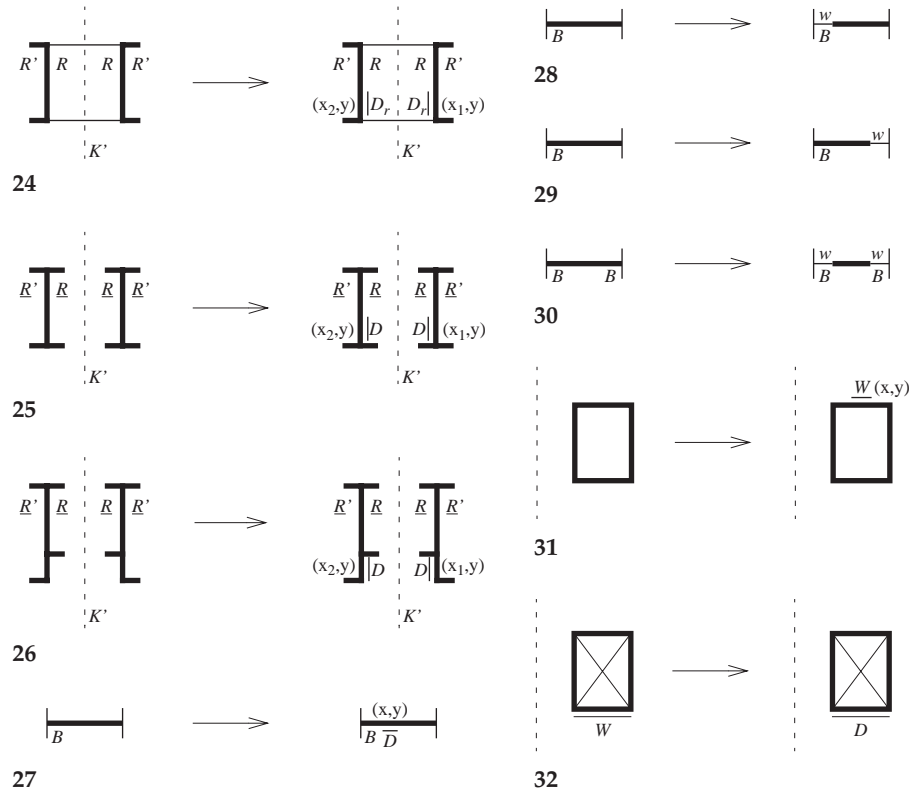
Figure 4.10. (Stage 5) Rules for generating windows and doors in a main building.

and the other group (rule 31) which insert 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[16] (see Figure 2.20). That is, the light beam

---

16. 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.

would not have been inside the range of the door (D_r). Moreover, the *Kè-jiā* believed that the light beam 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 *Mǐn-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 <u>R</u> and <u>R</u>' 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* respectively represent the length (vertical dimension) of the opening, its width, and its height measured from the ground. *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 4.11.
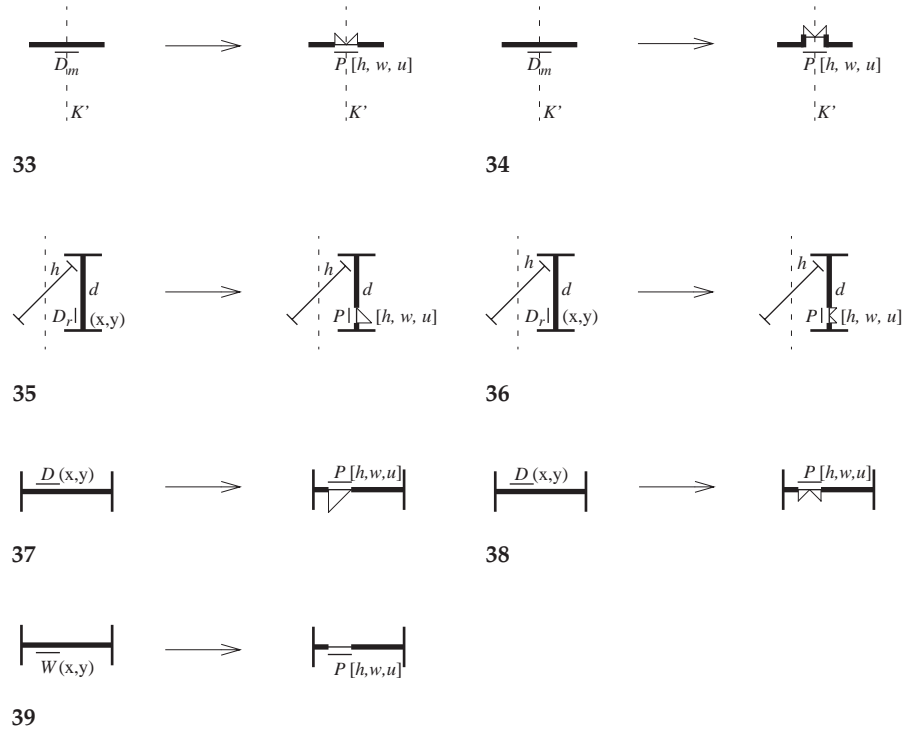
Figure 4.11. (Stage 6) Rules for replacing doors and windows by their icons.

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 2.20. The depth of the entrance porch is given by the stride measure, generally, minus one stride.[17] Also, there can be no beams within the trace of the door opening.

Rules 35 and 36 create a one- 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 can not be positioned inside the range of door. Again, see Figure 2.20.

---

17. The depth of the entrance porch was possibly determined by the *chǐ-bái* and *cùn-bái* (see Section 3.4.2).

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.[18] The dimensions, width (w) and depth (d), were determined by an odd number of strides, using the stride measure.

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.[19]
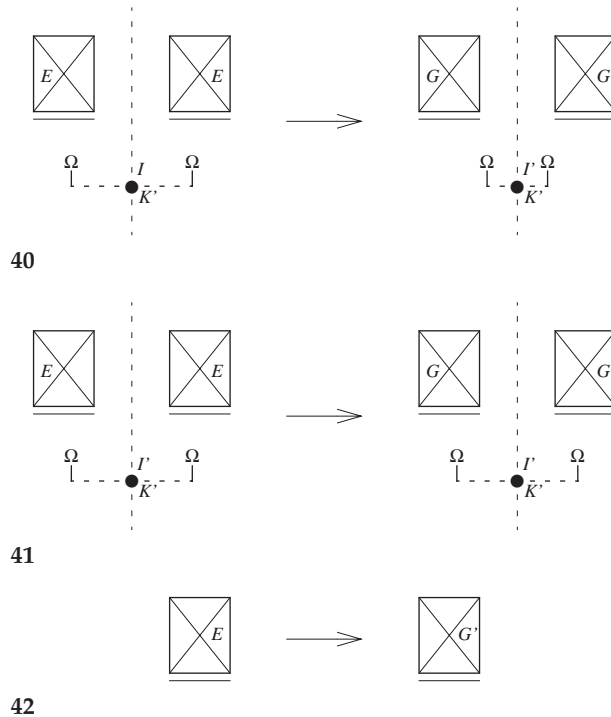

Figure 4.12. (Stage 7) Rules that mark the generation of a courtyard and secondary buildings.

18. One main building with a single secondary building (forming a L shape), can also define a courtyard. However, this case is not considered in this dissertation.

Rules 40 through 42 (Figure 4.12) mark the generation of a courtyard and secondary buildings. Rule 40 decrements, by two units, the scale bar $\Omega\Omega$. 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.

Rules 43 through 51 create courtyard enclosures. See Figures 4.13 and 4.14. The front walls shown in rules 43 through 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.

Rule 51, shown in Figure 4.14, generates a 'large' courtyard; the secondary buildings enclose both the courtyard and the main building.

The last four rules, also shown in Figure 4.14, 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'*.

---

19. 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.

47
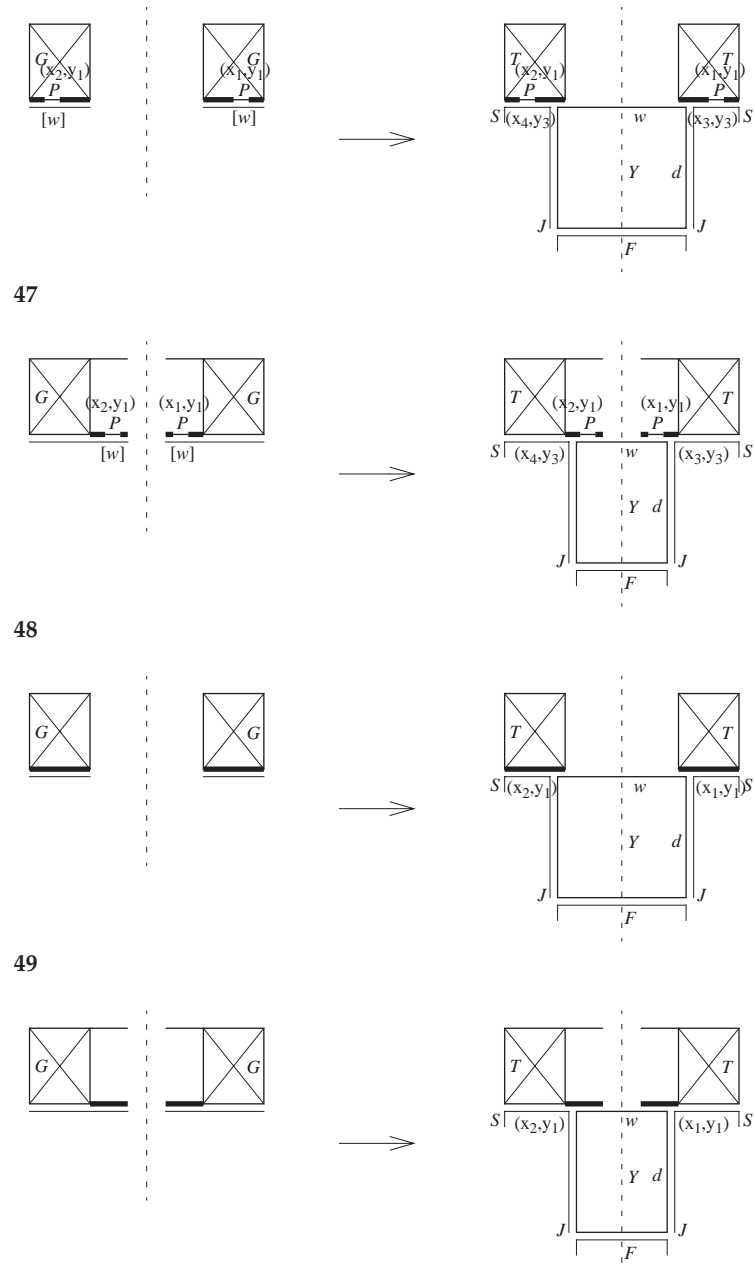

48

49
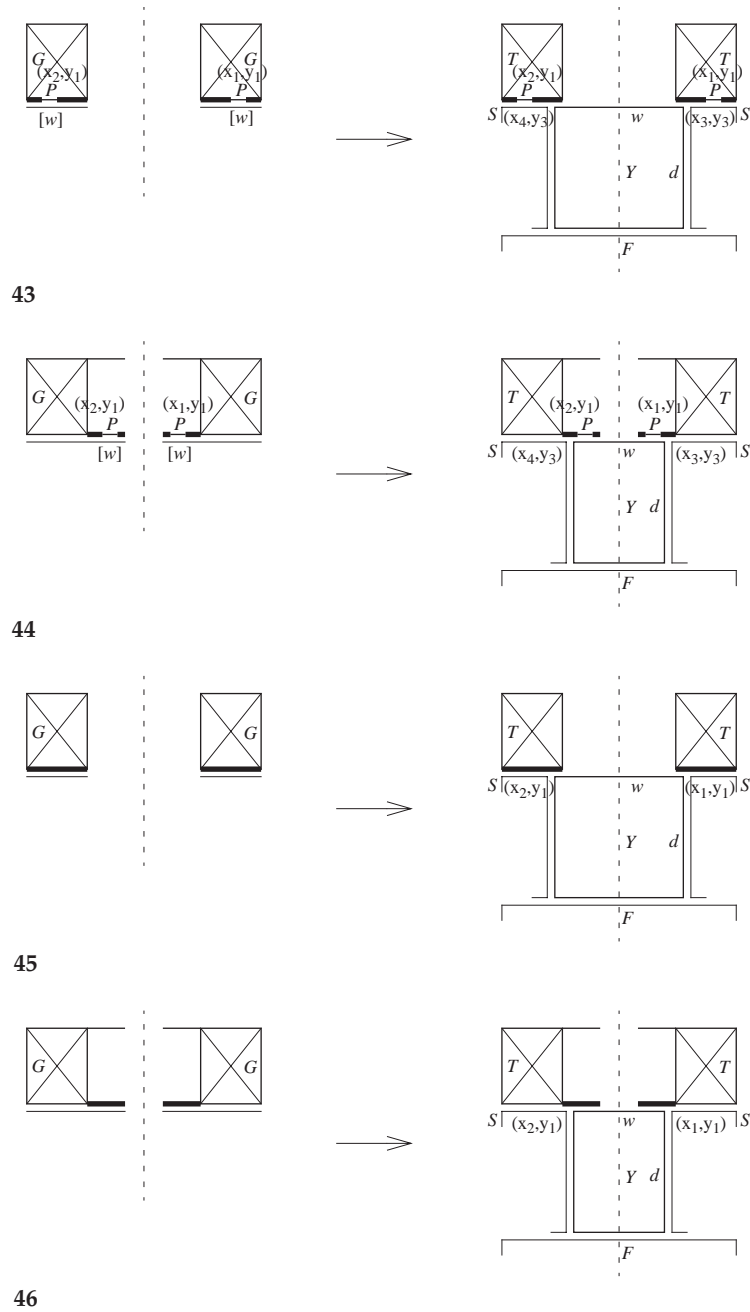

50

Figure 4.13 (continued).

Figure 4.13. (Stage 7) Rules for generating courtyards enclosed by
inner secondary buildings.
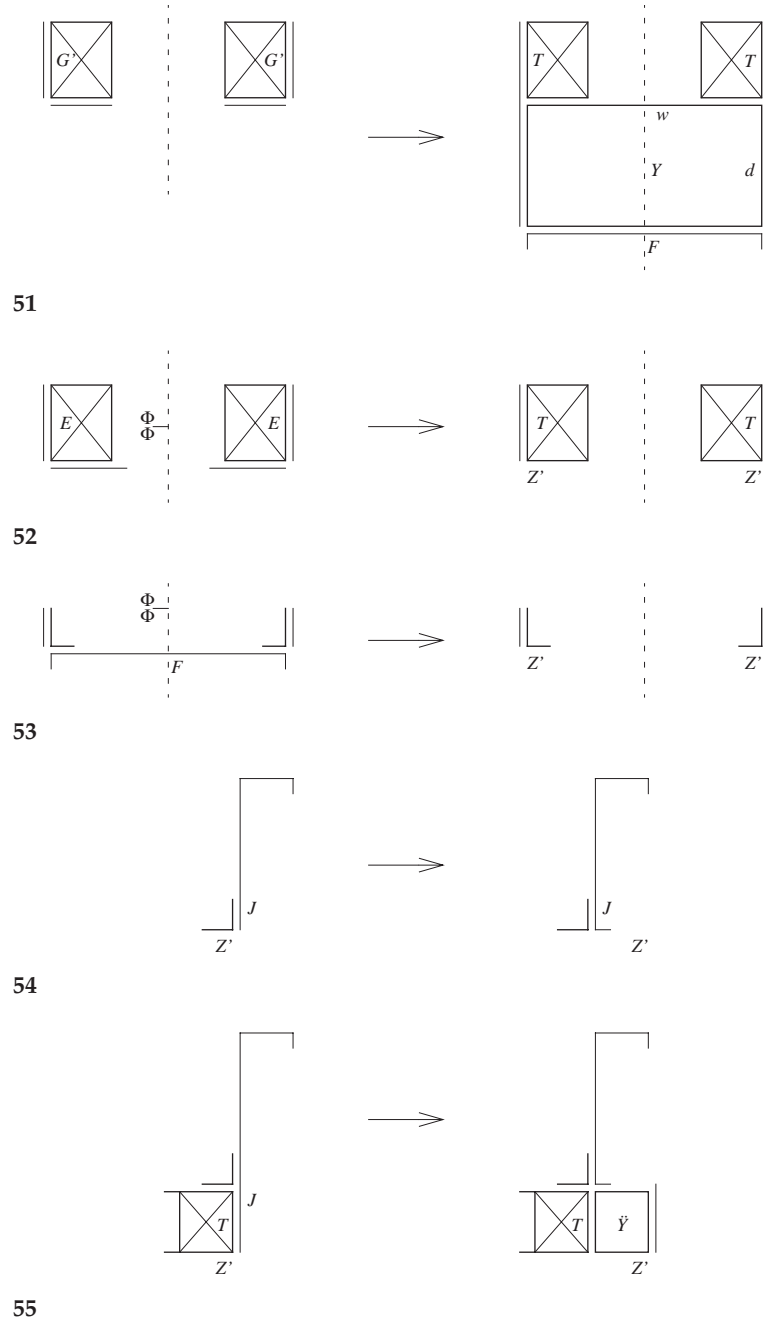
51

52

53

54

55

Figure 4.14. (Stage 7) Courtyard and terminating rules.

The last two rules, 54 and 55, constrain the inner secondary buildings; in particular, rule 55 adds a small corner yard to the 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. Then:

- 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.
- The central room had the largest width among the rooms in the secondary building.
- The total length of the secondary building was determined by the depth of the courtyard.
- 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.
- The basic width of a room in a secondary building was based on its length and the number of rooms in the building.
- $h' < h$, $w' < w,$ and in general, $d' < d$. Also $w' < h'$.
- 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 4.15, 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 4.16, 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
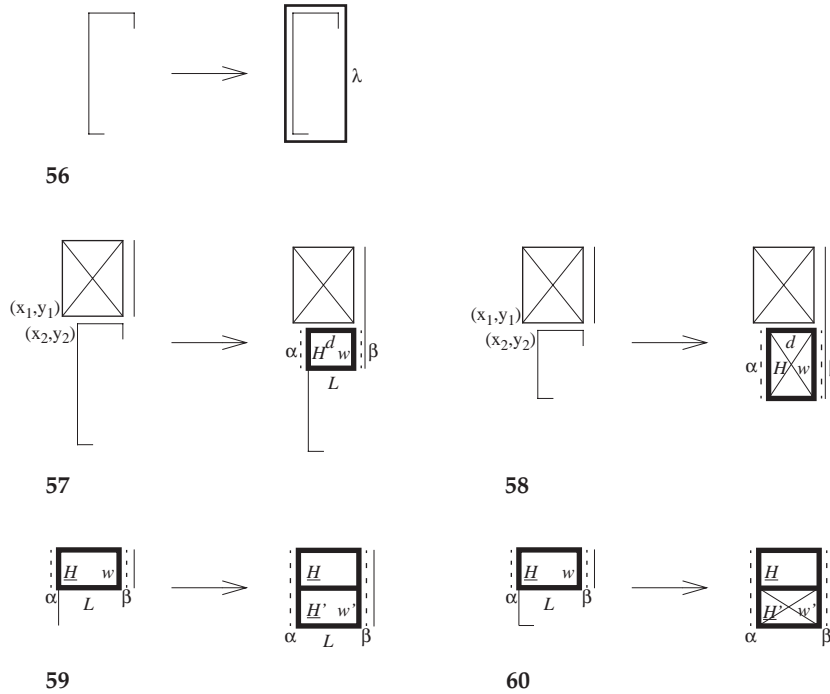
Figure 4.15. (Stage 8) Rules for generating rooms in a secondary building.

procedure (Section 3.4.1). 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.

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
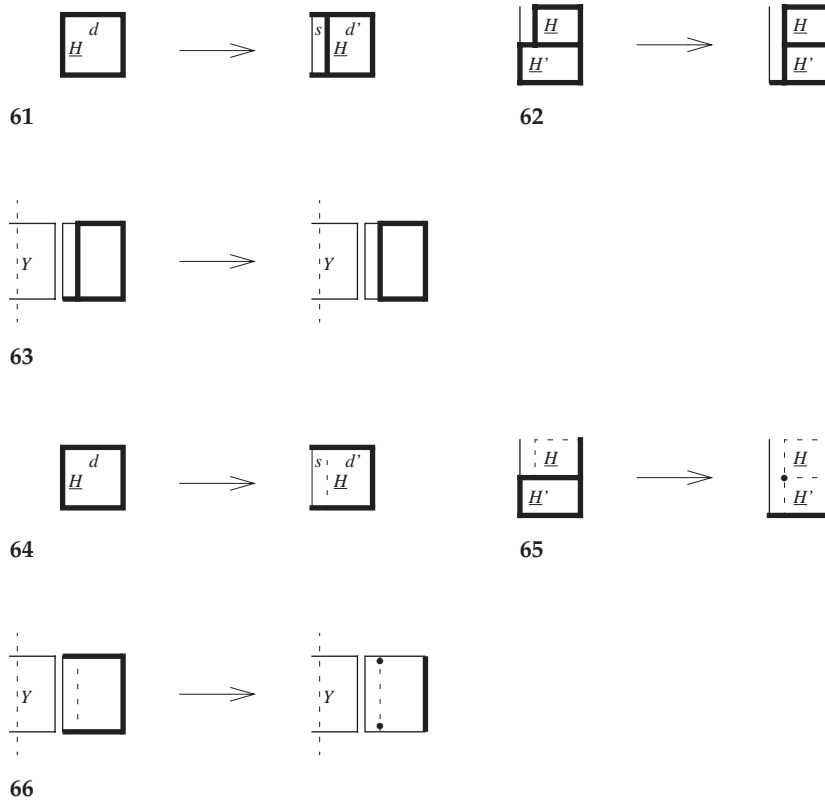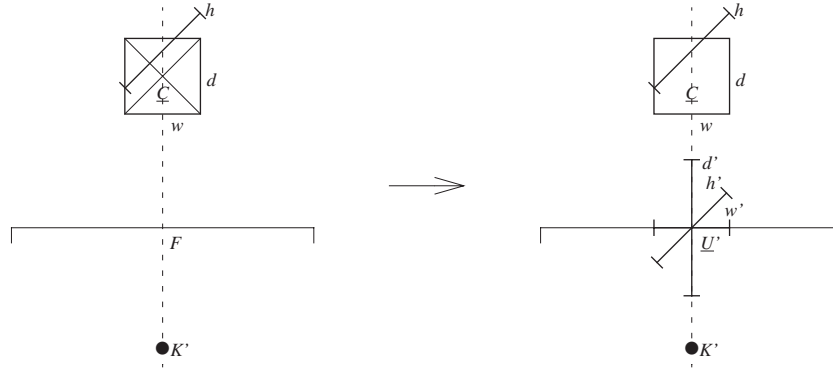

Figure 4.16. (Stage 8) Rules for adding porches and refining rooms.

67

Figure 4.17. (Stage 9) Calculate the fortunate dimensions of a new main building.

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:

$h' = f_h(\text{orientation}, h)$.
$w' = f_w(\text{orientation}, w)$ and possibly $w' \leq h'$ and $w' \leq w$.
$d' = f_d(\text{orientation}, d)$ and $d' \approx 1.3 \times h'$ and $d' < d$.
For convenience, we may assume $w' = h'$ and $d' = 1.3 \times h'$.

In the shape rule shown in Figure 4.17, 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 4.18 each generate the central room (hall) located on the symmetrical line. In addition,
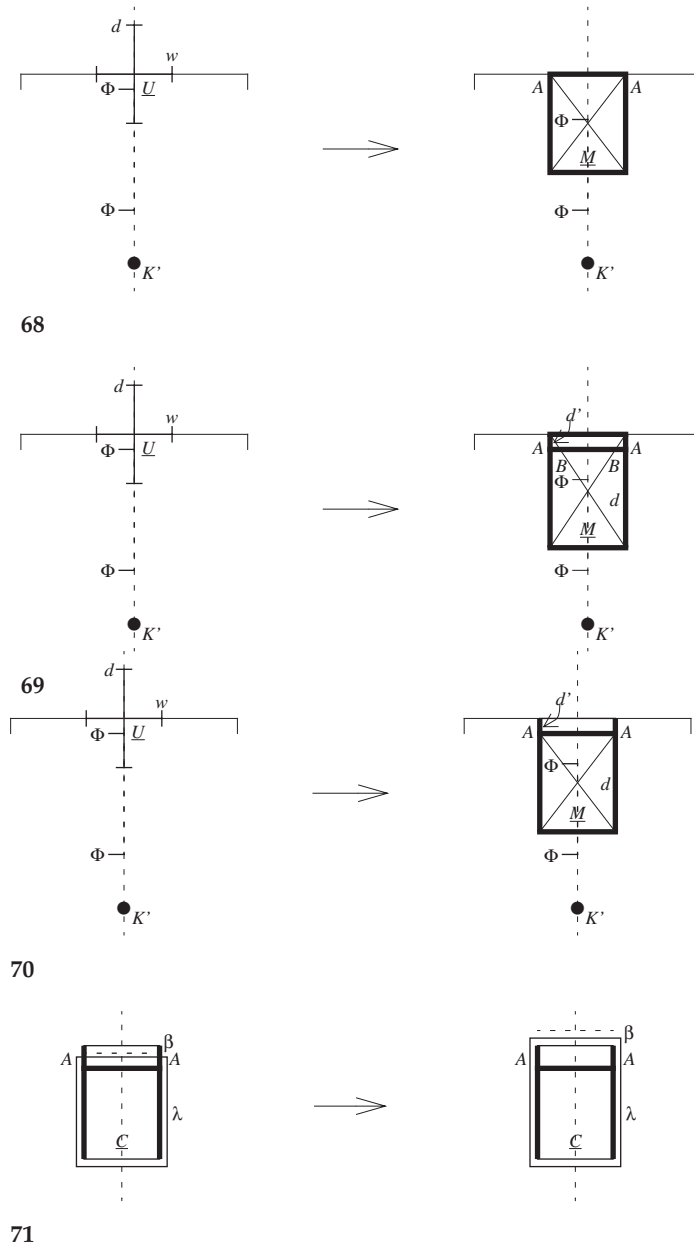

Figure 4.18. (Stage 10) Shape rules for generating the central room of a main building.
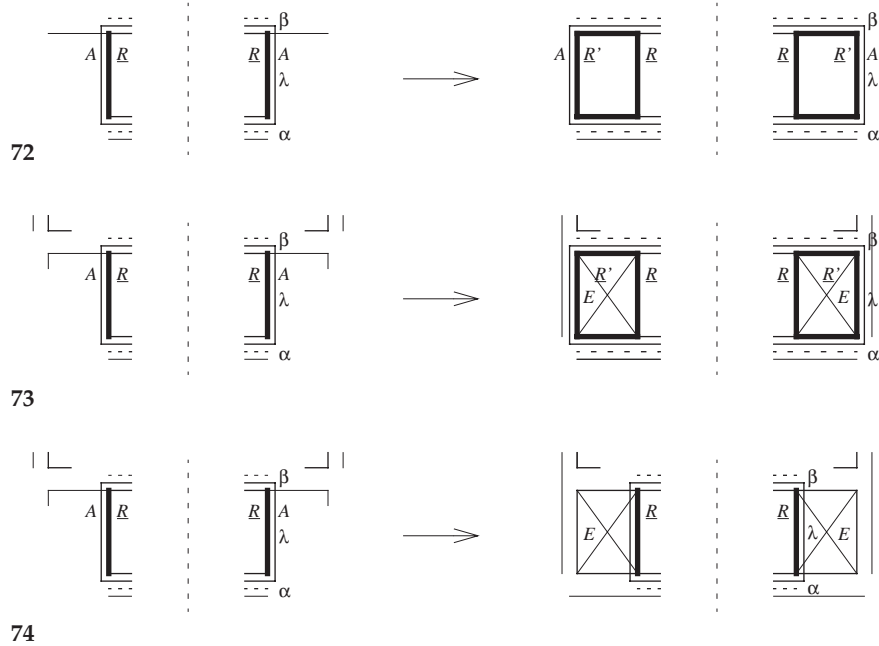
Figure 4.19. (Stage 10) Rules for generating rooms in a main building.

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 of the rear porch, is usually one stride less than the value given by the stride measure. In each rule, label $\underline{U}$ is replaced by label $\underline{M}$ 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 4.19, 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.

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. Shape rules 75 and 76 add a
secondary building. Rule 75 does so directly without a 'passing room;' rule
76 by inserting a space in front of the secondary building. Shape rule 77
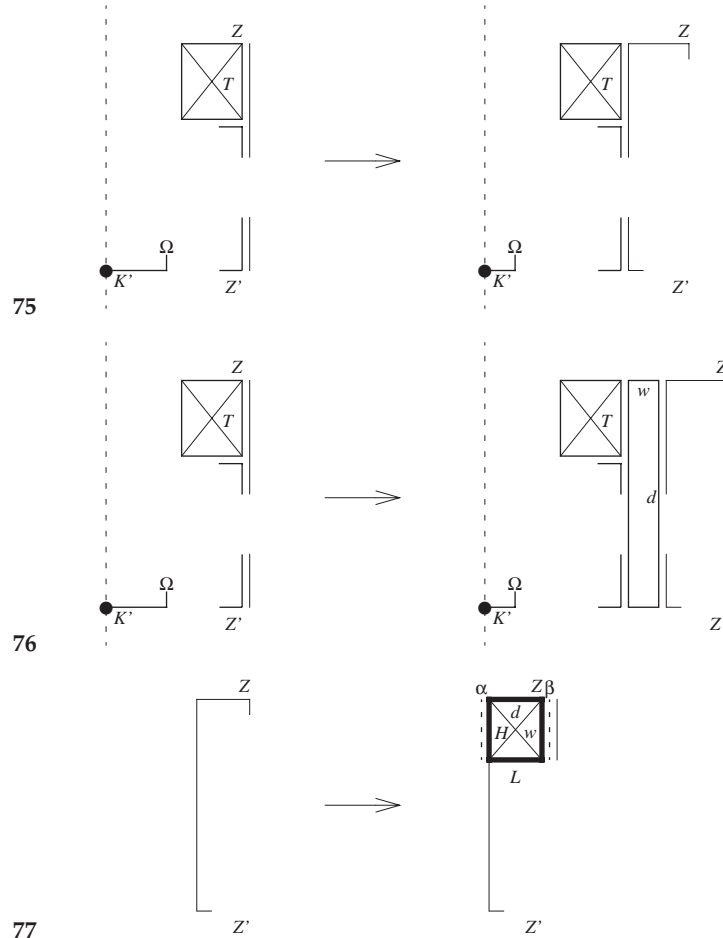creates the first room in this building. See Figure 4.20.

Figure 4.20. (Stage 11) Shape rules for generating secondary buildings
               that surround main buildings.

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 4.21.

Rule 78 adds a passing room that will allow the secondary building to be
generated inside it. Usually, $d' \leq d$, where d' and d are the depths of the
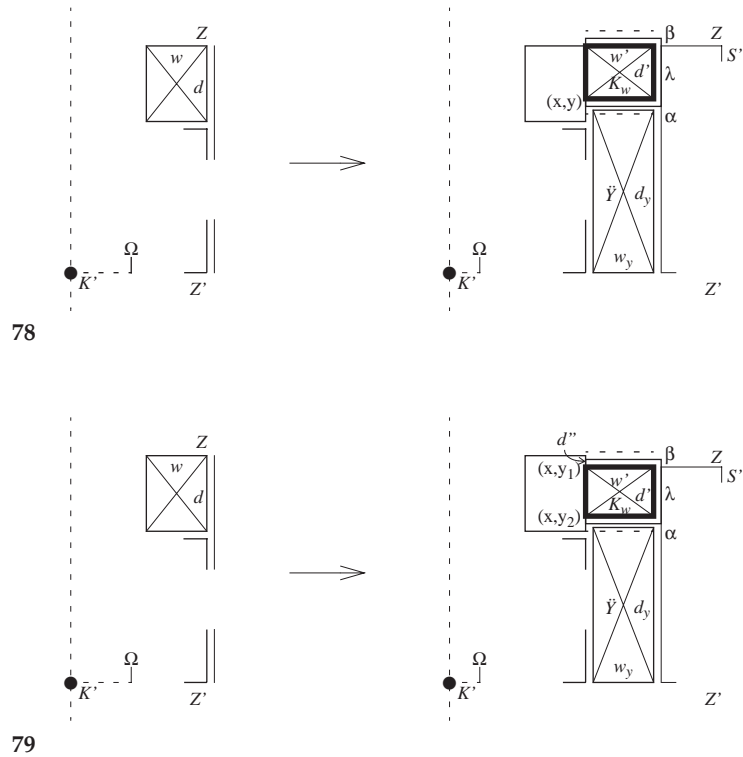
Figure 4.21. (Stage 12) Shape rules for generating secondary buildings that
connect with the main building through a passing room.

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 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, $d_1' \leq d_1$, and $d_2' \leq d_2$, 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.

Figure 4.21 (continued).

Rule 82 creates an additional passing room that connects the secondary building to the end room of the main building.

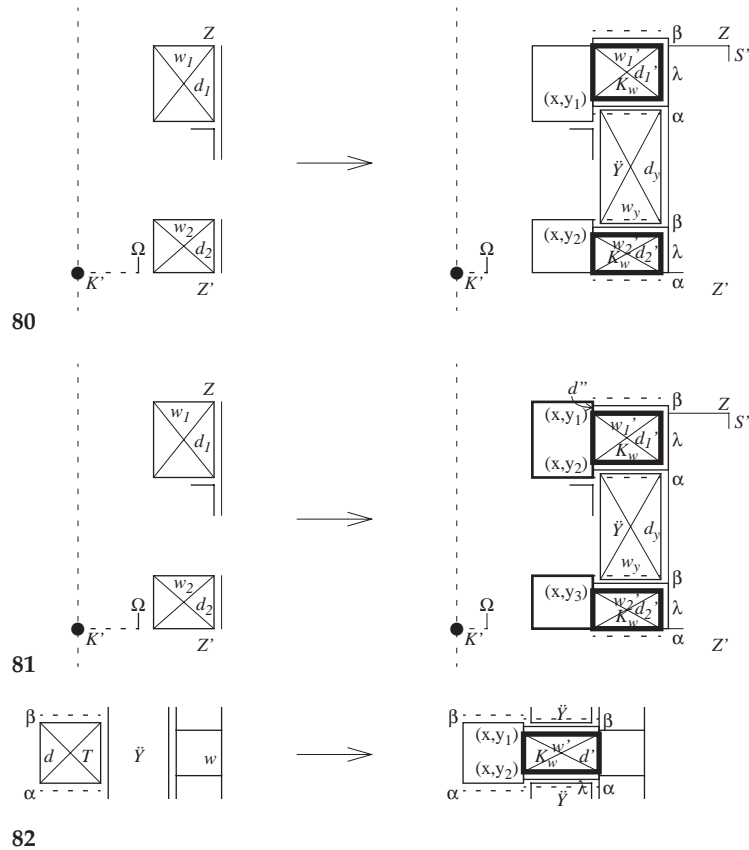For technical reasons that are required for the shape grammar formalism, we need one additional rule in this stage. Rule 83, shown in Figure 4.22, erases labels Z and Z' so that no further secondary buildings can be generated.
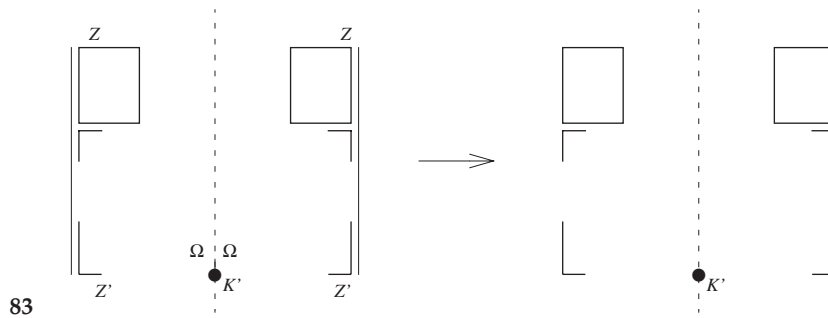
Figure 4.22. (Stage 12) Terminating rule.

Stage 13: Add openings to the secondary buildings

The shape rules are given in Figure 4.23.

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 through 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.
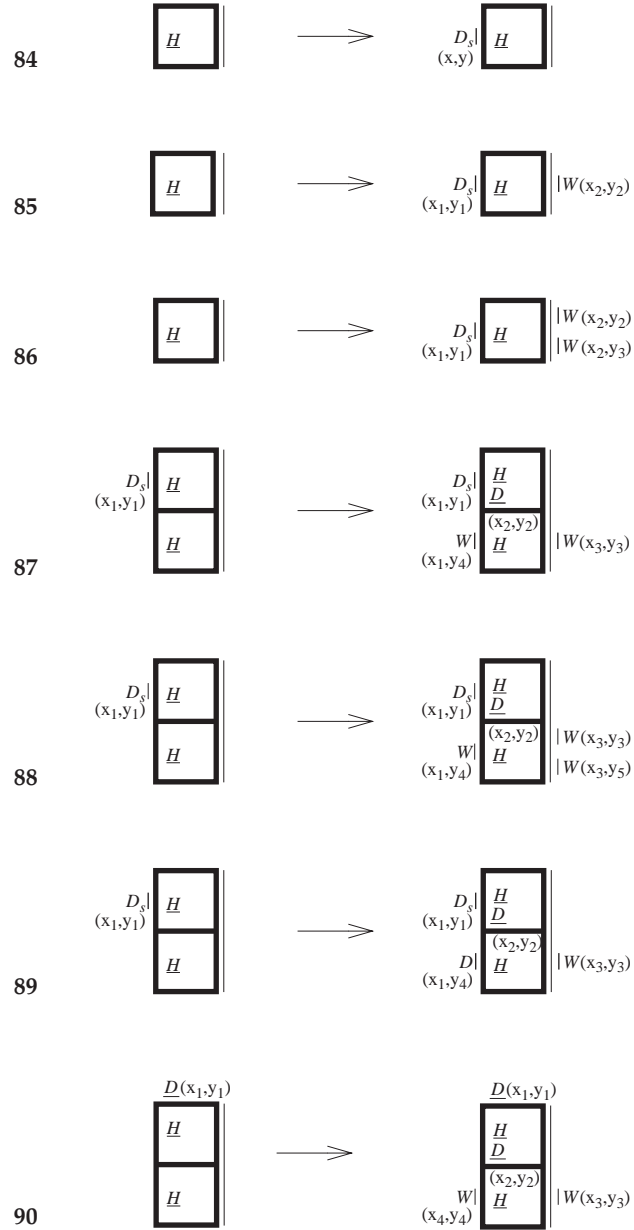
Figure 4.23. (Stage 13) Rules to add openings to secondary building.

91

92 $\overline{D}_s(x,y) \longrightarrow \overline{D}(x,y)$

93 $\overline{D}_s(x,y) \longrightarrow P[h, w, u]$

Figure 4.23 (continued).

Stage 14: Generate platforms

The shape rules are shown in Figure 4.24. 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.
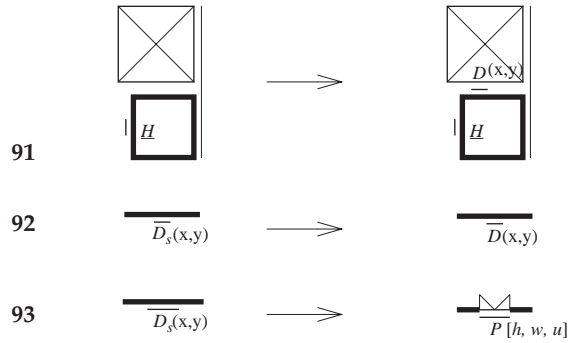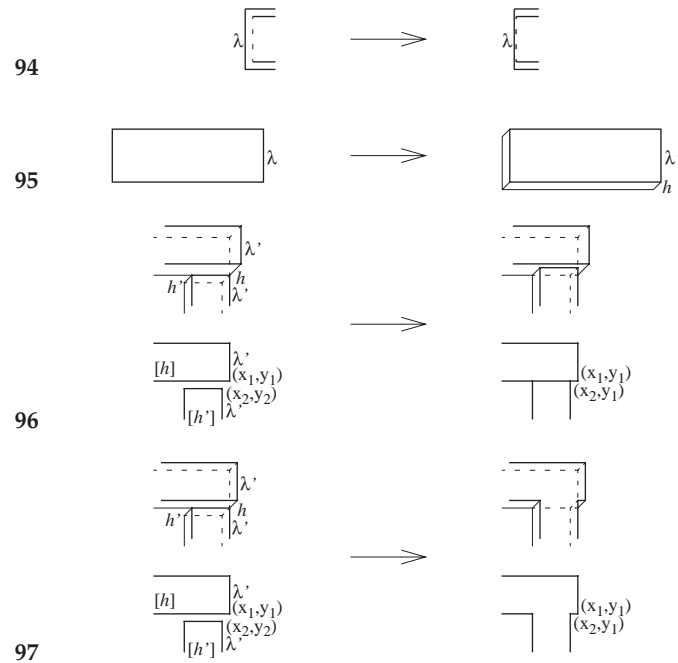

94

95

96

97

Figure 4.24. (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,[20] which are illustrated in Figure 4.25.
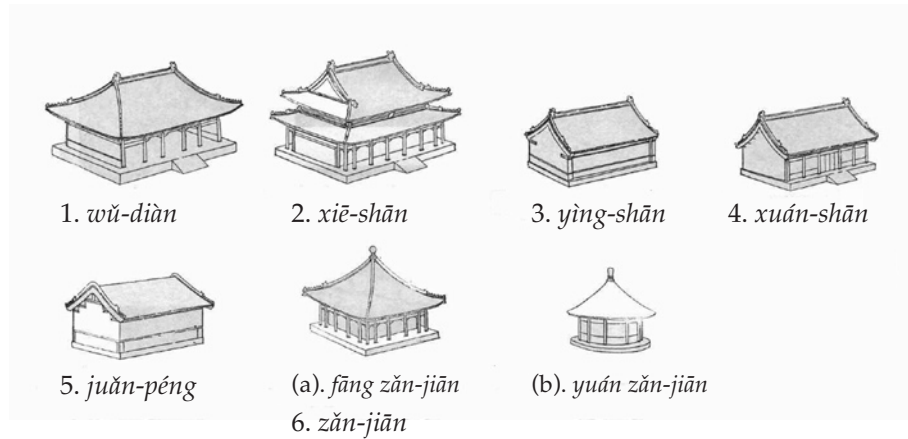
Figure 4.25. Various types of roofs. (After Liu, 1984: 383)

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.

---

20. *Wŭ-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 *wŭ-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 multi-roof generally holds a higher status than a single roof. The roofs in Figure 4.25 are given in their hierarchical order. That is, a *wŭ-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. See Figure 2.16.

The shape rules are given in Figure 4.26.

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 <u>R</u> or <u>H</u> (both representing rooms in the main or secondary buildings).
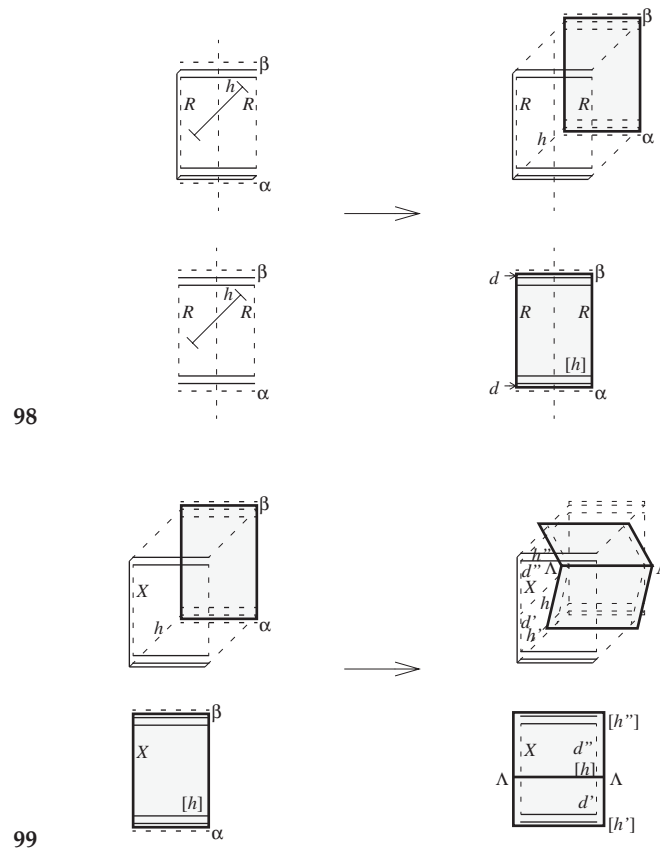
Figure 4.26. (Stage 15) Rules for creating roofs.

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, $n \geq n'$, $n \geq n''$ with $n' \approx n''$.
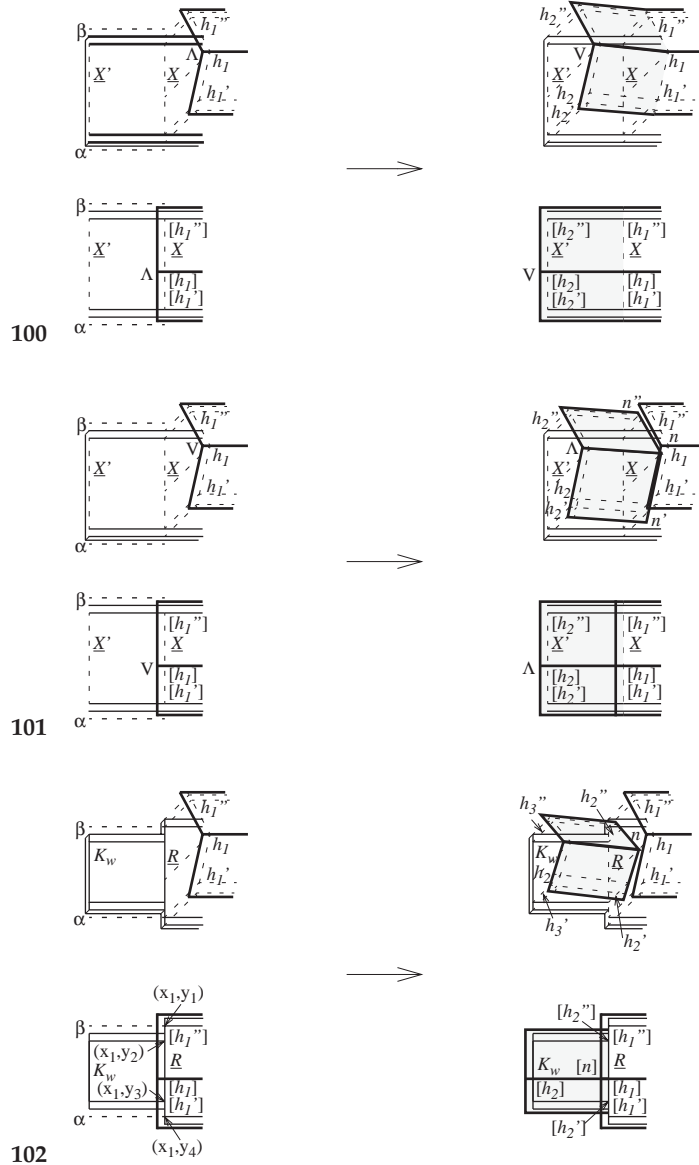
Figure 4.26 (continued).

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, $h_1{}' < h_2 < h_1$.

103

104

105

106
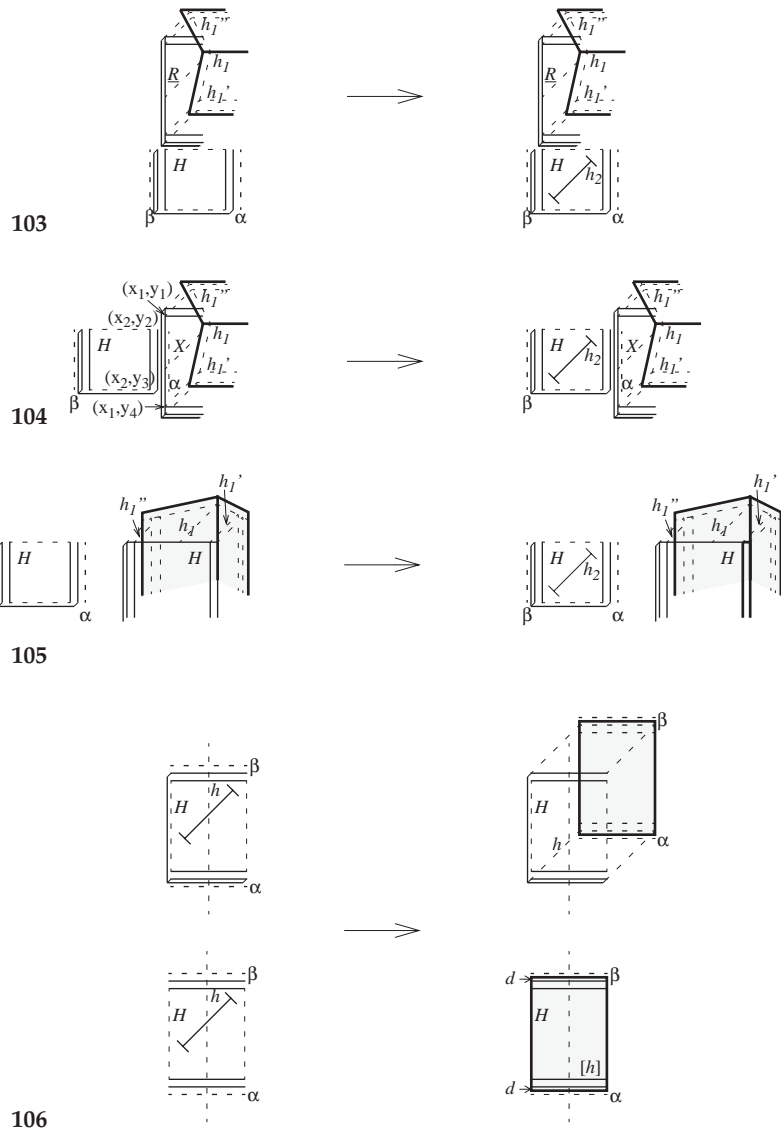
Figure 4.26 (continued).

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 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, $h_2 \geq h_1$.
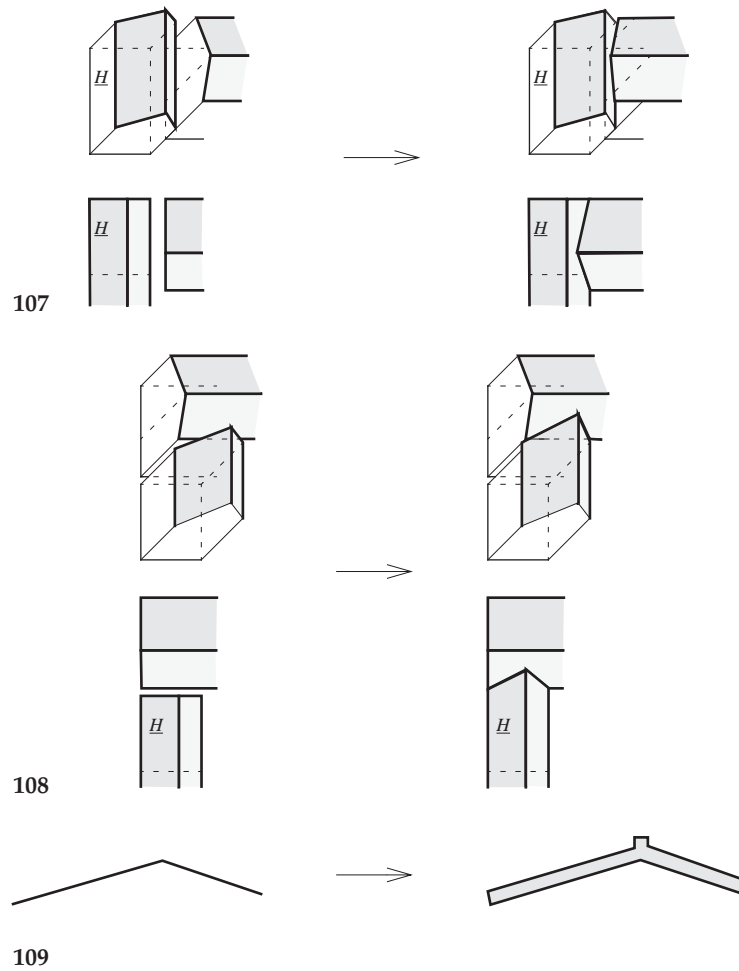
Figure 4.26 (continued).

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 2*d*, 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).

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 4.27. Rules 110 and 111 create two solid walls that intersect in plan at a point to form a corner or a T-junction, respectively.
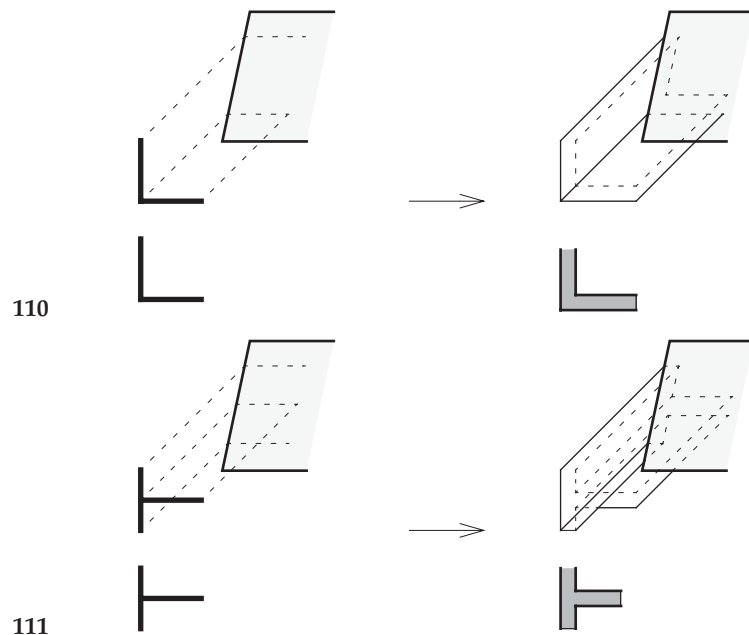
Figure 4.27. (Stage 16) Rules to transform lines to three-dimensional walls.

Likewise, rules 112 and 113 create a wall and an opening that intersect, in plan, at a point. In first case, the two form a corner, and in the latter, they form a T.

Similarly, rules 114 and 115 deal with the situation when a wall intersects, in plan, an opening of a room, at a point.
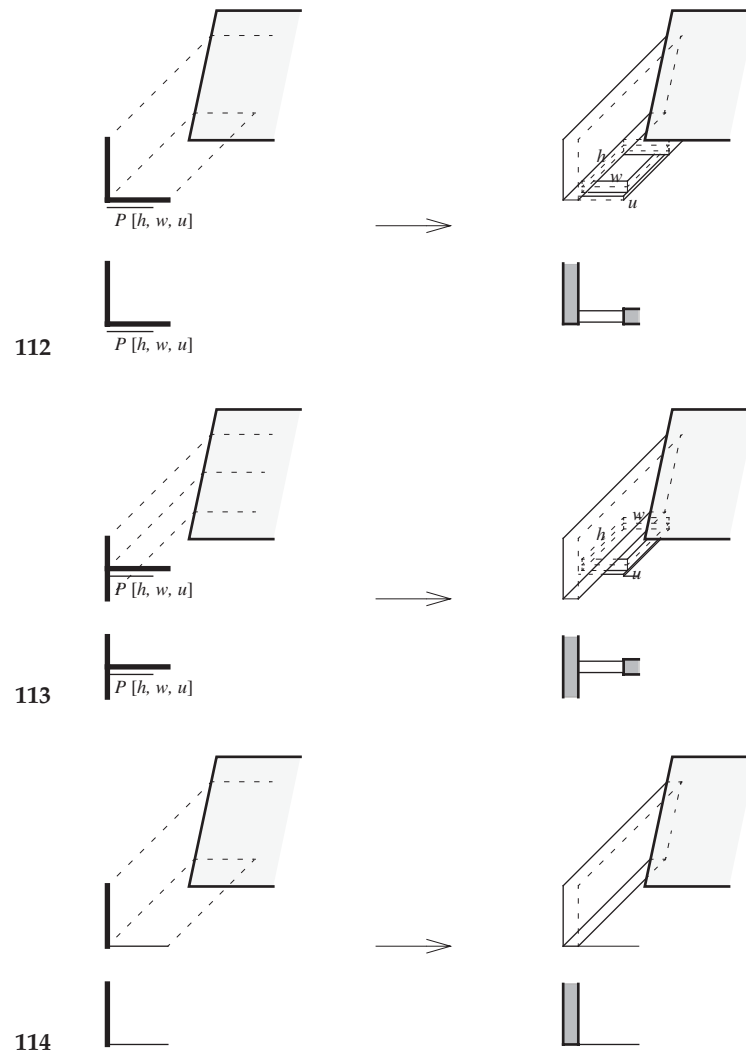
Figure 4.27 (continued).
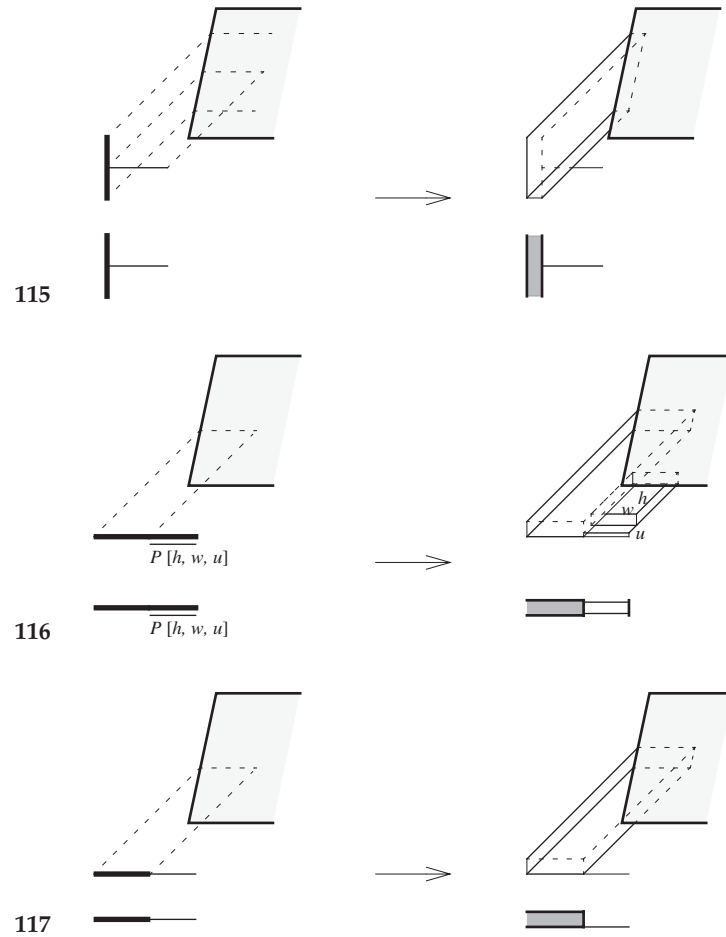
Figure 4.27 (continued).

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.
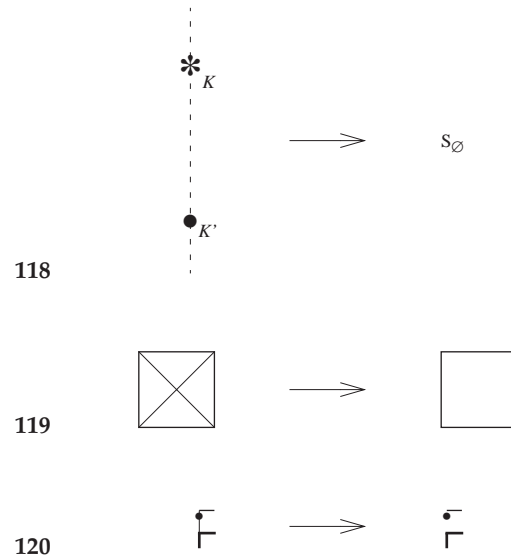
Figure 4.28. (Stage 17) Termination rules.

There are basically four shape rules in this stage, the first three of which are given in Figure 4.28. The fourth shown below is really 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 through 138, by substituting for the variable X, the labels A, $Å$, B, $\underline{C}$, $\underline{R}$, $\underline{H}$, K_w, E, T, S, S', Y, $\ddot{Y}$, Λ, V, λ', I, and I'.

$$(0,0): X \quad \longrightarrow \quad s_\varnothing$$

Chapter 5:
Examples of
Vernacular Dwellings

The efficacy of the parametric shape grammar for Taiwanese traditional vernacular dwellings is best illustrated through examples. In this chapter I consider, in increasing order of complexity, five exemplar dwellings that were all built in the nineteenth century. Of these, the *Zhōu* family house, *Dūn-běn-táng*, the *Zhāi-xīng Shān-zhuāng*, and the *Lín* family great house were built in the latter half of the nineteenth century; the last example, the *Lín-ān-tài* residence was built in the 1820s. The *Zhōu* family house is a small house and exemplifies the basic type of *sān-hé-yuàn*. The *Dūn-běn-táng* is an archetypal house. The *Lín-ān-tài* residence, the *Zhāi-xīng Shān-zhuāng*, and the *Lín* family great house are mansions.

Figure 5.1, taken from Kwan (1989), illustrates typical site plans for Taiwanese traditional dwellings. The site plans corresponding to the four of the examples considered in this chapter are indicated in the figure. The fifth example, *Zhāi-xīng Shān-zhuāng*, is not included in Kwan's collection of typical site plans.
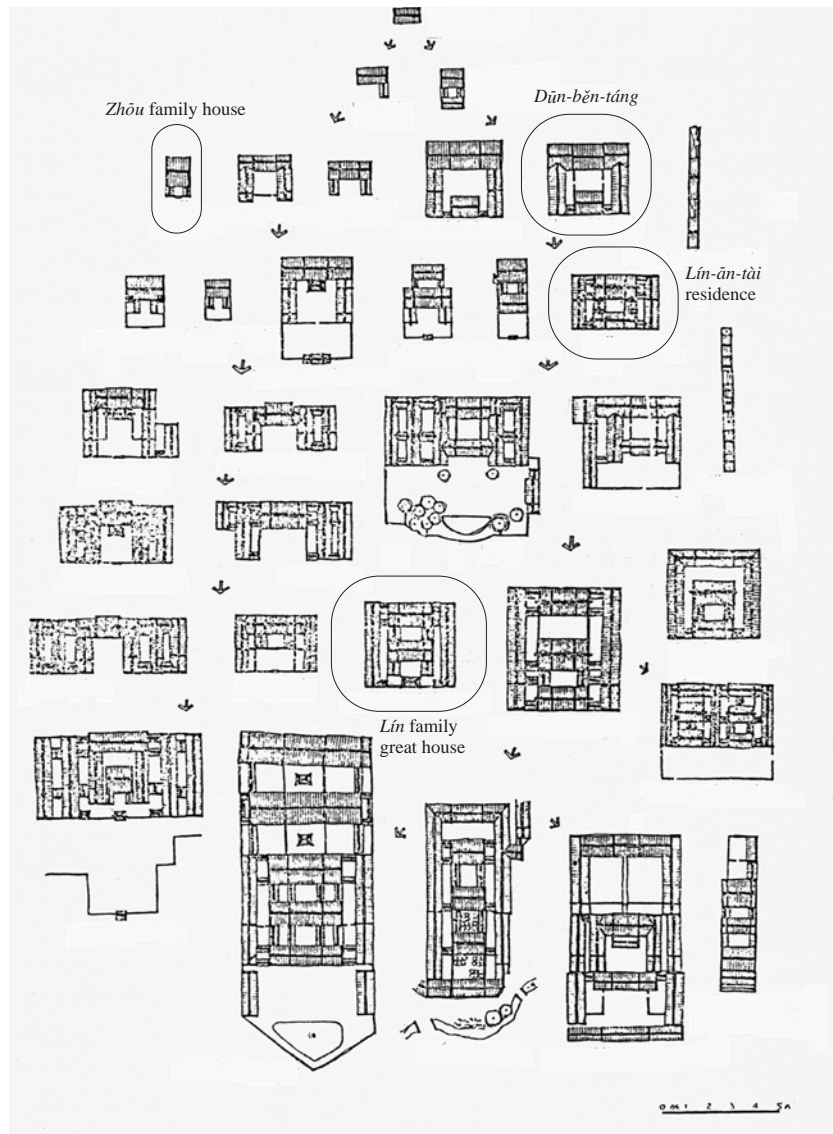
Figure 5.1. Typical site plans of Taiwanese traditional dwellings. (After Kwan, 1989: 36)

The generation of each example dwelling is given in a series of derivations, each of which may subsume one or more shape rule applications. The shape rules are listed, in the order in which the rules are applied, beneath the derivation symbol $\Rightarrow$. Where a rule is superscripted by a number, say n, the particular shape rule is applied n times in succession. Where a rule is enclosed within brackets [ ], the effect of the rule application is not illustrated because of the scale or resolution of the illustration. The shape rules correspond to those described in Section 4.3.

5.1 The Zhou Family House in Taipei

The *Zhōu* family house is a compact adaptation of a farmhouse, located in the *Wàn-huá* District, Taipei.[1] In plan, shown in Figures 5.2 and 5.3, it bears a similarity to houses of limited space found in urban surroundings. The house has one main building, two secondary buildings and three rooms in the principal building.

The house is a variant of the enclosure courtyard known as *jiē-wū* (a street house). In an urban setting, the site was rectangular with the narrow side
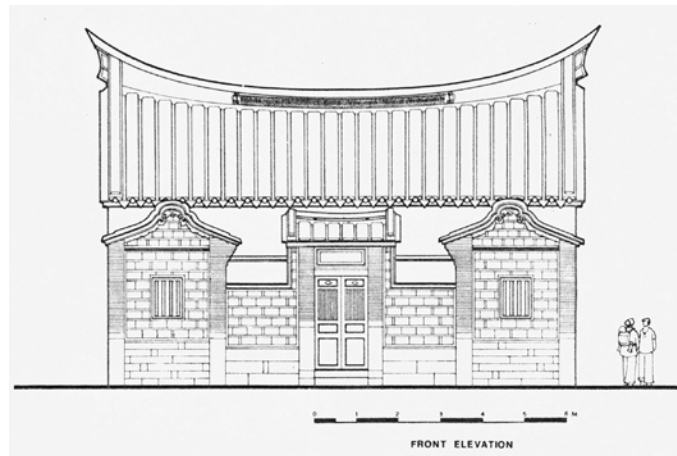
Figure 5.2. Front elevation of the *Zhōu* family house.
(After Dillingham and Dillingham, 1985: 12)

1.   *Wàn-huá* (as known as *Měng-jiǎ*) was the original city of Taipei.
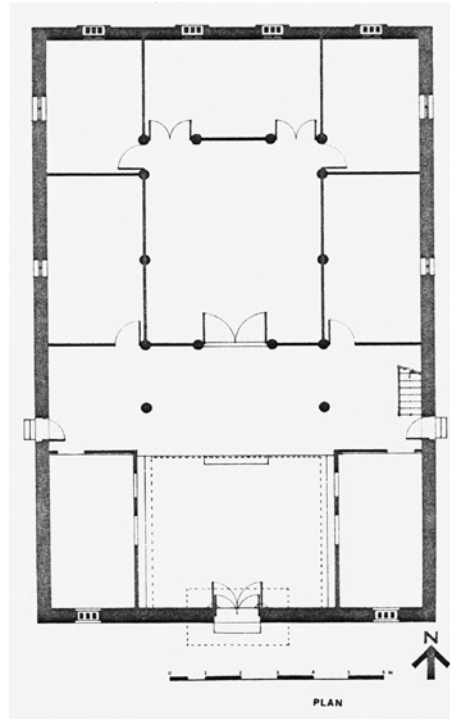
Figure 5.3. Plan of the *Zhōu* family house.
(After Dillingham and Dillingham, 1985: 15)

facing the street. Urban traditional dwellings followed much the same principles of the enclosure-courtyard as their rural compact counterparts. As can be seen from the elevation, in Figure 5.2, the roof is a *yàn-wěi* (swallow-tail) variation of the *yìng-shān* roof. The ridgepole is extended at either end and the roof is curved.

I now illustrate the generation of the floor plan and the *yìng-shān* version of the roof profiles.

Defining the initial shape

The artisan starts with a site which we indicate by an asterisk that marks the *key brick*, a location that the geomancer determines as fortunate for the owner. This is the initial shape.

(0,0)✻

Defining the scales of the building

We may approach the generation through the eyes of the artisan. The first step that the artisan takes is to decide upon the general layout and style in consultation with the owner, e.g., the number of *jìn*'s (enclosures), *lù*'s (routes), and *jiān*'s (bays), and so on. For this example, the numbers of *jìn*'s (ΦΦ) and *lù*'s (ΩΩ) are each one, and the number of *jiān*'s (ΠΠ) is three. We apply rule 1 to specify these scale bars.
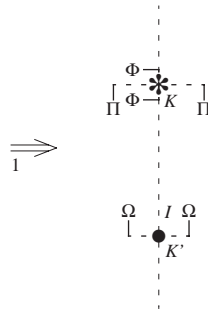
Computing the fortunate dimensions for the central room

Next, the artisan would have computed the fortunate dimensions for the central room (see Section 3.4.2). Rule 2 specifies the three fortunate measurements: height, *h*, width, *w*, and depth, *d*.
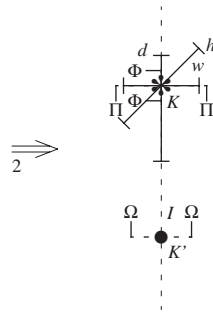
Generating the central room

Based on the fortunate measurements, the artisan generates the central room. The scale bars ΠΠ and ΦΦ are both decreased by one unit.
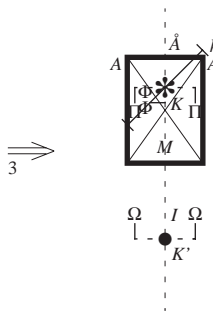
Adding extra space to the central room and refining it

By applying rule 4, the artisan adds an extra back space to the central room. The artisan can refine the central room by applying rule 6. He adds a front porch to the central room, marks the raised platform, and identifies the front and rear roofs. Once the central room is refined, the label *M* is changed to *C*.
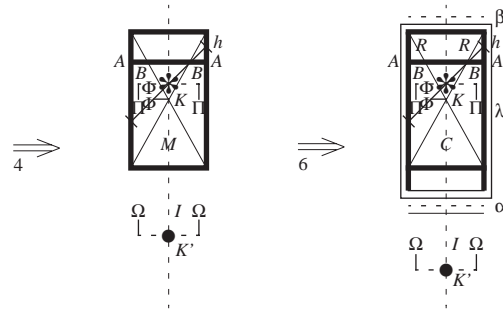
Adding openings to the central room

The artisan may add openings to the central room. Here, he applies rules 7 and 14 to add a main entrance to the front wall and two windows to the rear wall.
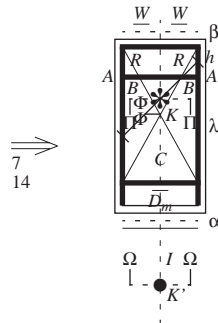
Extending the main building by adding rooms laterally on each side

Once the central room has been designed, the artisan extends the building laterally on either side until the total number of *jiān*'s in the principal building equals the intended value. The artisan applies rule 17 to add two rooms to the main building and decrease the bay scale bar (ΠΠ) by 2. As the bay scale bar becomes 0, he can apply rule 18 to mark the end room and eliminate further need for the scale bar. On the other hand, the artisan may extend the front porch by a *jiān* on each side (rule 20). For technical reasons, in order to apply rules at a later stage, rule 22 has to be applied twice.
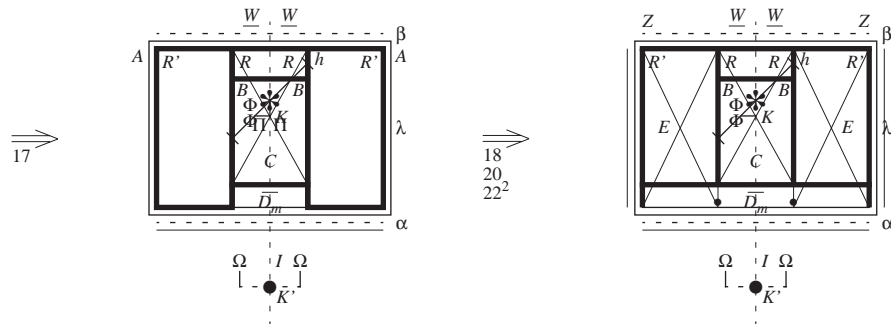
Refining the main building with openings and extra spaces

Before the artisan can finish the main building, he may add doors to the adjacent rooms (rules 26 and 27) and windows to each room (rule 31). Since the end room usually serves as a semi-public space, he may decide to replace the window by a door (rule 32). He may also decide to divide each room into two spaces (rule 19).
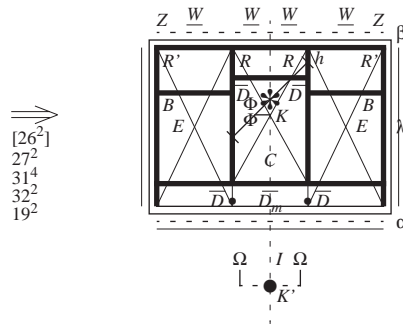
Generating a courtyard

In order to apply a courtyard in front of the main building, the artisan changes the label of end room to G and decreases the route scale bar ($\Omega\Omega$) by 2 for creating the inner secondary buildings (rule 40). Then, he applies rule 43

to create a courtyard, and marks the positions of the two inner secondary buildings.

Generating the layout of secondary building

Now, the artisan can add the label of raised platforms (rule 56) and rooms (rule 58) to secondary buildings. As the enclosure scale bar (ΦΦ) is 0, the label for generating the front-most main buildings is erased (rule 53).

Clearing labels

Once the artisan has designed the whole layout of the building, for reasons of clarity those labels that are no longer needed may be erased.

Generating the raised platform

The entire layout helps the artisan to start construction. Before this, he needs to work on the raised platform.
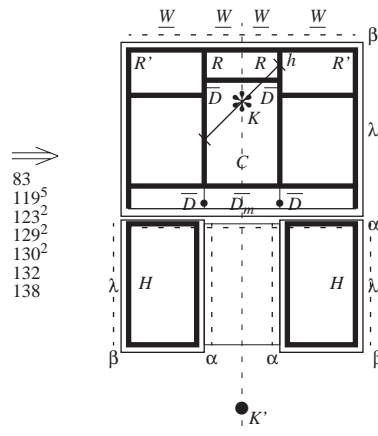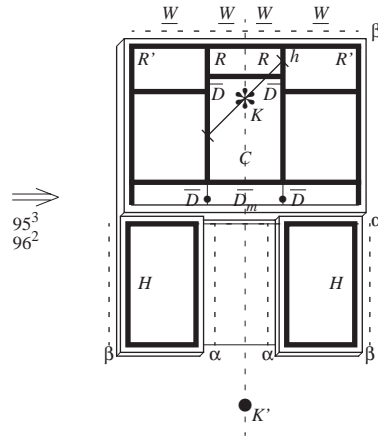
Generating the form of central room

The central room's design always plays an important role in a building's design and construction process. The artisan generates the three-dimensional form of the central room according to its layout and height.
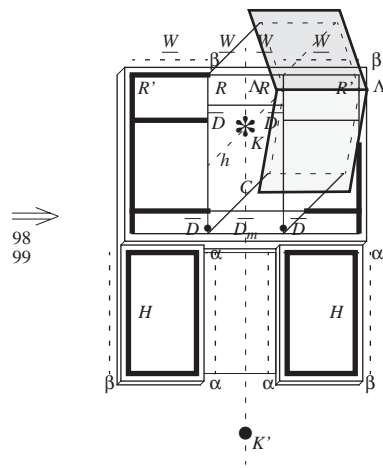
Generating the entire forms of main building and secondary buildings

On the basis of the design of the central room, the entire form of the main building can be defined. Finally, in a similar manner, the artisan can design the forms of the secondary buildings.
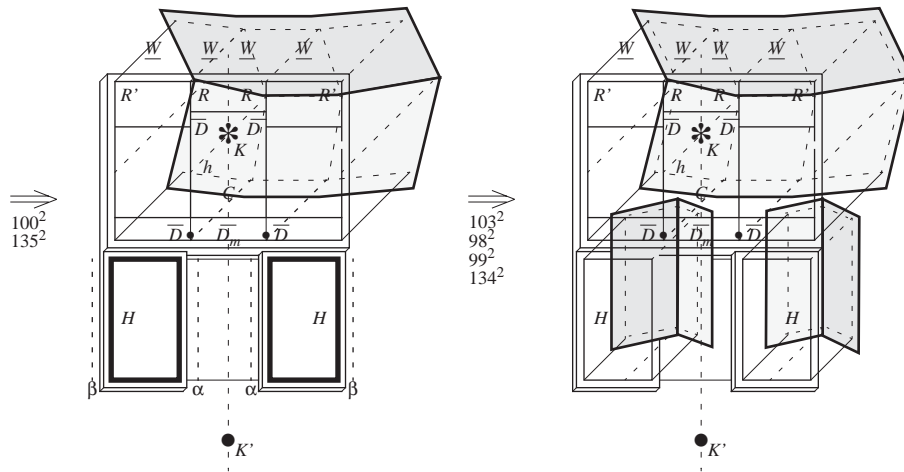
5.2   Dun-ben-tang (The Lin Family House in Nan-tou)

In the early *Jiā-qìng* Period (A.D. 1795-1820), *Qīng* dynasty, the twelfth generation of the *Lín* family migrated to Taiwan from *Zhāng-zhōu*, *Fú-jiàn*. After an event[2] involving the conflict between the peoples from *Zhāng-zhōu* and *Quán-zhōu*, they settled down in *Zhú-shān*, *Nán-tóu*, a village about 50 miles from Taichung, the third largest city in Taiwan. They ran a camphor business. Around A.D. 1895, *Lín*, *Yuè-tīng*[3], the sixteenth generation of this family, built a house in *Zhú-shān*, and named it *Dūn-běn-táng*. It was damaged in A.D. 1920 by the earthquake. The house was subsequently renovated, and the form of the roof was changed[4].

---

2.   See footnote 2 of Chapter 4 on page 99.

3.   *Lín*, *Yuè-tīng* was an elder of his village and also served as village head.

4.   The present roof style of second *jìn* is not the original. Evidence of change is indicated by the comparisons of material and style with the roof of the first *jìn*.
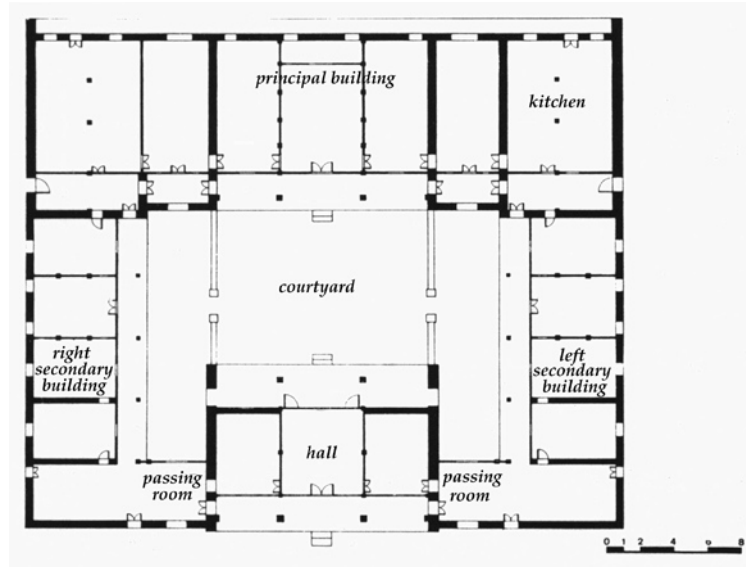
Figure 5.4. Plan of *Dūn-běn-táng*. (After Lin, 1990: 22)

The house, shown in plan in Figure 5.4, has two main buildings, though, without the inner secondary buildings being connected to the main buildings. There are three rooms in each of the main buildings. The inner courtyard was used, primarily, for celebratory occasions. Owing to its rural setting, the house was essentially a farm house. A feature of the house is its extreme neatness despite its rural setting and being located near mountains. The generation of this house plan is shown in Figure 5.5, although, without explanation. The considerations for rule application, advanced in Section 5.1, apply, in a similar fashion to the generation of *Dūn-běn-táng*.

5.3 The Lin-an-tai Residence in Taipei

In A.D. 1754, *Lín, Qīn-míng* with his family left their home town *Ān-xī*, *Fú-jiàn*, and moved to Taiwan. In the beginning, they were farmers in the countryside of ancient Taipei. Later, the *Lín* family started running a grocery business and their trade was brisk. *Lín, Zhì-néng*, the fourth son of *Lín, Qīn-míng*, did his own business in *Měng-jiǎ* (the original city of Taipei) and quickly became very wealthy. Soon after, circa A.D. 1785, he decided to build a new house. He

Figure 5.5 (continued).

purchased most of materials for the new house from *Fú-jiàn*, and engaged artisans from his home town *Ān-xī*. Although the house was built in circa A.D. 1785, the existing *Lín-ān-tài* residence may have been remodeled in A.D. 1822. This house is among the best preserved examples of existing traditional houses in Taipei. In A.D. 1977, it was moved to another site in Taipei.

Figure 5.5. Derivation of the plan of *Dūn-běn-táng*.

Figure 5.5 (continued).

Figure 6.5 (continued).
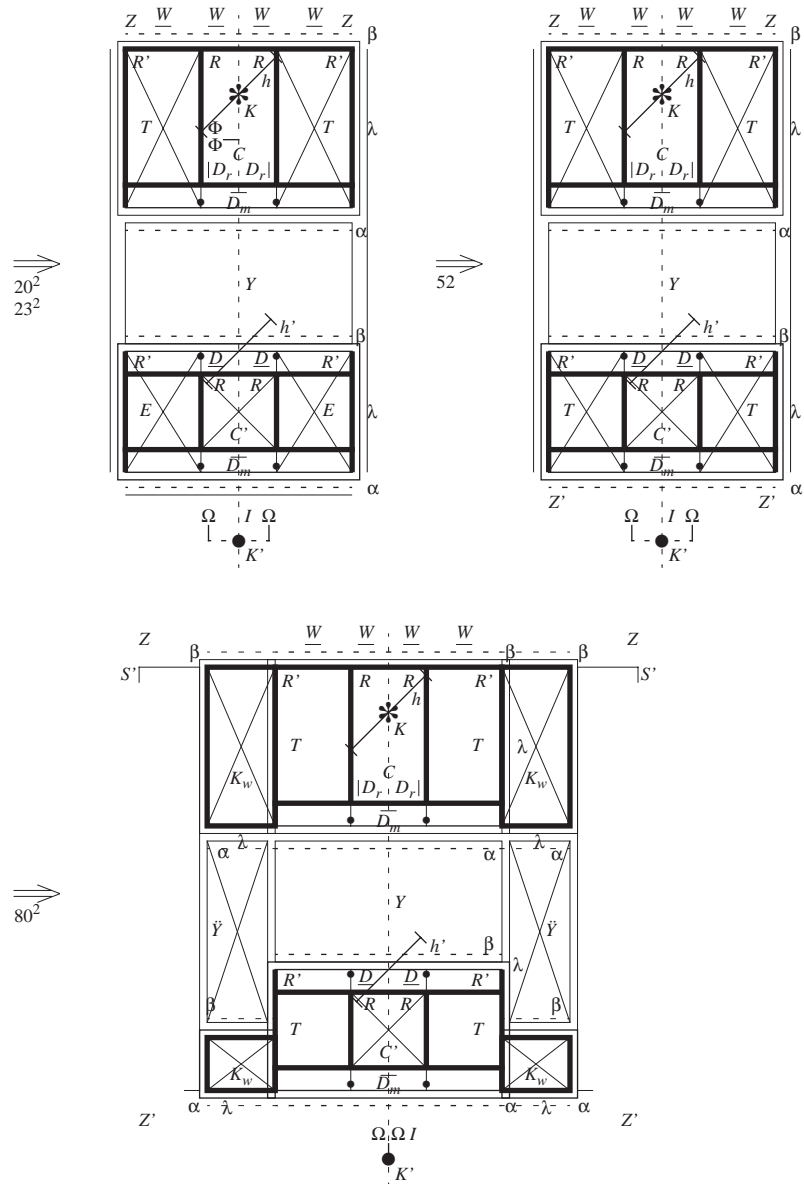
Figure 5.5 (continued).

This house is more complex than *Dūn-běn-táng*, in that, in addition to the two main buildings, it has four secondary buildings. Moreover, the main buildings have five rooms each. The outer secondary buildings were rebuilt during the period of Japanese colonization (A.D. 1895-1945). An interesting feature of this house is its series of *yàn-wěi* (swallow-tail) roofs, an indication that its owner, socially, held an elite position.[5] See Figures 5.6 and 5.7. The plan of the building is shown in Figure 5.8, and its generation in Figure 5.9.

5.4   Zhai-xing Shan-zhuang in Taichung

The *Lín* family originally lived in *Shào-ān, Zhāng-zhōu, Fú-jiàn*. In A.D. 1785, *Lín, Pò-zhí* and his brother migrated to Taichung, in the central region of Taiwan, and lived in *Tán-zǐ*, Taichung. They were farmers and business men, though poor. In A.D. 1832, *Lín, Pò-zhí*'s grandson, *Lín, Qí-zhōng*, was born. When *Lín, Qí-zhōng* was twenty years old, he decided to become a soldier in mainland China. About a decade later, he returned to Taiwan and inherited the property of his friend, *Wáng, Chéng-zhù* who was one of his fellow soldiers in army. Eventually, *Lín, Qí-zhōng* became a great landlord. In 1871, he
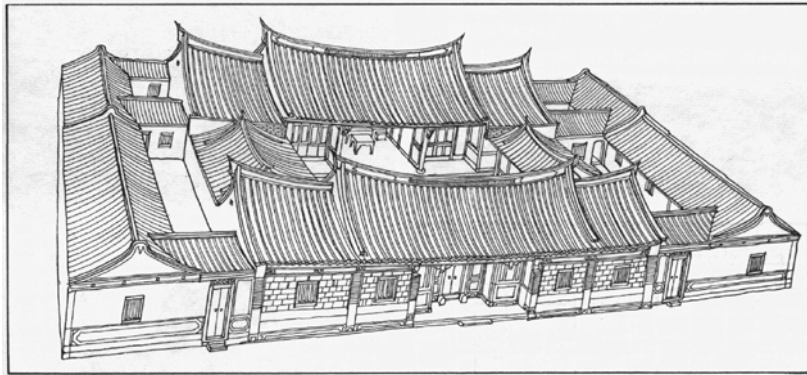
Figure 5.6. View of the *Lín-ān-tài* residence. (After Lee, 1980: 137)

---

5.   Generally, only officers or generals (*guān*) were allowed to use the *yàn-wěi* roof for their own houses. One is more likely to find *yàn-wěi* roofs on temples.
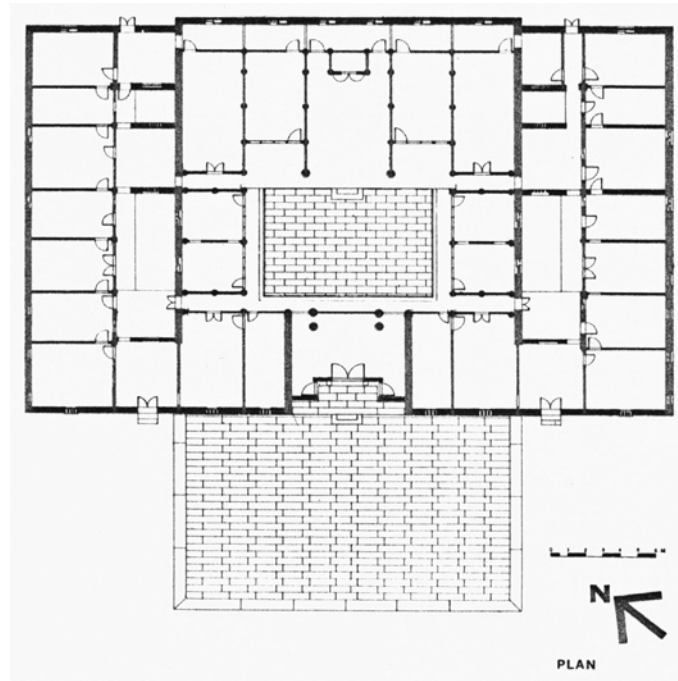
Figure 5.8. Plan of the *Lín-ān-tài* residence. (After Dillingham and Dillingham, 1985: 52)

Figure 5.7. The *Lín-ān-tài* residence. (After Lee, 1980: 126)
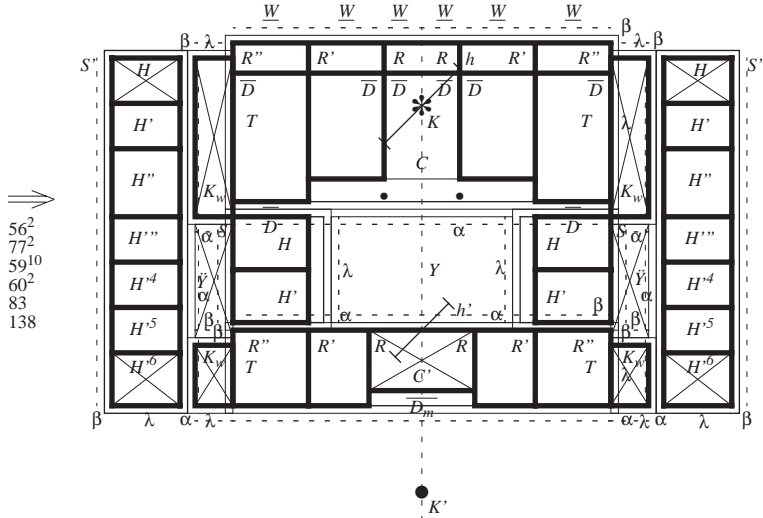
Figure 5.9 (continued).

started the construction of the house, *Zhāi-xīng Shān-zhuāng*, and completed it in A.D. 1879.
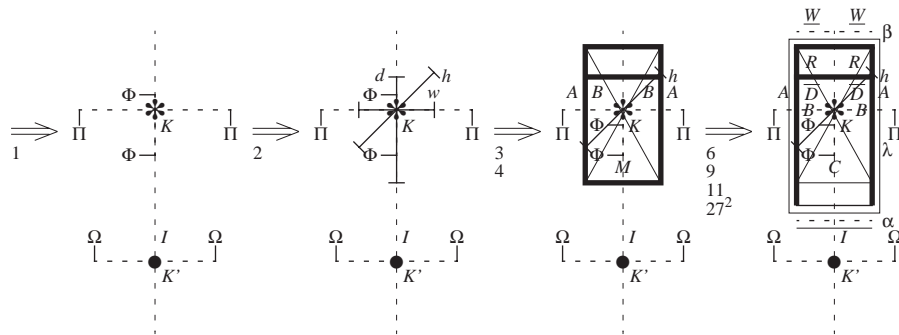
Figure 5.9. Generation of the *Lín-ān-tài* residence.
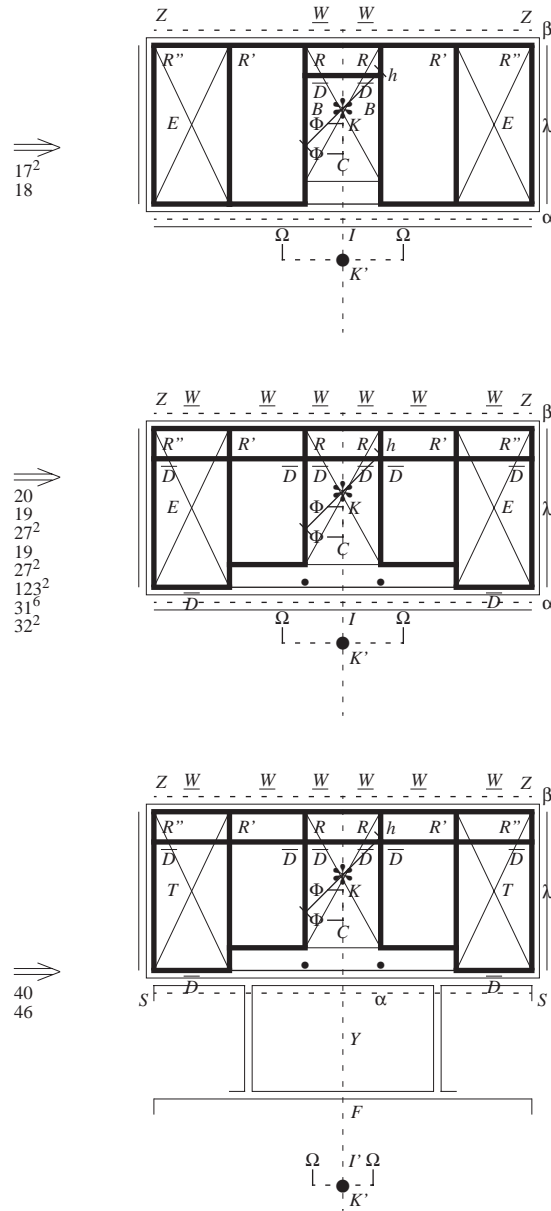
Figure 5.9 (continued).
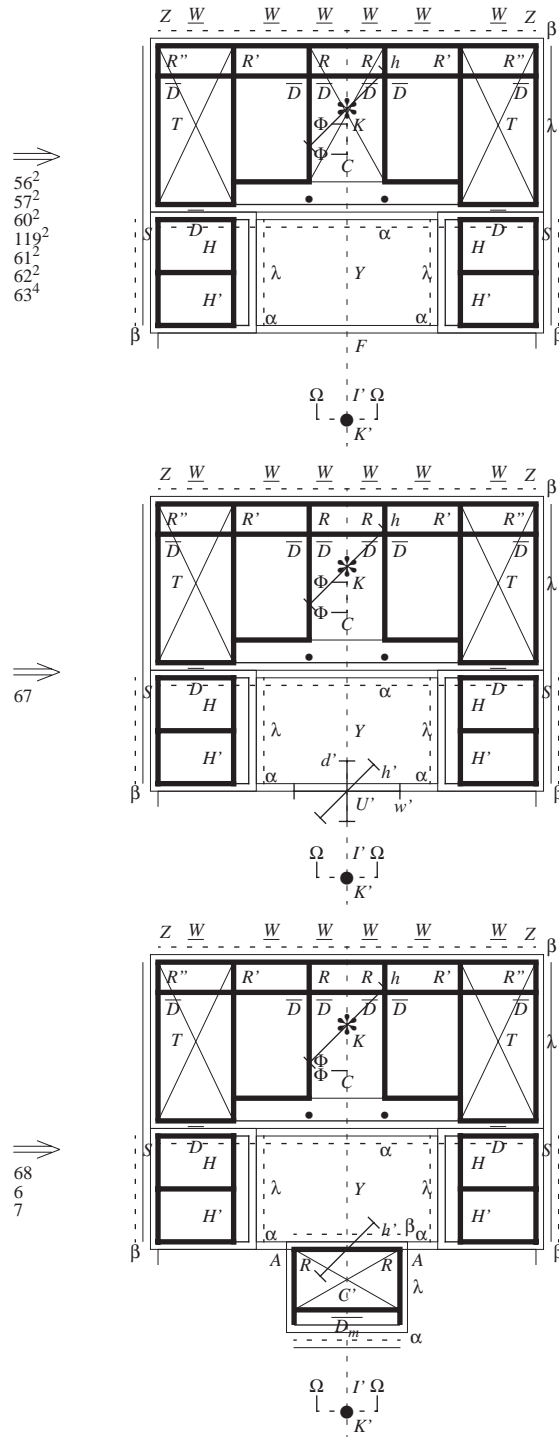
Figure 1.9 (continued).

Figure 5.9 (continued).
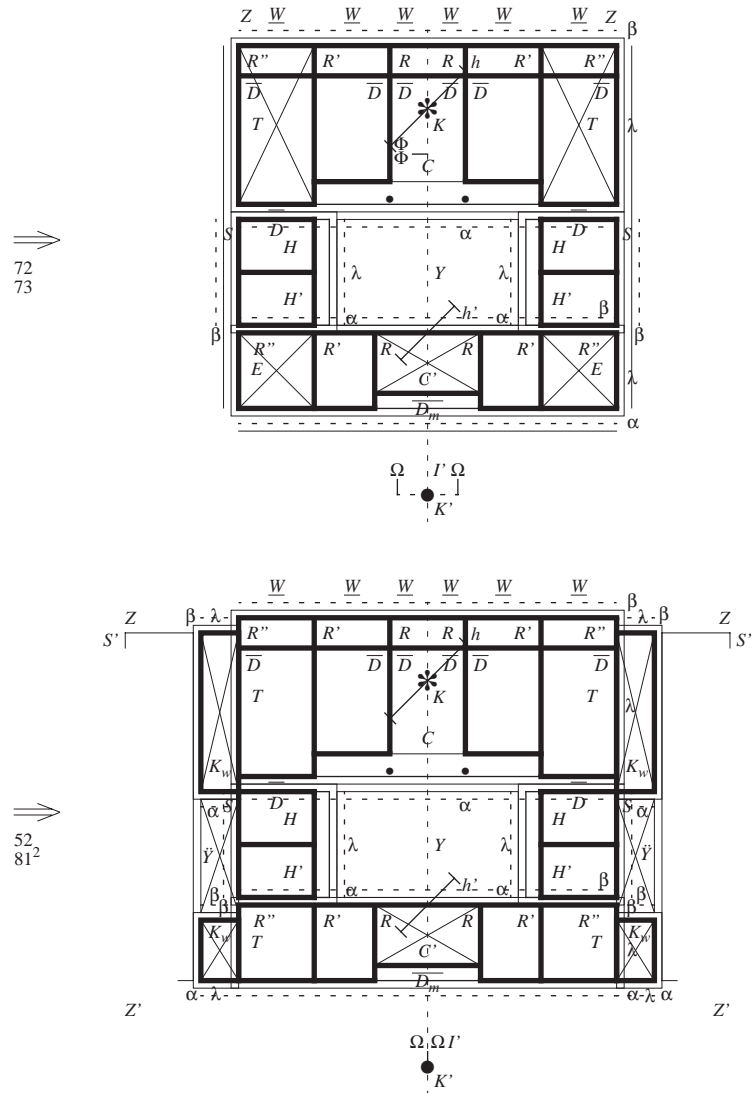
Figure 5.10. The front view of *Zhāi-xīng Shān-zhuāng*. (After Yang, 1984: 53)

The house, shown, in front view, in Figure 5.10 and, in plan, in Figure 5.11, has two main buildings, four secondary buildings, and three rooms in the principal building. The orientation of the house is south by west 7.5°. The generation of this house is shown in Figure 5.12.

5.5   The Lin Family Great House in Tainan

Lín, Wén-mǐn, a first generation immigrant to Taiwan of the *Lín* family, was a handyman at the harbor of *Ān-píng*, the original city of Tainan which is the oldest and the fourth largest city in Taiwan. He came from *Ān-xī, Fú-jiàn*. He later moved to *Má-dòu*, a town in the countryside of Tainan, and married a rich man's sister. After his marriage, he ran a grocery business and managed factories for the production of sugar and wine. His eldest son was also a tradesman. His seventh son was an officer in the government. The descendants of his fourth son, namely, the generation from the fourth branch of his descendants became civil officers in *Fú-jiàn* and decided to build a new

family house in Taiwan. Much of material for the house came from *Fú-jiàn*.

The *Lín* family great house, shown in plan in Figure 5.13, is a large farm house built in A.D. 1875. The house, in Tainan, is still in good condition with good wood carvings. In A.D. 1978, the left part of the house was torn down for apartments. It used to have three main buildings and two duo-secondary buildings. The original front main building was used as an independent entrance hall. The principal building has five rooms. The generation of this house plan is shown in Figure 5.14.
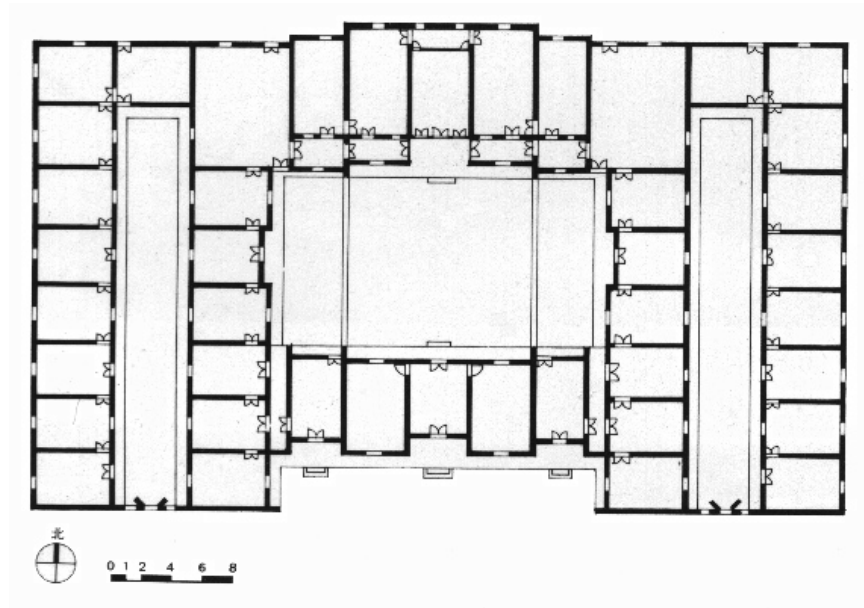
Figure 5.11. The plan of *Zhāi-xīng Shān-zhuāng*. (After Zeng, 1978: 80)

Figure 5.12. Derivation of the plan of *Zhāi-xīng Shān-zhuāng*.
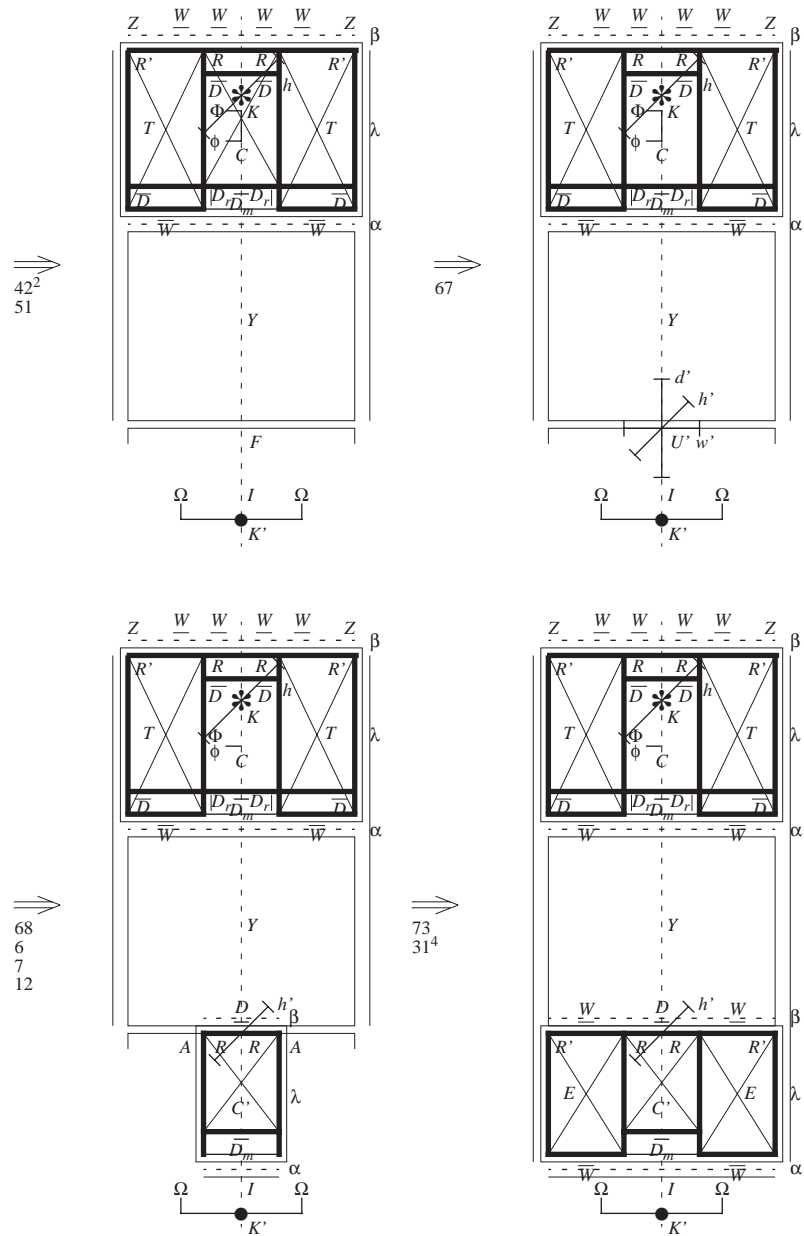
Figure 5.12 (continued).
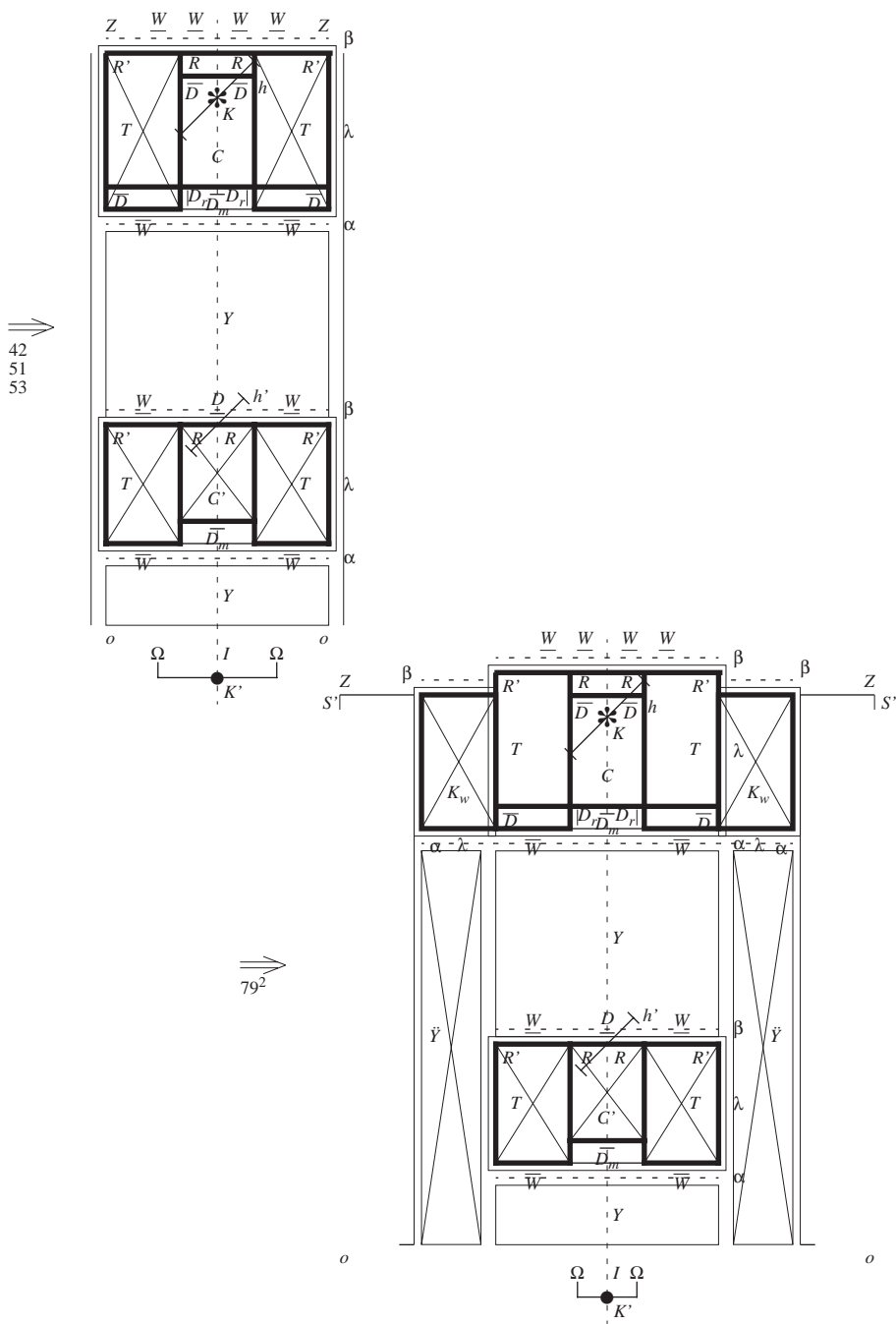
Figure 5.12 (continued).
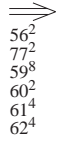
Figure 5.12 (continued).
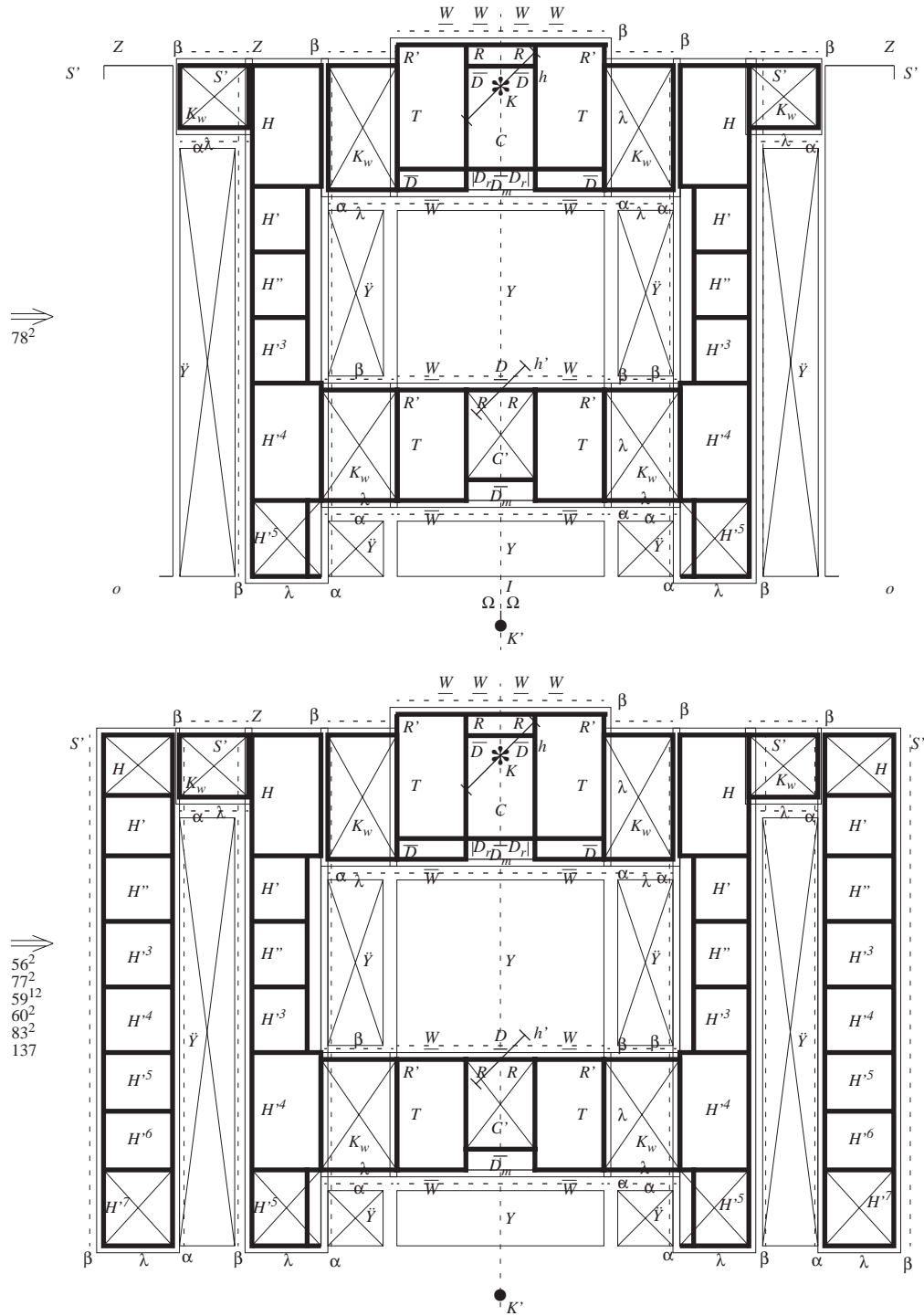
Figure 5.12 (continued).
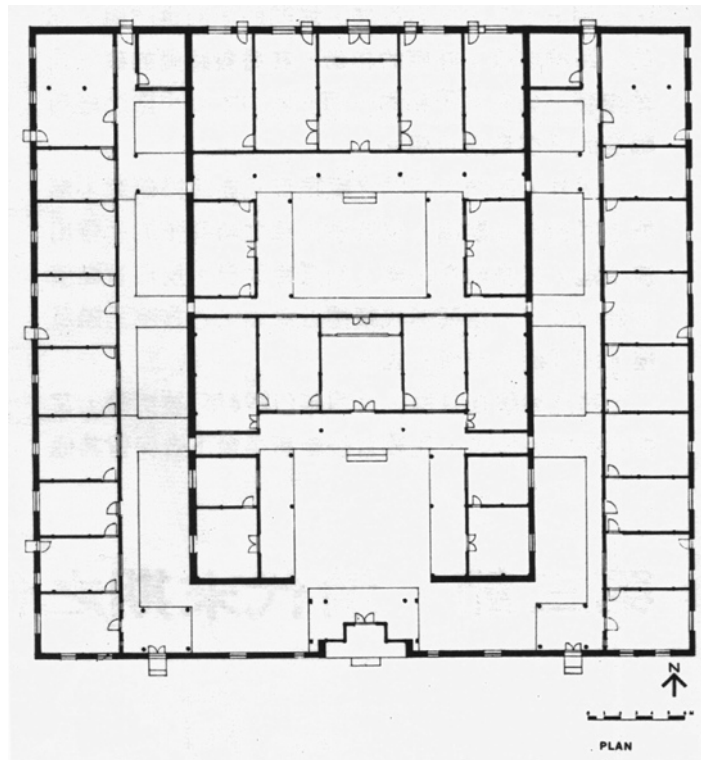
Figure 5.13. Plan of the *Lín* family great house. (After Lee, 1980: 180)
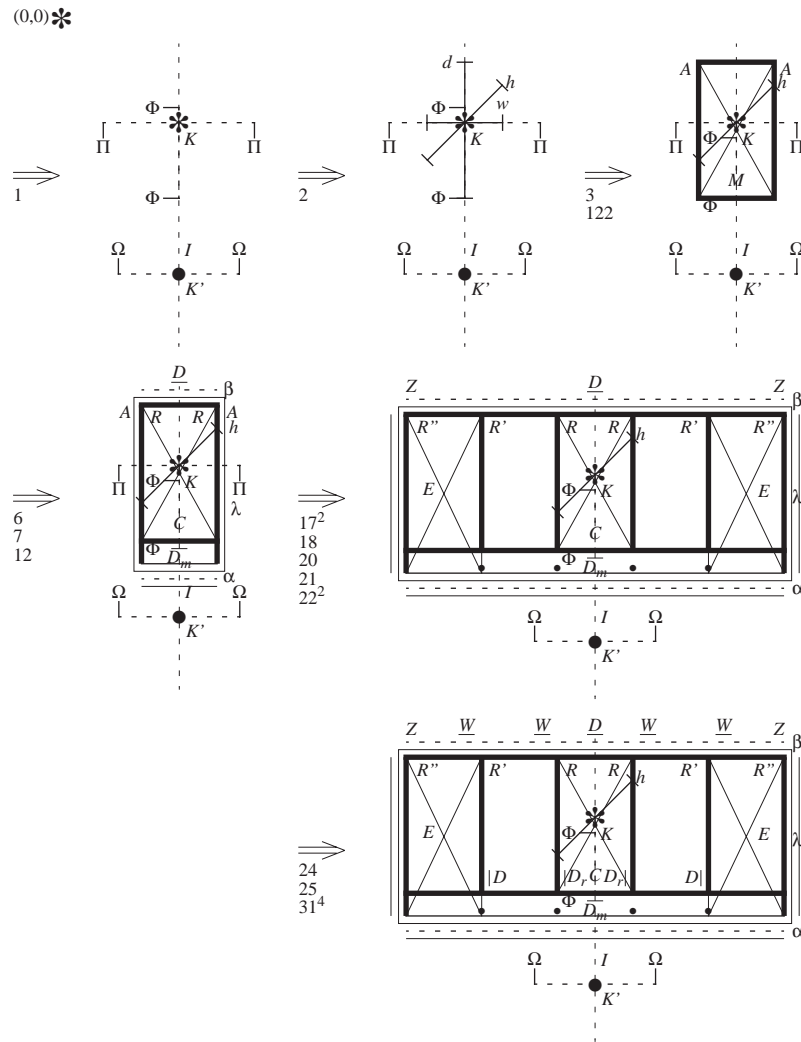
Figure 5.14. Generation of the *Lín* family great house.

Figure 5.14 (continued).
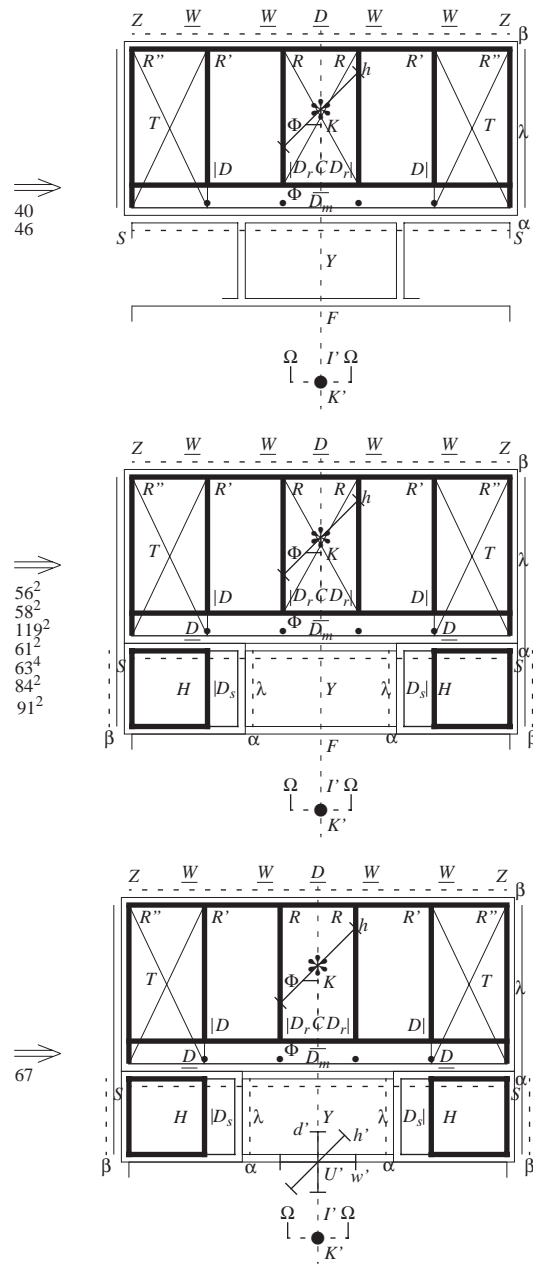
Figure 5.14 (continued).
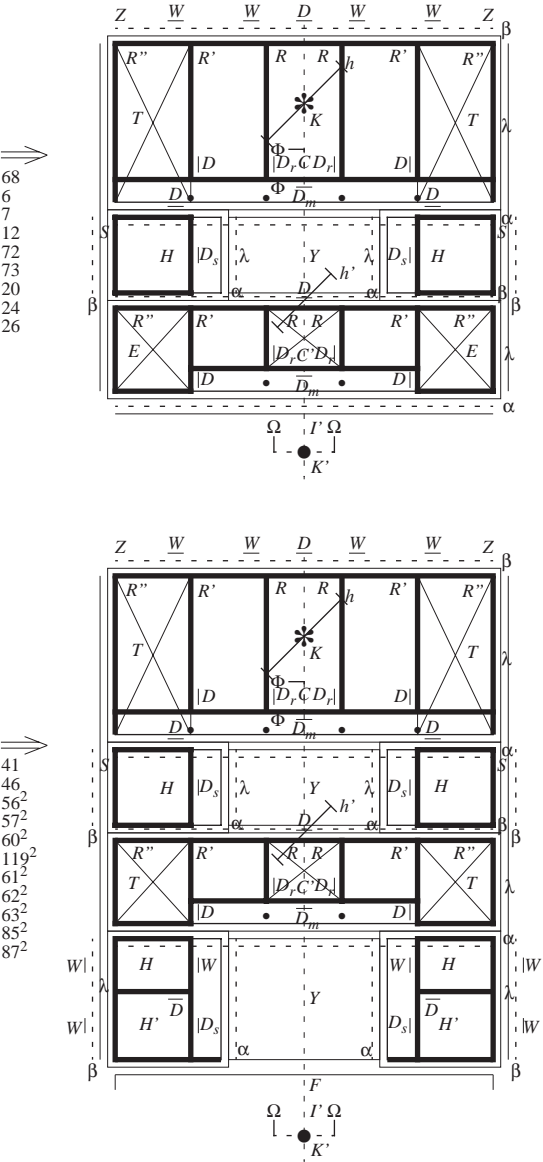
Figure 5.14 (continued).
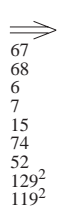
Figure 5.14 (continued).
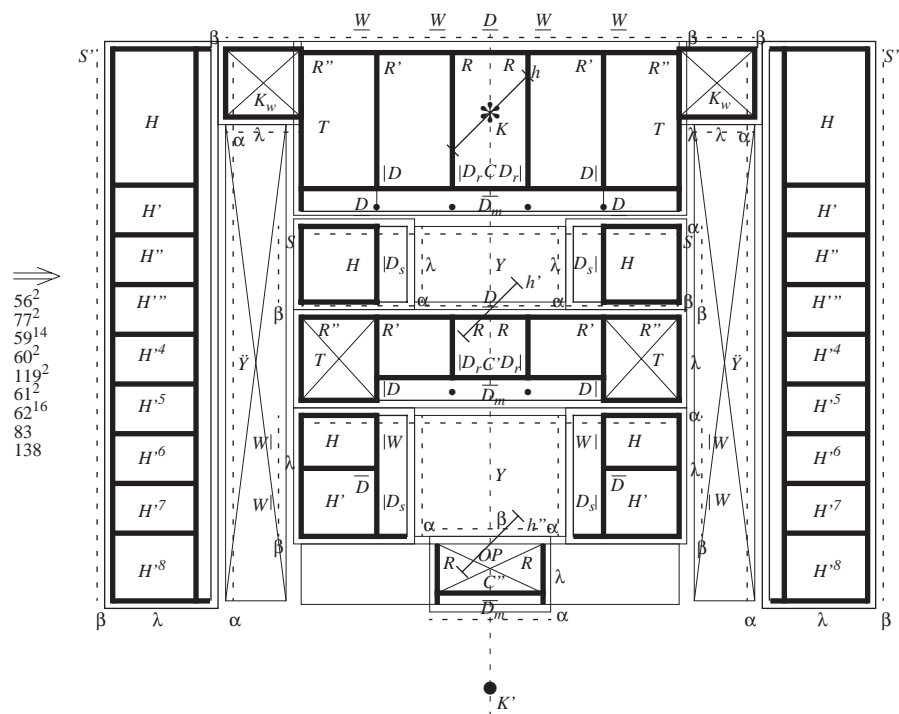
Chapter 6:

From Vernacular

Houses to Temples

Chinese architecture, though subject to Buddhist and Mohometan influence on the religious side, had its own as an indigenous style, and so the forms of to-day reproduce, with little change or progress, those of the early centuries of our era: moreover, there is no distinction between sacred and secular architecture, and temples, tombs, public building, and private houses, where great or small, all follow the same plan.

Banister Fletcher (1950: 913)

Many different types of traditional Chinese buildings share quite similar architectural forms. For instance, a plan of a *sān-hé-yuàn* (or *hé-yuàn*, courtyard) might have been used for a temple, a house, an official *yá-mén*

(government office in imperial China), and even the imperial palace. One way of distinguishing between the plan, say, for a house and that for a temple, is through the descriptions of the details, e.g., doors, eaves, roof, decoration, and so on. This concept of the reusability of an architectural form is distinct from the dictums of early modern Western architecture which has been characterized by Louis Sullivan (1981: 208) as: "Form ever follows function. This is the law." and by Le Corbusier (1986: 107) as: "The house is a machine for living in." The basic philosophy in Chinese traditional architecture was that space is flexible and man is adaptive. This same concept of reusability applied equally to the traditional Chinese clothing design. A new garment was not made for any particular person; its size would have been flexible enough for anyone who might, one day, wear (and thus, own) this piece of clothing.

6.1   Temples

> Thus it was not an uncommon practice in ancient times for a high official, or even a rich merchant, to donate his residence to the service of Buddha and have it consecrated as a temple.
>
> Liang, Ssu-ch'eng (1984: 21)

The temple is an important building type in Chinese architecture. Apart from the obvious religious reasons, a temple was and still is regarded as the total embodiment of the history of a local community and its society, its traditional popular arts, its building technology, and not least of all, people's thoughts. Temples were important and very influential in Chinese traditional culture and to its architecture, a role that was not dissimilar from those of early Western churches.

In this chapter, the grammar for vernacular dwellings, developed in Chapter 4, is extended to temples. However, any reliable grammar for traditional temples would require substantive field data. The extension and approach that I have taken are based on two important factors: (i) an account of the basic Taiwanese/Chinese popular religion, and (ii) an analysis of the traditional temple style of design. Although, the resulting grammar may not be altogether accurate, it does provide an educated explanation for traditional temple designs.

6.1.1 Popular Religion in Taiwan

> … every village and every small subsection of a town or city will
> have its community temples, generally the largest and most
> ostentatious structures in the neighborhood. Such a temple
> functions not only as a religious center for the community but
> often as a schoolroom, meeting place for community business,
> playground for youngsters, and threshing floor at harvest time.
> The construction of temples was a major expense to the local
> people, and the fact that the people would give so much of their
> meager income is in itself impressive proof of their sincere belief
> in the efficacy of the deities.
>
> <div align="right">Laurence G. Thompson (1989: 71)</div>

The popular religion in Taiwan derives from Chinese popular religion. It
inherits much of its characteristics from the religious practices in *Fú-jiàn* and
Guǎng-dōng.

The Chinese are tolerant, and in principle, of all religions. According to
The Analects of Confucius (*Lún-yǔ*), "The Master [Confucius] never talked of
prodigies, feats of strength, disorders, or spirits." (*Shù-ér* 7: 20) and "Do
reverence to gods and spirits, but stay at a far distance from them." (*Yōng-yě*
6: 20) In this sense, Confucianism does not oppose other religious beliefs.
Chinese popular religion takes, as its core, ancient spiritual beliefs and
combines them with the beliefs of Confucianism, Taoism, and Buddhism.
One can date Chinese popular religion to around the end of the *Hàn* dynasty.

The thoughts of Confucianism focus on rituals, in particular, ethic order,
i.e., the order of seniority among human relationships. The ethic order
concept surfaces in a number of aspects of Chinese life and culture; in
traditional architecture, it manifests itself through its application to the
arrangement of spaces (see Section 1.2.3).

Taoism, which began in the latter half of the *Hàn* dynasty, originates from
belief in Heaven. This is distinct from the philosophy of Tao (*Dào-jiā*) of
ancient China. Most Chinese believe that Taoism shares much similarity of
thought with Confucianism and Buddhism, the latter originating from India
also around the *Hàn* dynasty.

It is clear that the Taiwanese popular religion was brought to Taiwan by
the early migrants from *Fú-jiàn* and *Guǎng-dōng*. Respect for Heaven and

ancestral worships were the main tenets of Taiwanese popular religion. There are three forms of worships:

(a) Worship of nature such as the sun, moon, mountains, rivers, animals, plants, etc.

The worship of nature came about because the Chinese were aware of the powers of nature and, perhaps, also scared by them. Therefore, any natural phenomena, such as earth, water, wind, thunder, the stars (the heavens), in particular, the polar star, etc., were regarded as deities.

(b) Worship of objects such as cooking stoves, beds, doors, etc.

In particular, the Chinese worship objects for their usage. The Chinese respect for useful objects centers on concerns for safety in their life; they also expect such objects to bring good fortune. They believe that there is a god for each useful object.

(c) Worship of spirits such as ghosts, ancestors, etc.

According to the regulations of the *Qīng* dynasty, a hero, good officer, or anyone with loyalty, dutifulness, moral integrity, or righteousness could attain godhood, and, hence, be worshipped. It is for these reasons, Confucius is viewed as a god. For each occupational guild, there was, naturally, a god to protect them; for example, carpenters and builders worship *Lǔ-bān*.

In Chinese [and Taiwanese] popular religion, the gods of spirit world were fashioned with human images. Moreover, each god, spirit, and even ghost was assigned a distinct responsibility. Buddha too was considered a god. The Chinese 'created' a bureaucracy for the spirits, one which was hierarchical. Some of the gods 'worked' in the 'federal government,' certain others in 'local government.' The highest ranking of the gods was Emperor Heaven (*Yù-huáng Shàng-dì*), who also controlled the 'armies' (from *Wáng-yé*, Royal Lords) and the 'police' (from *Chéng-huáng*, Justice God). The armies were subdivided into five *battalions* (*yíng*'s), namely, east, west, south, north, and main (or central) *battalions*[1]. Figure 6.1 shows an example of the worship of the five battalions.

---

1. The east, west, south, and north battalions were placed at the four corners of a valley, with the main battalion positioned around (generally to the front of) the main temple, and thus, guarding the whole community. This layout, in fact, defines the boundary of a local community, both physically and religiously.
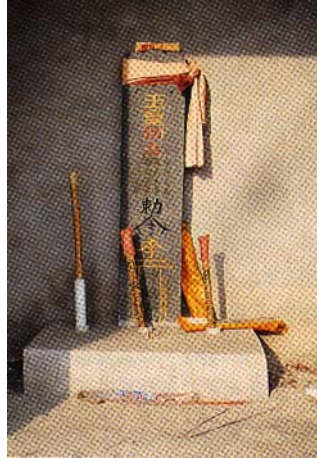
Figure 6.1. Worship of five battalions. (After Lin, 1990: 168)

The origins of Taiwanese popular religion can be traced backed to the end of the *Míng* dynasty when people from *Fú-jiàn* and *Guǎng-dōng* began to migrate to Taiwan for economic, social, or other reasons. Although migration to Taiwan was legal, regulations governing migration was unstable, resulting a number of illegal immigrants into Taiwan. Moreover, the journey through the Formosa Strait onto Taiwan was fraught with danger. In the local dialect, the Strait was referred to as the 'Back Ditch.' To ensure a safe passage to Taiwan, these migrants took with them gods, rather, idols, from their home towns. Eventually, when they arrived safely in Taiwan, these idols would be placed, temporarily, under a tree, barn house, or house. As the migrants settled and became wealthy, they would build temples for their idols. Normally, for different migrant groups the idols were different. The idols which the migrants brought with them from their home town were, typically, the principal deities that they had worshipped. In fact, in Taiwan, it is not difficult to trace the ancestry of any community by an examination of the principal god of the local main temple.   For any local community, its temple was not only the place of worship, but also the center of its civic activities.

6.1.2 Temple Architecture

> Despite a thousand variations, they share a similarity in appearance because all Chinese buildings, sacred or secular, derive from the same architectural principles. The temple is therefore just a more or less elaborately ornamented version of the Chinese "basic building."
>
> Laurence G. Thompson (1989: 70)

Temple architecture employed many, if not most, of the principles of Chinese traditional architecture – modules, axial planning, framework systems, and spatial organization. With perhaps more rituals and taboos during the construction phase, the design and its construction of temples followed along much the same lines as vernacular houses (see Section 2.5). Even so, there are some marked distinctions between temples and houses. To the Chinese, "the gods are alive because they have manifested themselves through their works" (Thompson, 1989: 62). Although the temple was, to put it simply, "a house of the gods," the gods were themselves almost all humanized. Thus, there was no reason to build temples in a fashion that was far different from the way houses were built. However, the need to differentiate between what was sacred from all else, the Chinese chose to use elaborate ornaments rather than develop a new building style or type for temples.

Temple Rank

The rank of a temple reflected the status of its principal god or deity and corresponded to the rank of this god in the hierarchy in accordance with the bureaucracy associated with the spirits. During the *Qīng* dynasty, regulations were established to stipulate the scale and size of an officer's house and his office (see Table 2.2). The *jiān* and *jià* of a building indicated its owner's social or political status. Likewise, a (principal) god of a higher rank would have a larger and higher temple. The scale and size of temples in imperial China that were built by the emperor or the government were subject to rigid regulations. On the other hand, for local temples or for temples built by the populace, its rank depended on the following four considerations.

(i) The number of doors

The number of doors of a temple reflected its rank. Usually, five-door temples were of the highest rank. The more popular temples in Taiwan tended to have three doors. Obviously, the single door temple was the lowest in the hierarchy and also one of the smaller structures. The number of doors was related to the number of bays; in fact, the former was generally no more than the number of bays. In a temple, each bay, usually, would have a door connecting it to the outdoors or a porch. Thus, the number of doors in the front wall of the main building, entrance hall or gate hall is an important indicator of the rank of a temple.

(ii) The number of main buildings

The more main buildings it had the higher up on the hierarchical order was the temple. The typical temple had, at most, two main buildings. For temples with more main buildings, the front most building (i.e., the entrance hall) was usually a 'gate hall.' The 'dome-well' (*zǎo-jǐng* or *jié-wǎng*, see Figure 6.2) was one of the more popular decorations for the gate hall in a large high ranking temple.

(iii) The height of the main building

The height of its main building reflected the temple's rank. The higher the temple the higher its rank and vice versa. On the other hand, the higher the temple, the more difficult it was to construct, and thereby, more costly. Thus,

Figure 6.2. A 'dome-well' in the temple design. (After Lin, 1990: 120)

higher temples were usually dedicated only to gods from amongst the highest ranks. The height of a temple was determined by the procedure described in Section 3.4.2, and is one of its fortunate dimensions. Unlike houses, where the fortunate dimensions were generally applied to inch measurements, in temple design and construction, measurements in both feet and inches had to be fortunate.

(iv) Orientation

The orientation of a temple was extremely important, because he Chinese believed it brought good fortune to the entire local community. As with most Chinese decisions, orientation was determined by geomancy. Generally, a temple faced a southerly direction, that is, its orientation was towards the south, although not oriented directly south. The reason for this is that the Chinese believed that the due south orientation was reserved for the emperor. As a consequence, most houses and temples (apart from those among the highest ranks) would have had their orientation shifted slightly towards an easterly or westerly direction were it, originally, have been determined to be due south. Some Taiwanese temples face a westerly direction, because their builders thought that the gods could then face towards their home town– of the builders and of the gods – on the mainland.

Plan

The plans for temples are similar to those of the vernacular houses. Apart from a few small low ranking temples, recent research (see, for example, Lee, 1986) suggests that there were four basic temple plan types. These types all derive from the plan of a *hé-yuàn*. Figure 6.3, taken from Lee (1983), shows the different temple layout designs found in Taiwan.

(a) Basic type

The first type of temple plan is identical to a *sān-hé-yuàn* with a single courtyard. The main building (principal building) is the area for worship. The idol(s)[2] of the principal god were placed on the center of the altar in the central bay of the main building. The other accompanying gods were placed either in the other bays of the main building or in secondary buildings, in accordance with their rank.

(b) Longitudinal type

The generic longitudinal type extends the basic type with a main building to the front. This additional front most main building was usually a 'gate hall' or 'entrance hall' forming a hollow square. The longitudinal type can be further extended by the addition of a rear main building, that is, a rear courtyard. Thus, the whole temple would have three *jìn*'s. This extension is not considered in the grammar described in Section 4.3.[3] The central main building is the principal building; thus, it is also the highest building of the temple. Moreover, all of the measurements for the temple were determined

longitudinal type

longitudinal type

longitudinal type

central building type
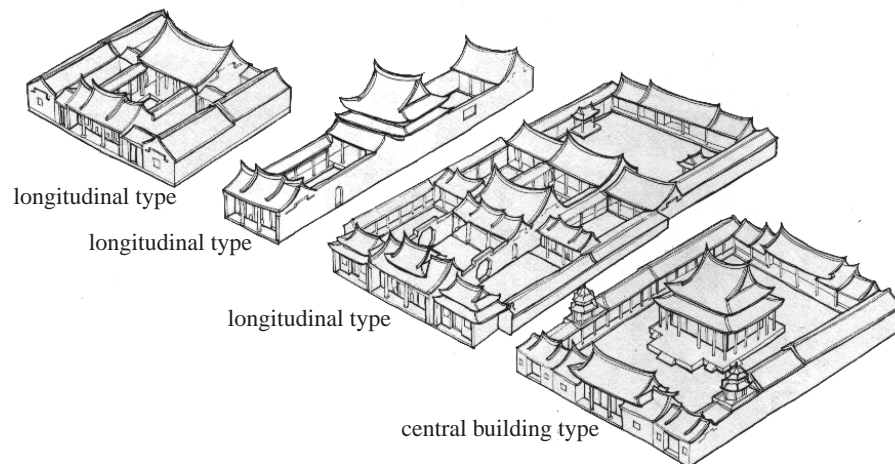
Figure 6.3. Different types of temple layout. (After Lee, 1983: 28)

2. The deities were not necessarily individuals. They may also have included groups or multiples. An example of a group would be "Kings of Three Mountains." By multiples is meant many individual deities sharing the same title, for examples, the local earth gods (*Fú-dé*) and Justice Gods (*Chéng-huáng*). Furthermore, it was necessary for the principal god (an individual) to be represented by a single idol. According to the beliefs of *líng* (spirit) in the popular religion, a god can have multiple idols (usually, three or five). These multi-idols were placed in a specific fashion on the altar, and each had different responsibilities. One might claim some similarity between this basic belief in Chinese popular religion and Christianity, where the Father, Son, and Holy Spirit may be regarded as one and the same, but each different.

3. The grammar described in Section 4.3 defines the rear most main building as the *principal building*.

by the measurements of its central bay. The principal god of the temple is placed in this principal building.

(c) Central building type

This type can be treated as a variation of the longitudinal type. The principal building is isolated from the rest of the layout with no connections to the secondary buildings. It is the same as placing the principal building within a hollow square layout. Temples of this type required large sites, and were, usually, built by the government. Such temples were also more costly to construct; therefore, it is generally reserved for the higher ranking temples. Temples for Confucius were usually of this type.

(d) Compound type

This type of temple with parallel axes courtyards are a combination of the previous types. It is similar to an extension of parallel axes layout discussed in Section 2.3. It combines two or three temples into one single group. However, each temple is separate with its own principal building, and gate hall. This form is used when there were many gods that share a single principal deity, or when there was a need for multiple temples to share a public space such as the front yard.

Framework System

The framing system used in a temple was, usually, either *tái-liáng* (column-beam-and-strut) or *dié-dǒu*. This is different from the more common *chuān-dǒu* (column-and-tie) system used in dwellings (see Section 2.4). In temples, there are, usually, no partition walls between the central (*míng*) bay and *cì* bays. Between *míng* and *cì* bays, the framing system *tái-liáng* or *dié-dǒu* was used, which allowed the space for worship to be extended across to the *cì* bays. In the central bay, the two *tái-liáng* or *dié-dǒu* frames were made up of four key-pillars (*sì-diǎn-jīn-zhù*), which defined the space for worship.

Roof

The most striking part of the temple is its roof. It is colorful with rich decorations. The most popular roof type for temples was *xiē-shān* or the multi-roof form of *xiē-shān*. For smaller or lower ranking temples, the *yìng-shān* roof form was used. See Figure 4.25. In higher ranking temples the
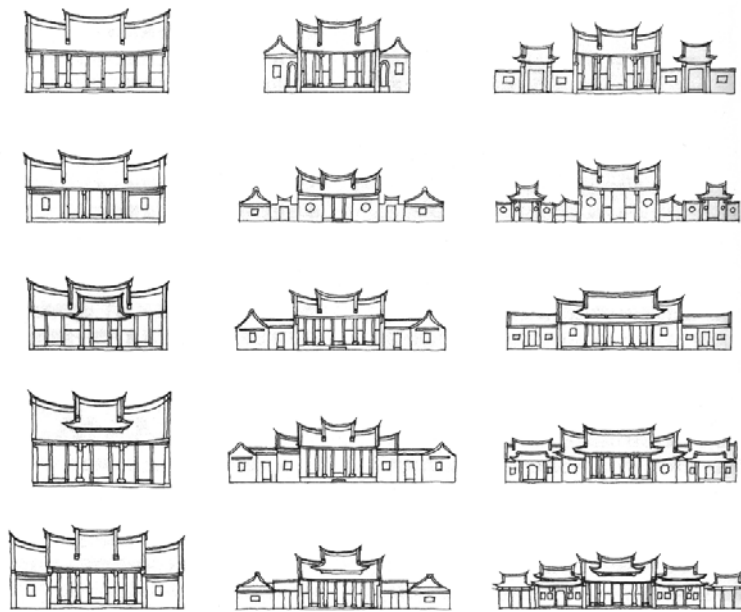
Figure 6.4. Different roof design in Taiwan's temples. (After Lee, 1980: 240)

ridges of the roofs were usually extended to be even higher. The roof was thus steeper allowing for more decorations. Figure 6.4 shows a collection of roof design found in Taiwanese temples. It is clear that the roof forms for temples are much more complicated than those for houses.

Auxiliary Buildings

In temple architecture, a worship-stall was usually added to the front of the principal building to extend the space for worship from the central bay to the stall. Of course, according to religious practice, a furnace for burning worship-papers was necessary, but its location depends on the site and layout of the temple. Sometimes, towers were added to both sides of the temple, a feature that is popular in Buddhist temples. A stall for staging plays and shows may be added to the rear of the gate-hall; however, this was not all that common.

Decorations

As with the roof, rich decorations were another important feature of temples. In addition to those for conferring blessings and good fortune, these decorations centered around stories dealing with such subjects as loyalty, duty, moral integrity, or righteousness.

Design and Construction Process

The design and construction for temples was similar to that of the dwellings except more rituals and taboos were incorporated into the process (see Section 2.5). Apart from official temples, such as those for Confucius, a temple was usually built and decided by the leaders of the local community.[4]

Figure 6.5. An example of declarations in temple. (After Lee, 1983: 78)

---

4. According to Thompson (1989: 71), "Community temple would be under the overall management of a local committee and might or might not have the permanent services of a resident priest. The priest might belong to the Taoist order whose vocation was noncelibate and whose function was the practice of magic and exorcism. Or they might be served by low-level religious 'technicians,' such as mediums or shamans."

    It should be noted that these leaders may themselves be determined by the principal god or local gods. These leader may 'ask' their god through a priest or spirit writing, namely, *jī-tóng* or *fú-luán* (see, also, footnote 26 of Chapter 2 on page 45).

The siting for a temple was, sometimes, based on, for want of a better description, fantastic circumstances. For instance, a site may be chosen because of happenstances or events such as the 'seeing' of light on the site on a dark night (which people took to be a sign presented by the gods). In general, site and orientation were determined by geomancy.

Once a site and orientation were decided, leaders of the local community would engage an artisan-group[5] to build the temple. Artisans who worked on temples were much more skilled than those that worked on houses, primarily owing to the complexity of design and construction. On occasion, two artisan-groups may be engaged to build the temple (see footnote 40 of Chapter 3 on page 88). Figure 6.6 shows an example of temple in Taiwan which was built by two artisan-groups. Note that the decorations of both sides are stylistically very different.

Figure 6.6. An example of temple built by two artisan-groups. (After Lee, 1983: 66)

---

5. Usually, the artisan group to build a temple was much larger than that for a house. Other artisans may be brought in, such as masons, painters, carpenters who worked on 'minor' carpentry (doors, window, or detail decorations, etc.). However, the chief artisan was generally the person who was also a carpenter who worked on the 'major' wood construction.

6.2   A Temple Grammar

The grammar for temples can be derived from the grammar for vernacular dwellings by augmenting it with rules that take into consideration specific changes to the spatial form that distinguish the traditional temples. I classify these rules into three categories, labeled A, B, and C. The shape rules of category A pertain to the plan types that are specific to temples, namely, the longitudinal and central building types. The shape rules of category B relate to the framing system used in constructing temples. The shape rules of category C consider certain specific characteristics of temples such as porches, verandahs and the relationship of the end-room to the secondary buildings.

A. Shape rules for dealing with special temple layouts

For temple layouts of the longitudinal and central building types, rules are defined to extend the courtyard to the rear. Unlike dwellings the principal building of a temple is not the rear-most. For convenience, all main buildings to the rear of the principal building are referred as *rear-main buildings*.

Four shape rules, A1 through A4, create rear courtyard enclosures. See Figure 6.7. In addition, the scale bar used to the record the number of main buildings $\Phi\Phi$ is also decreased by a single unit.

Rule A1 creates a rear courtyard connecting with the two end rooms with openings (generally doors) to the rear. The constraints on the x-coordinates x_3 and x_4 are such that these can not have values that lie within the openings P if the rooms have other openings. The label Y denotes a courtyard.

Rule A2 creates a rear courtyard connecting with the two rooms adjoining the end rooms and which also have openings to the front. The constraints on the x-coordinates x_3 and x_4 are the same as in rule A1.

Rule A3 creates a rear courtyard connecting the two rooms adjoining the end rooms with no openings to the rear.

Rule A4 generates a large rear courtyard; the secondary buildings enclose both the courtyard and the main building. This shape rule can be applied to generate the central building type in which the principal building is isolated from the other buildings.
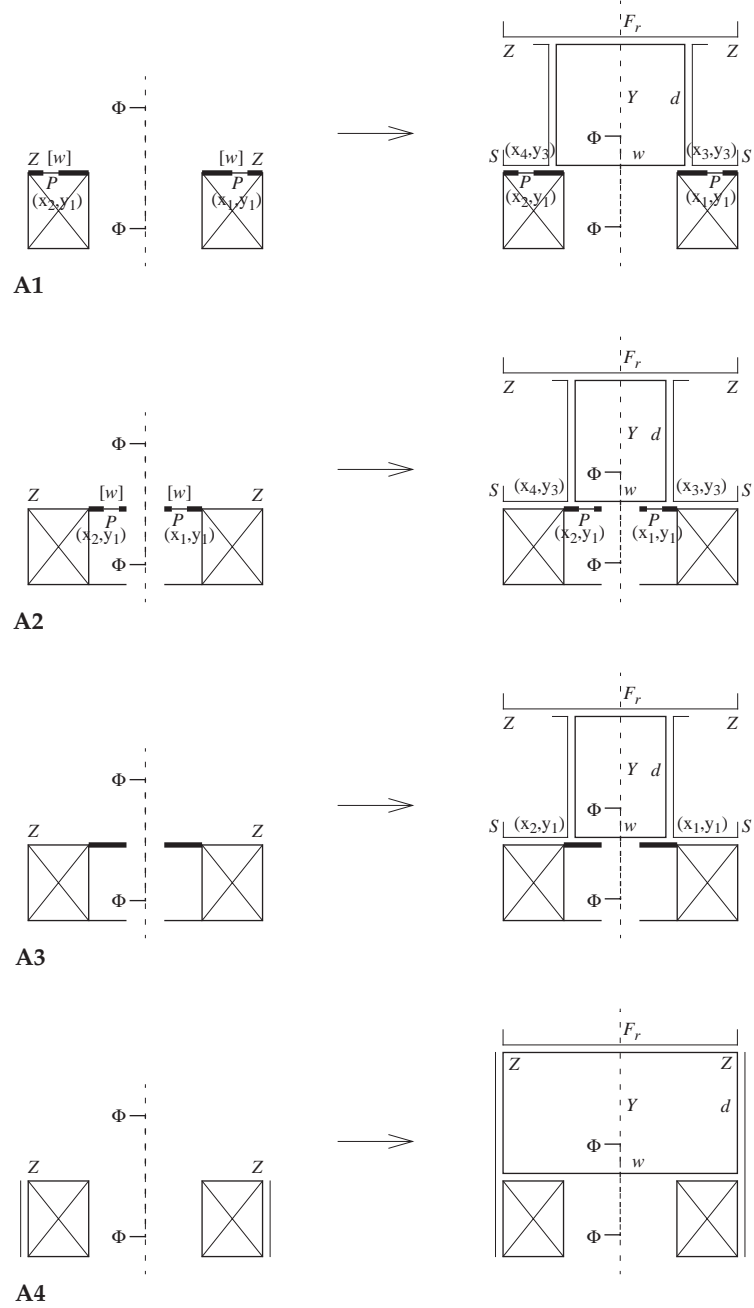
Figure 6.7. Rules for generating courtyards enclosed by inner secondary buildings.

A5
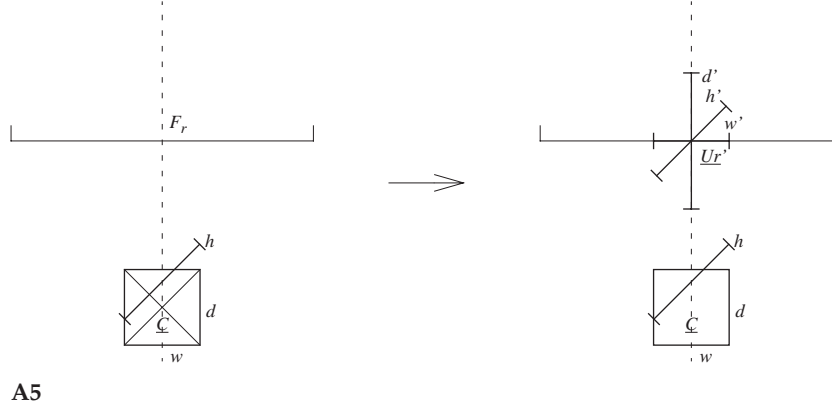
Figure 6.8. Calculate the fortunate dimensions of a new main building.

Rule A5, shown in Figure 6.8, initializes the generation of a rear-main building. The rule specifies the basic dimensions for the design. The procedures to determine the dimensions of the building are similar to those described in Stages 1 and 9 of Chapter 4. There are other constraints imposed on this building of which, perhaps, the most important is its height, which must be lower than that of the principal building, but may be higher than previously generated rear-main building. Assuming that the dimensions of the previous rear-main building are, say, h, d, and w. Let the corresponding dimensions for this new building be h', d', and w'. Let the height of the principal building be H. We then have the following constraints:

$h' = f_h(\text{orientation}, h)$ and $h' < H$.
$w' = f_w(\text{orientation}, w)$ and possibly $w' \leq h'$ and $w' \leq w$.
$d' = f_d(\text{orientation}, d)$ and $d' \approx 1.3 \times h'$ and $d' < d$.

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

In the shape rule A5, the position of label $\underline{Ur}$ is determined from the position of $\underline{C}$.

Rules A6 and A7, shown in Figure 6.9, each generate the central bay (room) located on the symmetrical line.

Rule A6 creates the central bay in the rear-main building. Rule A7 generates a room with a front porch, where d', the depth of the rear porch, is
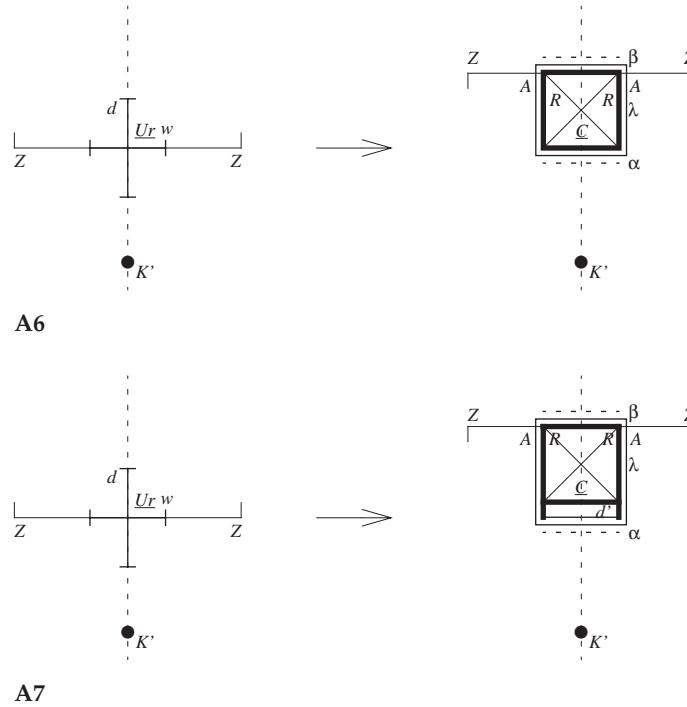
Figure 6.9. Shape rules for generating the central bay of a rear-main building.

usually one stride less than the value given by the stride measure. Both shape rules also specify a raised platform, and associate the label, λ, with it. Labels α and β respectively identify the positions for the front and rear roofs to be specified by a later rule. The marker of the rear-main building and labels Z's are shifted to align the rear wall of the central bay. This is simply a technical convenience that permits the applications of certain shape rules from the grammar of vernacular houses. In each rule, label $\underline{Ur}$ is replaced by label $\underline{C}$ to signify the central bay of a new rear-main building.

Shape rules A8, A9, and A10, given in Figure 6.10, add two rooms to the rear-main building. Rules A9 and A10 are terminating rules in that they can be used to generate the end rooms of the building. In rule A10, the end room is an open space. Basically, these three rules are minor modification of rules

A8

A9

A10
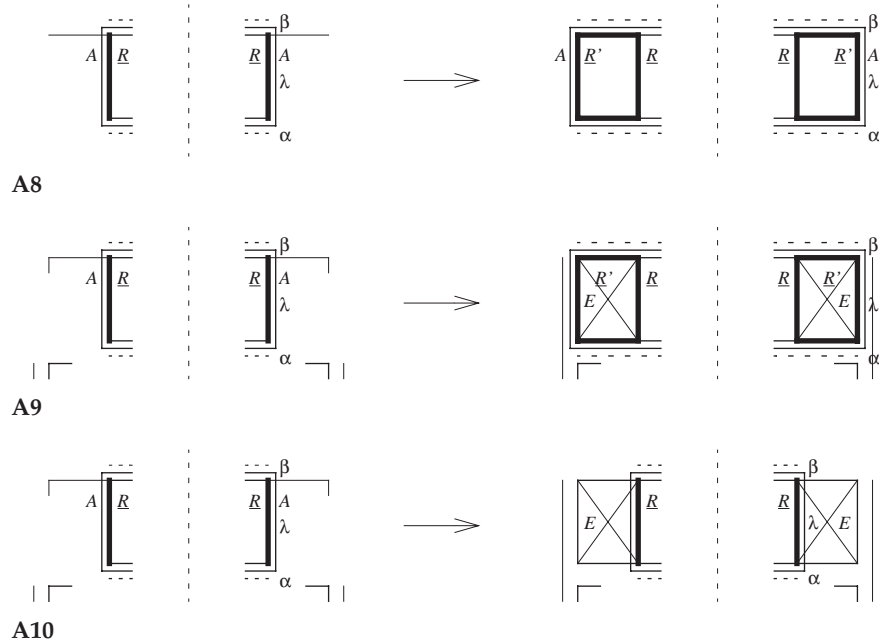
Figure 6.10. Rules for generating rooms in a rear-main building.

72, 73, and 74 owing to the fact that the front label is not needed for the rear-main building.

B. Shape rules for dealing with the framing system

For vernacular houses, each bay corresponded to a room. This is expressed within the shape rules by a thick line segment which essentially represents a wall between the *míng* and *cì* bays. In the case of temples, this thick line may be considered to be representative of the framing system. At any rate, a line simply indicates a 'partition' which may be considered to represent either a frame or a solid wall.

Rules B1, B2, and B3, given in Figure 6.11, changes the indication of a line from a representation of a solid wall to that of a frame. Rule B1 is applicable to the central bay of main building which extends its space to three bays. This rule changes the partition (solid) wall to a framing system, namely, *tái-liáng* or *dié-dǒu*. In this rule, the four points (labels Ψ's) are the main structure of the
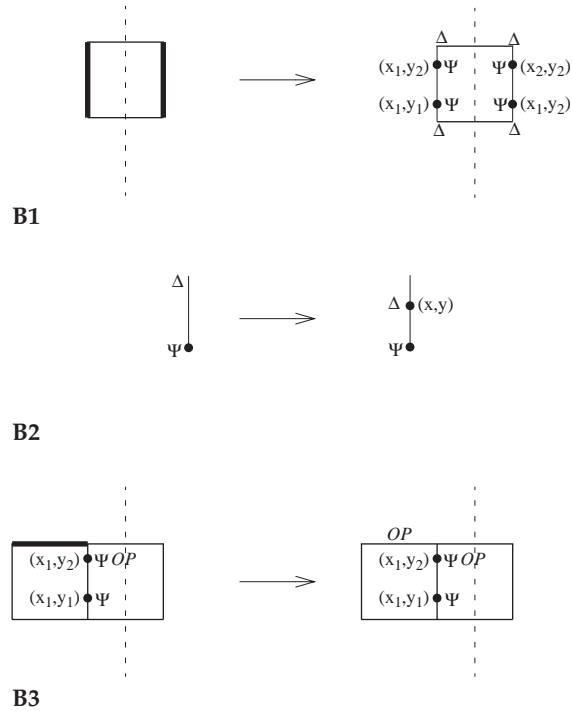
Figure 6.11. Shape rules to account for the framing system.

central bay and indicate the four key-pillars. These four points (in the principal building) define the worship space.

Rule B2 arbitrarily adds one more column between labels Ψ and Δ. This rule is used to refining the frame structure. Rule B3 refines the spaces next to the central bay. It extends the semi-open space across one more bay from the central bay if the line as a representation of a 'wall' is changed to that of a frame.

C. Shape rules for dealing with porches and verandahs

The following rules though particular to temples, might apply to certain traditional houses. The main reason for introducing these rules is that in temples the end room of a main building may have porch, and that the rear

wall of the end room generally has a door that connects to the rear-main building.

Rules C1 through C8, shown in Figure 6.12, are derived from rules 43 through 50 (see Stage 7 of Chapter 4). These rules consider verandahs or porches to the front.

Rules C1 and C5 create a courtyard that connects the two end rooms which have openings to the front. The constraints on the x-coordinates x_3 and x_4 are such that these can not have values that lie within the openings P if the rooms have other openings. Label Y denotes a courtyard.

Rules C2 and C6 create a courtyard connect the two rooms adjoining the end rooms which also have openings in the front. The constraints on the x-coordinates x_3 and x_4 are the same as in rule C1.

Rules C3 and C7 create a courtyard that connects the two end rooms which have no openings to the front.

Rules C4 and C8 create a courtyard that connects the two rooms adjoining the end rooms which have no openings to the front.

Rule C9, shown in Figure 6.13, is introduced to account for the case of an end room with a porch, and creates a passing room to connect it to the secondary building. Rules C10 and C11, also in Figure 6.13, change the label w (window) to D (door) which for accessing the inner secondary building through the end bay (room).

6.3   The Yin-shan-si Temple

The temple grammar is illustrated through an example of an existing Taiwanese temple. The *Yín-shān-sì* (*Yín-shān* Temple), located in *Dàn-shuǐ*, Taipei, Taiwan, was built in circa A.D. 1822 by a small group of migrants from *Tīng-zhōu*, *Fú-jiàn*. The principal deity of the *Yín-shān-sì* is a Buddha called *Dìng-guāng-fó*. The orientation of the *Yín-shān-sì* is west. The *Yín-shān-sì* is a typical middle-size and well-preserved temple in Taiwan. The layout of the temple is basically a longitudinal type.

The temple, shown, in front view plan, in Figure 6.15 and, in front view, in Figure 6.14, has two main buildings, four secondary buildings, and three bays

C5

C6

C7

C8
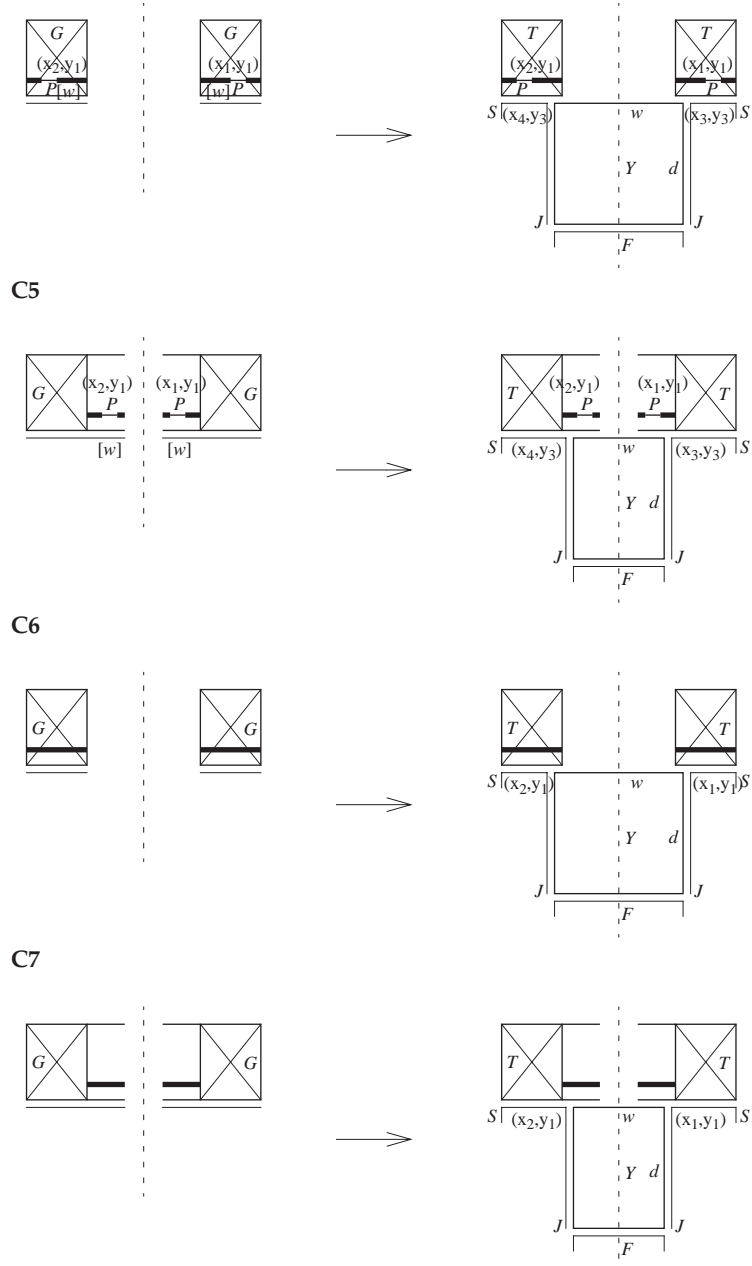
Figure 6.12 (continued).

C1

C2

C3

C4
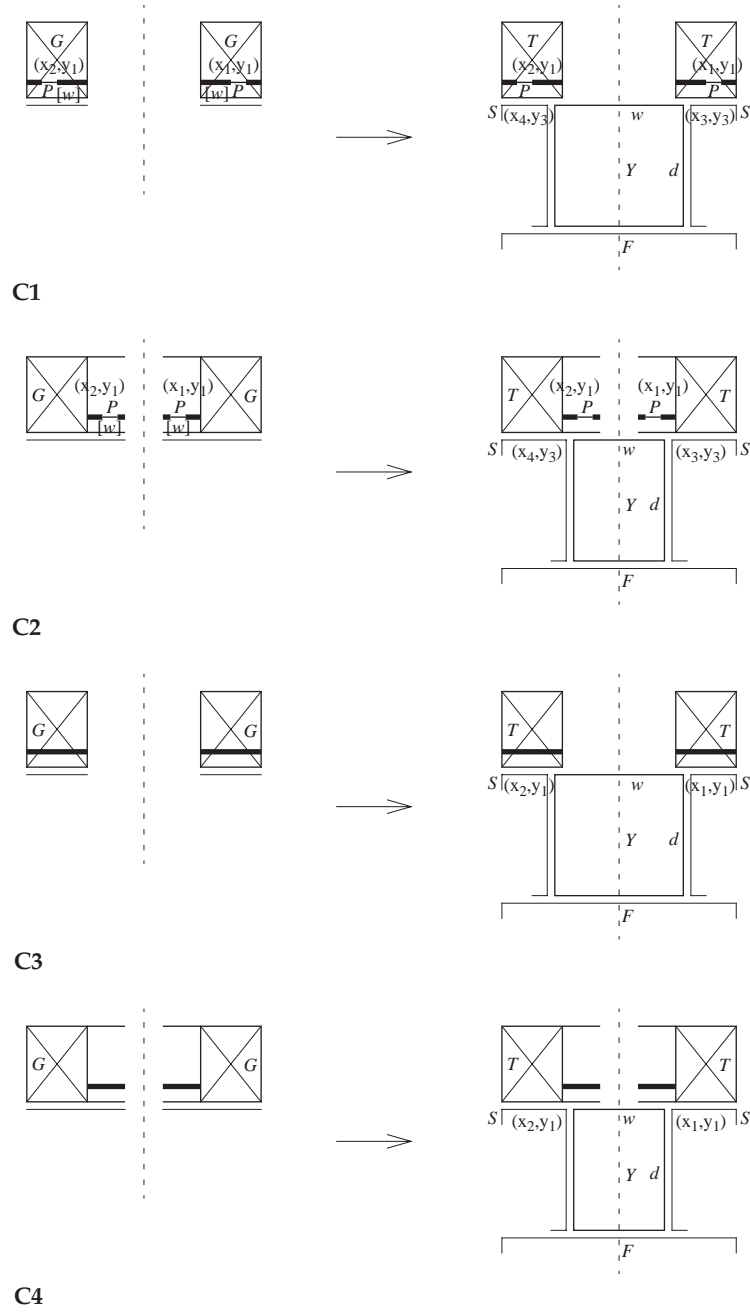
Figure 6.12.   Added Rules for generating courtyards enclosed by inner secondary buildings.

C9

C10

C11
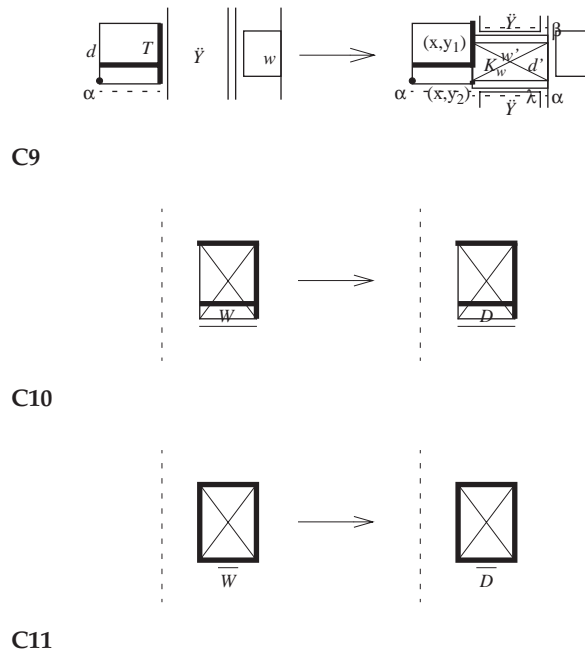
Figure 6.13. Modified and added rules for end room

in the principal building. The generation of this temple is shown in Figure 6.16.

Figure 6.14. The front view of *Yín-shān-sì*. (After Lee, 1983: 64)
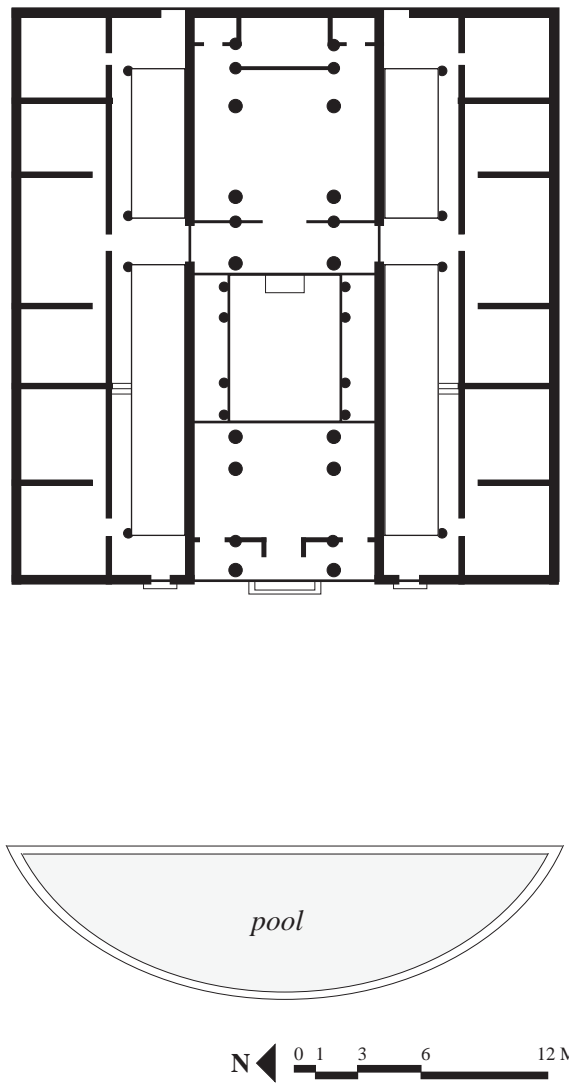
Figure 6.15. The plan of *Yín-shān-sì*. (Redrawn after Lee, 1980: 155)
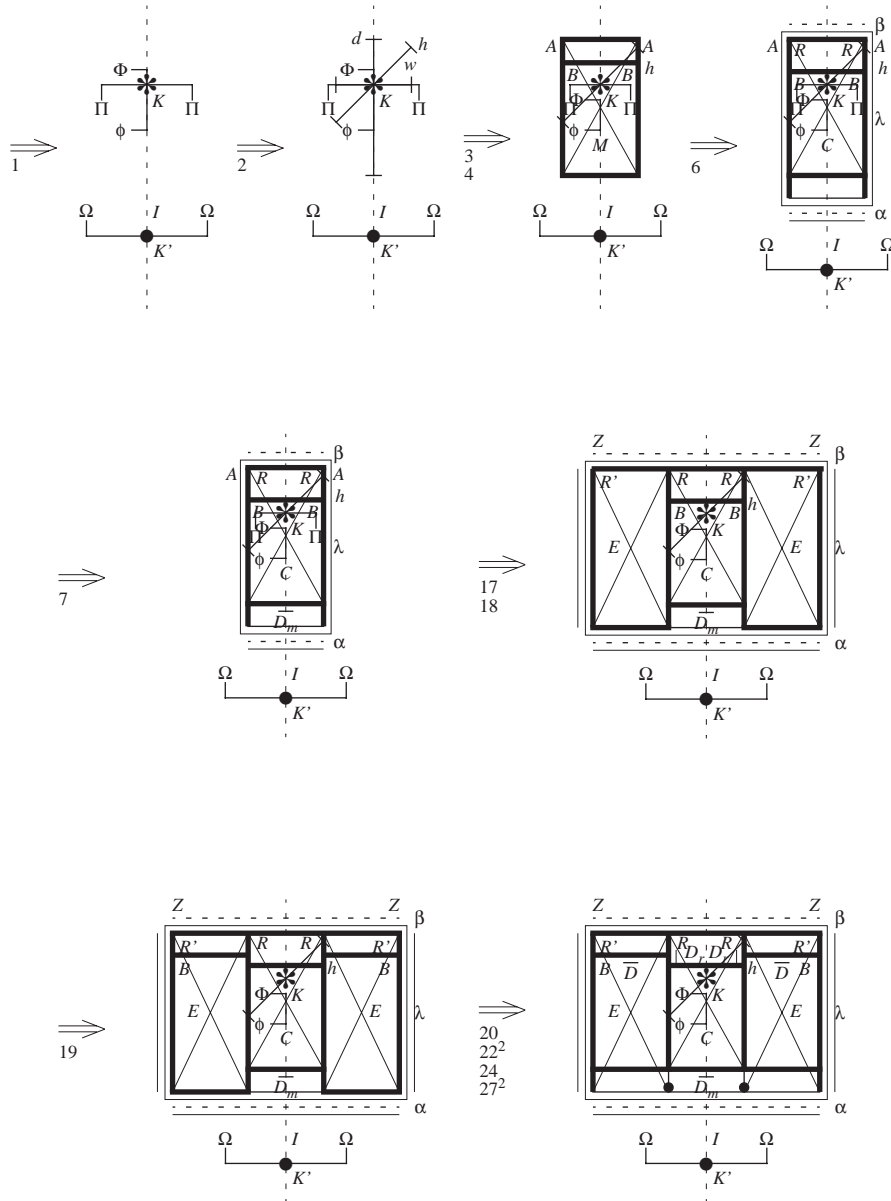
Figure 6.16. Derivation of the plan of *Yín-shān-sì*.

Figure 6.16 (continued).
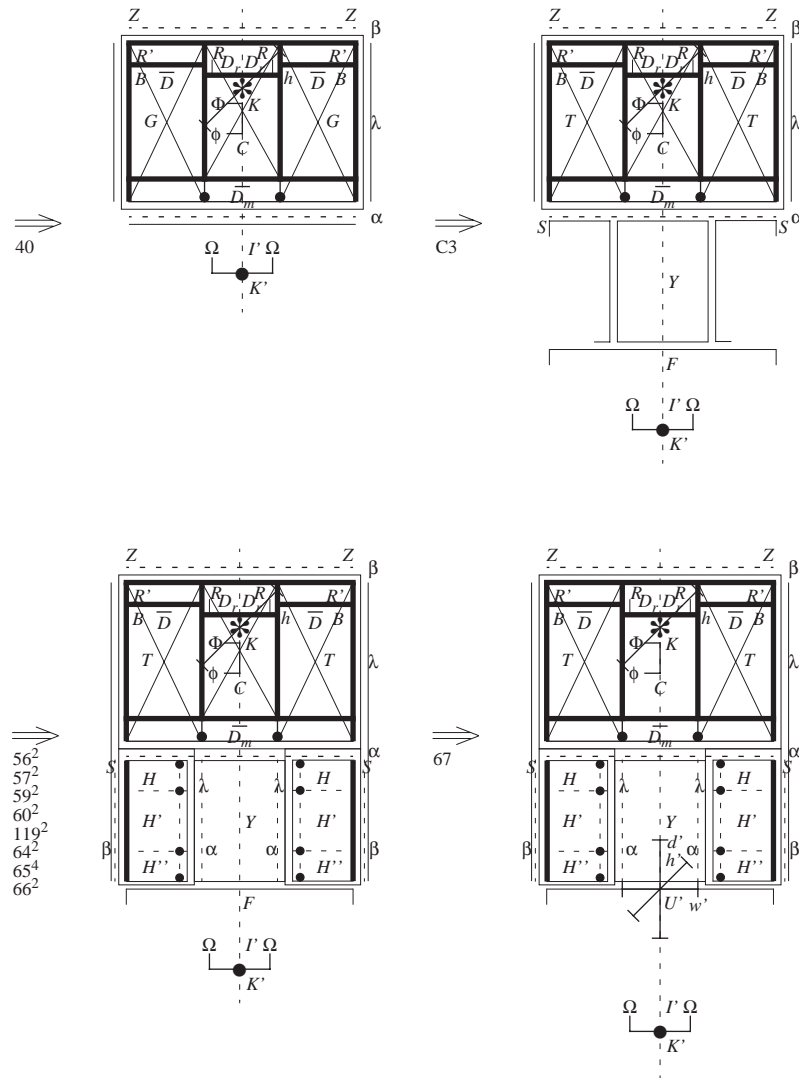
Figure 6.16 (continued).
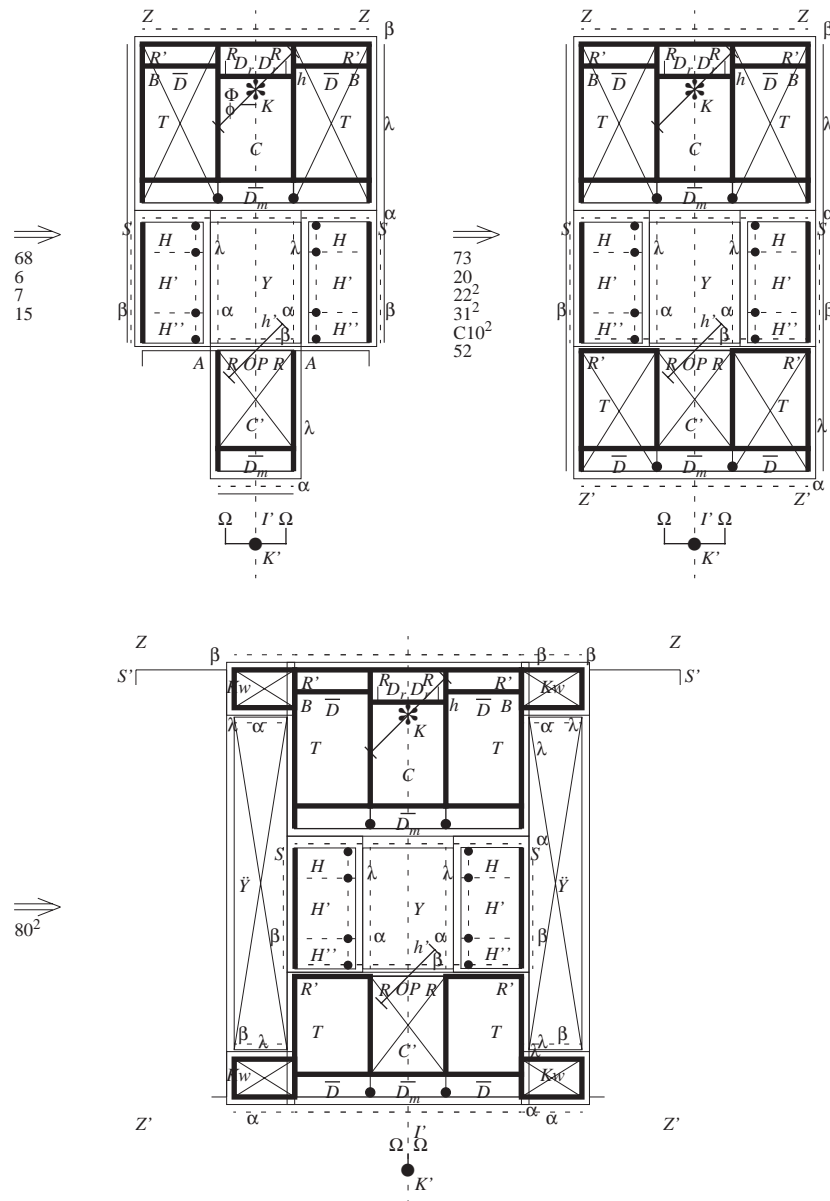
Figure 6.16 (continued).
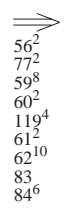
Figure 6.16 (continued).
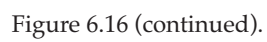
Chapter 7:
A Language for
Describing Shapes

7.1   Describing Shapes

Ultimately, the efficacy of computation cannot be shown without reference to some form of demonstration. In practical terms, this is typically a programmed implementation. In the case of shape grammars, there are number of issues that have to resolved as the following quote indicates.

> GRAIL is a quest for an environment for the interactive representation, modelling and generative composition (shape grammars) of two- and three-dimensional geometric objects with or without non-spatial attributes. Currently, work in GRAIL focuses on efficient implementations of the algorithms based on

> the maximal representation of shapes, on user interaction issues related to rule-based generative and drawing systems, on radiosity based rendering techniques, on semantic interface issues and on shape grammar applications with or without associated descriptions (Stiny, 1990). Planned work on GRAIL include the maximal representation of solids and subshape recognition in three dimensions for line, plane and solid shapes.
>
> Ramesh Krishnamurti (1992b: 464)

Among the issues include the need for a unifying representation [i.e., maximal element] of shapes, for transformation and recognition of shapes, for user-interface and interaction design, for presentation and selection of shapes and rules, and dealing with weighted (attributed) shapes or geometries. Also implied by this quote is the distinction between internal and external aspects. In its own right, each of these issues is difficult, as three recent dissertations indicate: Stouffs (1994), Chase (1996), and Tapia (1996).

Stouffs lays the foundation for an algebraic treatment of shapes based on a maximal element representation and develops the algorithms for the three-dimensional shapes that forms the kernel upon which my programmed demonstration, described below, is based. Chase explores modeling through weighted geometries and demonstrates his ideas through a logic programming paradigm. Tapia explores issues the presentation and selection of rules. His work includes a refinement of Krishnamurti's (1982) original shape grammar implementation. None of these dissertations, however, touch upon the issue of describing shapes independent of an underlying internal representation. This is an important issue in the context of developing shape grammar implementations.

The basis of my work on describing shapes is the treatment of weighted geometries that is currently being pursued and researched by Stouffs and Krishnamurti (1996). Their work, though not yet fully completed, is sufficient enough for me to proceed with an initial development of a shape description language. Stouffs is currently implementing a new GRAIL kernel in both Java and C. I am using a version of his new C language kernel as the programming framework for my own effort. The remainder of this chapter is focussed on such a language for describing shapes.

7.2   Sorts, Individuals, and Forms

Shapes are described by their geometry and by associated attributes. A way of unifying the treatment of shapes is through the notion of sorts. A brief outline is provided [I omit the mathematical details].

Sorts are collections of entities that are characterized by representative *characteristic individuals,* which can be considered to specify information types. For example, a sort of points can be specified by the information type associated with the notion of a point, which, at a base level, is simply an ordered tuple of coordinate values: x, y, z, etc. An elements of a sort is an *individual*. For instance, a point is an individual of the sort of points.

A *form* is a collection of one or more individuals within the same sort. A collection of points thus defines a form. This collection is also a set. Forms can be operated upon algebraically through operations such as sum, difference, and product. The operation on two forms of a sort yield a form of the same sort.

Sorts can be classified according to the nature of their individuals: if a sort only allows forms to be single individuals, it is said to be *singly-associated*; otherwise, it is *multiply-associated*. An example of a singly-associated sort would be that of colors, since colors combine to form a single color. On the other hand, the sort of labels or annotations are multiply-associated. An object may have as many labels as it needs.

Sorts can be operated upon algebraically; that is, individuals of different sorts can be combined to form individuals of an entirely new sort. Any individual of a sort can be assigned *attributes*, creating a form of a simple sort. A simple sort is thus the result of composing two simple sorts under a cartesian product ($\times$). The first component is the individual, and the second is the *weight* of the individual. A weight can itself have an attribute sort, thus permitting a simple sort to be composed of multiple simple sorts.

[For now] simple sorts can be composed under sum ($+$); the result is a *composite sort*. The corresponding form is called a *metaform*. A simple sort defines a conjunction of simple sorts, whereas a composite sort specifies the disjunction of simple sorts. Each of these sorts can provide a form for the metaform of a composite sort.

7.3 Algebraic Operations on Forms

GRAIL employs a maximal representation for weighted geometries. For any sort, GRAIL represents its forms by maximalizing, in order, its constituent forms. Sorts are treated as algebras and there are pre-defined algebraic operations on forms. I outline the basic algebraic operations in GRAIL. Forms are denoted in upper case letters and individuals in lower case. Below, *A*, and *B* are forms of the same sort, and *a* is an individual of the same sort as *A*.

form_sum (A, B) ≡ *A = A + B ; purge (B)*

Takes the sum of two discrete forms *A* and *B*, and stores the result in *A* and purges *B*.

form_difference (A, B) ≡ *A = A - B*

Takes the difference of two discrete forms *A* and *B*, and stores the result to *A*.

form_product (A, B) ≡ *A = A * B ; purge (B)*

Takes the product of two discrete forms *A* and *B*, and stores the result to *A* and purges *B*.

form_sym_difference (A, B) ≡ *A = A / B ; purge (B)*

Takes the symmetric difference of two discrete forms *A* and *B*, and stores the result to *A* and purges *B*.

form_partition (A, B, C) ≡ *C = A * B ; A = A - C; B = B - C*

Partitions two discrete forms *A* and *B*, and stores the common partition in *C* and the disjoint partitions are stored in *A* and *B*.

form_part_of (A, B) ≡ *A <= B*

Return true if form *A* is part of form *B*.

form_equals (A, B) ≡ A == B

Returns true if two forms *A* and *B* are equal.

form_duplicate (A, B) ≡ A = form_duplicate (B)

Makes form *A* a duplicate of *B*.

form_add (A, a)

Add an individual *a* to the multiple form *A*; after which *A* is sorted and maximalized. Since the form *A* may contain an attribute, the individual *a* can be also added to any particular individual as an attribute by using the index operator, @.

attribute_add (A, a)

Adds an attribute *a* to the individual *A*.

form_sort (A)

Sort a multiple form *A* and restores the result to *A*.

form_maximal (A)

Maximalize a multiple form *A* and restores the result to *A*.

7.4   Sort Definition

Although the language definition is given in the sequel, it is best to first deal with sorts in the context of the shape description language. For my purpose, a sort is a set of similar models for a given abstract entity. A sort is represented by four components, "any particular instance of this sort is defined by the system of characteristic equations (over characteristic and instance parameters) and a tuple of values for instance parameters." (Stouffs and Krishnamurti, 1996: 3)

There are two types of sort: *simple sort* and *composite sort*.

A *sort* is specified by a *sort name*, an associated *sort expression*, and optional *sort conditions*. A *sort expression* is a combination of sorts, containing sum (+)

or product (*). Each *constructor* for a sort expression is either an existing sort or a pre-defined characteristic individual.

    sort <sort name> ':' <sort expression> ['{' < sort conditions> '}'] ;

```
sort points : point;           // points is a sort made up by the
                               // characteristic individual point
sort labels : label;           // labels is a sort made up by the
                               // characteristic individual label
sort labeled_points : (p : point) * (l : labels);
                               // labeled_points is a sort made
                               // up by the characteristic
                               // individual point with the
                               // the sort labels as its attribute
```

Note that the sort expression under product, recursively defines a sort taking the first constructor as the individual, and the other as the attributes. For example:

    sort dummy : (p : point) * (p : point) * (l : label)

is equivalent to the following definition

    sort dummy : (p : point) * ((p : point) * ((l : label) * nil))

7.4.1 Instances of Sort

A form of a given sort is specified by an *instance definition*.

    instance <instance-name> : <sort-name> ;

```
sort binary : int {binary == 1 || binary == 0};
instance x : binary;
instance y : binary;
x = 1;
y = 1;
```

Note that, for the above examples, x and y are actually identical because they are both the same instance (1) of binary sort except one is named x and the other y.

7.4.2 Characteristic Individuals for Shapes

Characteristic individuals define sorts. Each characteristic individual also uniquely specifies a category. GRAIL provides nine primary characteristic individuals for describing shapes[1]:

- point;
- line (infinite line) and lineseg (line segment);
- boundary and plane;
- shell and volume;
- label and fractional.

We can use the characteristic individuals, in an object-oriented fashion, as a description of its sort, as a function that creates individuals of the same sort, and as a truth-functional predicate. In the latter case, for notational convenience, we append the suffix '?'.

Point

The information type point is the characteristic individual for specifying a sort of points. The corresponding function point() defines an individual point through its cartesian coordinates. Coordinates can be either reals in which case the point is given by the *cartesian coordinates* (x, y, z), or integers in the point is in *homogeneous coordinates* (x, y, z, w). The function point?() detects if a given value is an individual of the sort point. Thus we have:

point '(' x, y, z : real ')' or point '(' x, y, z, w : int ')'

point? '(' _ ')' : boolean

---

point(0, 0, 0, 1);
point(0.0, 0.0, 0.0);

---

1.   Rudi Stouffs (private communication).

Line

The object line is a characteristic individual for specifying a sort of infinitely long lines. Notice that the two reference points are specified by individuals of the composite coord + point. The point indicates a point of the line and the coord specifies a direction.

```
line '(' p1, p2 : vector + point ')'

type coord : (x : int) * (y : int) * (z : int) * (w : int) + (x : real) * (y : real) * (z : real)

line? '(' _ ')' : boolean
```

```
line((0, 0, 0, 1), (2, 0, 0, 1));
line(point(0, 0, 0, 1), (2, 0, 0, 1));
line((0.0, 0.0, 0.0), (2.0, 0.0, 0.0));
```

Line Segment

The characteristic individual lineseg is provided for line segment which is made up of two distinct points.

```
lineseg '(' p1, p2 : vector + point ')'

lineseg? '(' _ ')' : boolean
```

Boundary

The characteristic individual boundary specifies the boundary lines of a simple planar surface, and has at least three distinct ordered line segments. The end point of any line segment must be identical to the start point of its adjacent line segment.

```
boundary '(' …')'

boundary? '(' _ ')' : boolean
```

Plane Segment

The characteristic individual plane defines a plane segment made up of one or more boundaries. The first boundary is outer, and all others are inner.

plane '(' …')'

plane? '(' _ ')' : boolean

Shell

A *shell* is similar to a boundary. A shell is made up of planes.

shell '(' …')'

shell? '(' _ ')' : boolean

Volume Segment

The characteristic individual volume specifies a volume segment. Each volume is made up of shells, and the first one being outer, all others inner.

volume '(' … ')'

volume? '(' _ ')' : boolean

Label

The characteristic individual label specifies a sort of labels. An individual label can be a character, string, integer, or real.

label '(' l : char + string + int + real ')'

lanel? '(' _ ')' : boolean

---

label("square");
label(2);

Fractional

The characteristic individual fractional specifies a sort of weights, such as thinkness. An individual fractional can be an integer, or real.

fractional'(' l : int + real ')'

fractional? '(' _ ')' : boolean

```
fractional(2);
fractional(2.0);
```

7.5   The Shape Description Language

The preceding description for sorts and individuals are incorporated in an interpretive language for describing spatial representation: the shape description language (SDL). SDL is type sensitive, namely, each operation replies on strong typing. The initial design goals are to have:

- flexibility in describing shapes.
- a simple syntax
- easily extensible
- capability of incorporating computable non-geometric information.

My goal is to keep SDL as small and simple as possible, making it easier to program, debug, and more importantly for a user, to learn. Keeping the language small makes it more robust, since there are fewer opportunities for programmer errors. The syntax of the language was shaped by the above notions of sorts and individuals. We begin with the usual definition for the legal character set.

7.5.1   Character Set

The *character set* for SDL includes some *graphic* as well as *non-graphic* characters. Graphic characters are those that are printable. Non-graphic character are represented by escape sequences consisting of a backslash \ followed by a letter. The graphic characters are summarized in Table 7.1.

Comments

SDL allows user comments. Comments are prefixed by // and any sequence of characters between // and a new line is ignored (i.e., treated as a comment). They can be placed freely in a SDL program.

Character	Name	Usages	Examples
0 … 9	decimal digits	int, real, string	12
A … Z	uppercase letters	identifier	Me
a … z	lowercase letters	identifier	me
//	double slash	comment	// a comment
:	colon	sort/type declaration	sort x: int;
;	semicolon	statement separator	x = 3;
,	comma	element separator	(1, 2, 3)
	space	element separator or	(1 2 3)
"	double quotation mark	string	"a string"
(	left parenthesis	tuple, parameters	(1, 2, 3)
)	right parenthesis		
[	left (square) bracket	list index	x[3]
]	right (square) bracket		
{	left brace	list, function/statement body	{1, 2, 3}
}	right brace		
!	exclamation point	boolean negation	!true
&&	double ampersand sign	boolean and	true && true
||	double vertical bar	boolean not	true || false
<	less than	logical operation	2 < 3
<=	less than or equal to	logical operation	2 <= 3
>	greater than	logical operation	3 > 2
>=	greater than or equal to	logical operation	3 >= 2
==	equal to	logical operation	2 == 2
+	plus	arithmetic add	1 + 2
-	minus	arithmetic substraction	1 - 2
*	asterisk	arithmetic multiplication	1 * 2
/	slash	arithmetic division	1 / 2
%	percent sign	arithmetic remainder (mod)	3 % 2
^	caret/circumflex	concatenation	"abc" ^ "def" {1, 2, 3} ^ {3, 4, 5}
::	double colon	list cons operator	1:: {2, 3}
=	assign to	assignment	x = 1 + 3;
.	period	real, member separator	12.3
@	"at" sign	member/ individual index	x.@1
?	question mark	predicate	int?(2)
\	backslash	escape sequences	\"

Table 7.1.   Character set for SDL.

Separators

There are two kinds: (i) semicolon (;) to separate statements; (ii) comma (,) to separate elements in a list, array, or tuple.

7.5.2 Primary Data Types

SDL provides five primary data types: boolean for logical values; int and real for numerical values; char and string for a single character and a sequence of characters respectively.

Nil

There is a type nil to provide for empty model of individuals. When nil is included in a type specification, it serves to optionalize individuals. This is useful, for example, for defining the empty shape as an individual.

Boolean

The boolean type consists of the values true and false. Ordinary negation is available through the unary ! (not) operator. Likewise, the operators && (and) and || (or) are provided.

!true	⇒ false
true && false	⇒ false
true || false	⇒ true
!(true || false)	⇒ false

The conditional statement:

if '{' *exp* '}' then '{' *statements₁* '}' [else '{' *statements₂* '}'] ;

is considered here because its first argument, *exp*, must be a boolean. The else clause is optional.

```
if {true} then {
                        // do something here
};
```

Numbers

There are two number types: int for positive and negative integers, and floating numbers is presented as real. Integers are presented in the usual way. Real numbers can be presented as decimals or exponentials. The exponent is indicated by an E or e. Negative numbers are written with a minus sign.

The *arithmetic operators*, +, -, *, / (div), and % (mod) are provided for numbers, with % being an integer operation. For integers / represents integer division.

The *relational operators*, <, <=, >, >=, ==, and != are also provided. Each takes two numerical expression and returns a boolean according to whether or not the relation holds.

int as a function takes as an argument a real number or a character. In the former case, it truncates the number to an integer; in the latter case, it returns ASCII character set encoding for the character. real as a function converts an integer to the corresponding real number representation.

```
3 + 4               ⇒ 7
4 / 3               ⇒ 1
4 % 2               ⇒ 0
3 > 4               ⇒ false
int(3.4)            ⇒ 3
in('A')             ⇒ 65
3.4 + 1.2           ⇒ 4.6
3.4 + 1                     // illegal expression,
                            // both operands must be the same type
3.4 > 1.2           ⇒ true
```

```
3.4 > 1                          // illegal comparison
                                 // both operands must be the same type

real(3)              ⇒ 3.0

3.4 + real(1)        ⇒ 4.4
```

Three functions, floor, ceil, and round respectively return the floor, ceiling, and the nearest integer of its real argument.

```
floor(3.5)           ⇒ 3

ceil(3.5)            ⇒ 4

round(3.5)           ⇒ 4
```

Characters

The type char specifies a single character, which are presented as a single character or an escape sequence within single quotes ('…'). The complete set of escape sequence is:

\a	alert (bell) character	\\	backslash
\b	backspace	\?	question mark
\f	formfeed	\'	single quote
\n	newline	\"	double quote
\r	carriage return	*ooo*	octal number
\t	horizontal tab		where *o* is an octal digit (0..7)
\v	vertical tab	\x*hh*	hexadecimal number
			where *h* is a hexadecimal digit (0..9, a..f, A..F)

Internally, a character is an integer corresponding to its numeric value in the machine's character set. For example, in the ASCII character set, '0' has the value 48. I provide a char function which converts an integer to a char according to the ASCII character set. As previously stated, the function int takes a char and returns its integer value in the ASCII character set.

The arithmetic operators + and - are provided for chars as too are the usual relational operators, <, <=, >, >=, ==, and !=.

'a'	// a character 'a'
' '	// nil character
char(48)	⇒ '0'
int('0')	⇒ 48
'a' + 'b'	→ char(int('a') + int('b')) ⇒ char(97 + 98) = ' '
'a' <= 'b'	→ int('a') <= int('b') ⇒ true
'a' == 'a'	⇒ true

String

The type string specifies the set of finite sequences of characters. Strings are written in the conventional fashion as characters between double quotes ("…"). The double quote itself is escaped as "\"". The *concatenation operator* (^) is an *infix* append operation that takes two strings and *merges* them into one. The function slength returns the length of a given string.

The relational operators, <, <=, >, >=, ==, and !=, are available for strings. Each take two strings and returns a boolean. Suppose *a* and *b* are two strings, The relation *a* == *b* is true if *a* and *b* are identical, and *a* < *b* is true if a is a *substring* of *b*.

"abc"	// a string
abc	// not a string
""	// an empty string (nil)
" "	// a string which is a space
"abc" ^ ""	⇒ "abc"
"abc" ^ " def"	⇒ "abc def"
slength("abc def")	⇒ 7
"ab" == "ab"	⇒ true
"bc" <= "abcd"	⇒ true

7.5.3 Type Definition

Type definition in SDL is provided for the grouping of one or more (possibly) different data types under a single name, to organize data by treating related variables as a unit. It is similar to the *struct* and *typedef* constructs in C. Types are specified by a name, a type expression, and optional type conditions.

> type <type name> ':' <type expression> ['{' < type conditions> '}'] ;

The type expression is a combination of types, specified either as a sum (+) or product (*).

> type coord : (x : real) * (y : real) * (z : real) + (x : int) * (y : int) * (z : int) * (w : int);

Each constructor in a type expression is either an existing type or a simple data type. When specified as a sum, type expressions indicate different type alternatives; when specified as a product they define a structure or combination in which data is represented as a tuple (see Section).

A good example for type definition is in specifying shape rules. A shape rule can be defined as a pair of shapes: *lhs* and *rhs*. Thus a shape rule can be specified by the following type definition.

> type rule : (lhs : shape) * (rhs : shape);

For labeled shapes, the following type definition can be used:

> type rule : (lhs : labeled_shapes) * (rhs : labeled_shapes);

In both examples, the sorts *shape* and *labeled_shape* are assumed to have been previously defined.

7.5.4 Identifiers, Declarations, and Bindings

Identifiers must be declared before they are used. Since identifiers can be used in different ways in SDL, there is a form of declaration for each usage.

Identifiers and Variables

An *identifier* is a sequence of letters and digits of arbitrary length. The first character must be a letter; underscore (_) counts as a letter. Letters are case distinct. x, X, y, _var_x, … are examples of variables.

Declarations (Instances)

An variable is specified by the keyword instance together with an associated *type expression* or a *sort* (see Section 7.4).

    instance <identifiers> ': ' <type expression or sort> ;

---

    instance x: int;   // declare x is an instance of int

7.5.5 Assignments

An *assignment statement* binds a variable with a particular value according to its type/sort. If the type/sort of a value is different from the type/sort of the identifier, an error is encountered and the variable is not changed.

    <identifier> '=' <value expression> ;

---

    instance x : int;
    x = 20 + 30;
    x = x * 12;
    x = "abc";   // an error, type inconsistency
    instance x : string;   // re-declare x
    x = "abc";

Garbage Collection

For reasons of storage efficiency, memory that is no longer in use has to be recovered or deallocated. Typically, a language implementation performs *garbage collection* to free unused memory space. At this stage in the design,

SDL does not perform automatic garbage collection and an explicit destructor purge() is provided for the user to free the content of a constructor.

Suppose, for example,

```
x = y;
x = z;
```

If *y* is no longer in use, the user can free the memory space for *y* by invoking

```
purge(y);                        // free the memory for y
```

Once memory for *y* has been freed, the following statement will generate an error.

```
w = y;                           // an error, y has been freed
```

7.5.6 Sets of Data

List

The elements of a list are of a single type. Elements are separated by commas or spaces and enclosed within a pair of braces ({}). The declaration of a list is indicated by a type and square brackets ([]). The size of an list can be specified within the square brackets. The length of a list can be inquired by the function llength.

The list of no elements, is presented either as nil or []. The value of any element can be accessed via an index. Indexing starts from 1.

```
instance x1, x2: int[];          // two integer list
instance y: real[3];
y = {1.2, 3.4, 4.5};             // a real list with length 3
llength({1, 2, 3, 4})    ⇒ 4
```

The concatenation operator (^) appends the second list to the first. The cons operator (::) appends an element to the end of a list. The operators +, -, and * are provided for list union, difference, and intersection respectively.

```
{1, 2, 3} ^ {3, 4, 5}      ⟹ {1, 2, 3, 3, 4, 5}
7 :: {1, 2, 3}             ⟹ {7, 1, 2, 3}
3 :: nil                   ⟹ {3}
1 :: 2 :: 3 :: nil         ⟹ {1, 2, 3}
{1, 2, 3} + {3, 4, 5}      ⟹ {1, 2, 3, 4, 5}
{1, 2, 3} - {3, 4, 5}      ⟹ {1, 2}
{1, 2, 3} * {3, 4, 5}      ⟹ {3}
```

There are two special functions for list: head and tail. head retrieves the first element of a given list, and tail returns the list of the remaining elements.

```
head({1, 2, 3})           ⟹ 1
tail({1, 2, 3})           ⟹ {2, 3}
given any list x, x == head(x) :: tail(x)
```

Lists can be nested.

```
instance x: int[][3]= {{1, 2, 3} {2, 4, 5} {8, 9, 10, 11}};
x[1]                      ⟹ {1, 2, 3}
x[1][2]                   ⟹ 2
x[3]                      ⟹ {8, 9, 10, 11}
x[3][4]                   ⟹ 11
x[3][5]                              // wrong index accessing
```

Tuple

A *tuple* is formed by taking a list of two or more expression of any type, separated by commas, and enclosed within parenthesis. Usually, a tuple is

specified by a type definition. The length of a tuple can be inquired by the function tlength.

(1, 1.5, "me") is a tuple of type int*real*string, and its length is three.

Given a tuple or a variable whose value is a tuple, we can access the *i*-th component by applying the @*i* index operator.

```
(1, 1.5, "me").@1 ⇒ 1          // 1st component
(1, 1.5, "me").@2 ⇒ 1.5        // 2nd component
(1, 1.5, "me").@3 ⇒ "me"       // 3rd component
tlength((1, 1.5, "me")) ⇒ 3
```

7.5.7 Conditions, Defaults, and Current

Conditions

The *condition binding* is used to define constraints. It is specified in the same way as logical expressions.

```
instance <identifiers> ': ' <type expression or sort> '{' <instance conditions> '}' ;
```

```
instance pint : int {pint >= 0};    // pint is an instance of integer
                                    // greater than or equal to 0
instance alist : int[] {llength(alist) >= 3};
                                    // alist is an instance of any integer list
                                    // with at least length 3
```

Defaults

The *default binding* provides for defining default values. Defaults can be dynamically changed. The default binding is useful for specifying parametric shapes.

```
default <type or sort> '=' <default values> ;
```

```
instance x : int {x >= 0};        // define an instance x
default x = 5;                     // set default for x
default x = 10;                    // reset the default for x
default x = -5;                    // wrong statement, because x
                                  // must be greater than or equal to 0
```

Note that the default value for an identifier has to be set explicitly using the default binding. Two auxiliary functions are also provided. The function rdefault retrieves the default value. An example, $x + \text{rdefault}(y)$ adds the value x to the default value of y (which may be different from the current value of y). The other function has_default? detects whether a given identifier has default value set.

Current

Current is a special instance which may be of any data type or sort. Its data type or sort depends on its value setting. If a value is not assigned to any particular variable (identifier), it is automatically assigned to current.

```
12;                               // 12 is assigned to current;
"a string";                       // current = "a string"
```

Note that the above are equivalent to setting values to the keyword current.

```
current = 12;
current = "a string";
```

7.5.8 Functions

Defining Functions

The function definition in SDL is similar to conventional programming languages, such as C or Pascal. A function definition starts from the keyword function. Arguments to a function have to be explictly typed at the time of function definition.

```
function <function name> '(' [ <parameters> ] ')' ':'
        <type expression or sort> <function body>;
```

```
function twice(x:int): int {
   twice = 2*x;
};
function add(x:int+real, y:int+real): real {
   add = real(x) + real(y);
} ;
function x:real = add(3, 1.5); ⇒ x = 4.5
function y:int = twice(3); ⇒ y = 6
```

Type versus Function and Predicate

In SDL for each basic type, there is a function with same name as its type. For example, int is both a type and a function which truncates a real and returns an integer. The function identified by the type name with the suffix ? detects if a given value is of the type or not and returns a boolean value.

The following are some of the built-in functions for the basic data types.

nil?

The predicate nil? is provided for detecting if a given variable is a nil.

```
nil? ( _ ) : boolean
```

boolean and *boolean?*

The boolean function returns any non-zero integer or real to true; otherwise, returns false.

```
function boolean(x : int + real + boolean) : boolean {
        if {x != 0} then {boolean = true;} else {boolean = false;};
}

boolean? ( _ ) : boolean ;
```

boolean(3)	$\Rightarrow$ true
boolean(false)	$\Rightarrow$ false
boolean?(3)	$\Rightarrow$ false
boolean?(false)	$\Rightarrow$ true

int and *int?*

The int function truncates a real to integer, or convert a character into an integer value according to ASCII character set. The predicate int? detects if a given value is an integer or not.

```
int ( x : int + real + char) : int

int? ( _ ) : boolean
```

int(3.6)	$\Rightarrow$ 3
int(3)	$\Rightarrow$ 3
int?(3.0)	$\Rightarrow$ false
int?(3)	$\Rightarrow$ true

real and *real?*

The function real converts an integer to real. The predicate real? detects if a given value is a real number or not.

```
real ( x : int + real) : real
```

real? (_) : boolean ;

---

real(3)   ⇒ 3.0
real(3.6)   ⇒ 3.6
real?(3)   ⇒ false
real?(3.0)   ⇒ true

---

char and *char?*

The function char can be used in two ways. Firstly, it converts an integer to a char according to the ASCII character set. Secondly, it returns the character for the given index of a string. The predicate char? detects if a given value is a char or not.

char (x : char + int {x >= 0 && x <=255}) : char

char (x : string, index : int) : char

char? (_) : boolean ;

---

char('A')   ⇒ 'A'
char(65)   ⇒ 'A'
char("a string", 3)   ⇒ 's'
char("a string", 9)   ⇒ '' or nil
char?('A')   ⇒ true
char?(65)   ⇒ false

---

string and *string?*

The string function converts a character into a string or a *substring* of a given string. The predicate string? detects a given value is a string or not.

string (x : char + string) : string

string (x : string, start : int, end : int) : string

```
string? ( _ ) : boolean
```

```
string('a')                ⇒ "a"
string("a string")         ⇒ "a string"
string("a string", 2, 5)   ⇒ " str"
string("a string", 9, 12)  ⇒ "" or nil
string?(23)                ⇒ false
string?('a')               ⇒ false
string?("a string")        ⇒ true
```

7.6   A Tutorial on SDL

I now give a short overview of programming in SDL. My aim here is to show the essential features of the language as currently implemented. SDL is implemented in C under the UNIX environment. The current graphic display is simple and based on the X window library.

7.6.1   Getting Started

The user enters *sdl* (or the full pathname) at the UNIX prompt (%) to run the shape description language. A SDL prompt will appear after program initialization.

```
% sdl
Shape Description Language Based on GRAIL
(c) 1996

SDL 1>
```

7.6.2   Exiting SDL

To exit the SDL program, the user simply types 'exit' or 'quit.'

```
SDL 1> exit
Exit program!! Bye.
%
```

or

```
SDL 1> quit
Exit program!! Bye.
%
```

The program terminates and returns the user to the UNIX shell.

7.6.3 Input

The basic idea in SDL is to let the user interactively describe a shape. The user can enter any SDL statement at the SDL prompt. There are three ways to input descriptions to SDL.

Command line input

The user can specify a resource file when she/he starts the program as a command line argument. SDL will take the first argument as a resource file and execute each description.

```
% sdl sdl_dummy

Shape Description Language Based on GRAIL
(c) 1996

SDL 1>
```

Sourcing an SDL program

The user can source a file containing SDL statements using the *source* function.

SDL 1> source("sdl_dummy");

Interactively

Normally, the user input the description statements after the SDL prompt. Each statement is ended by the semicolon (;). The description statements include sort/type definitions, expressions, and functions. Any characters between the reserved symbol double slash (//) and the new line are treated as a comment.

SDL 2> // add a comment here

>> comment

SDL 3> print(x);

unknown: x

SDL 4>

Note that the program will prompt the result or (error/warning) message after it executes each description statement.

7.6.4 Defining New Sorts

The user defines a new sort by following the sort definition. The sort name has the same restriction as the identifier. If a sort name was already defined before, the new definition will overwrite the old one. Furthermore, any sort definition will be reduced to the composition of the basic sorts. For instance, supposed that sort x was defined by the simple sorts a * b before, and a new

sort y is defined by sort x, the sort y will be reduced to a * b. The following
example illustrates these cases.

```
SDL 4> sort labeled_points : (points : point) * (labels : label);
name 'points' is assigned the sort '[Point]'
>> sort (points): (points:point)
    sort: (points = [Point])


name 'labels' is assigned the sort '[Label]'
>> sort (labels): (labels:label)
    sort: (labels = [Label])


name 'labeled_points' is assigned the sort '[Point] * [Label]'
>> sort (labeled_points): ((points:point)*(labels:label))
    sort: labeled_points = (points = [Point]) * (labels = [Label])


SDL 5> sort weight_lineseg : (lines : lineseg) * (weight : fractional);
name 'lines' is assigned the sort '[LineSegment]'
>> sort (lines): (lines:lineseg)
    sort: (lines = [LineSegment])


name 'weight' is assigned the sort '[Fractional]'
>> sort (weight): (weight:fractional)
    sort: (weight = [Fractional])


name 'weight_lineseg' is assigned the sort '[LineSegment] * [Fractional]'
>> sort (weight_lineseg): ((lines:lineseg)*(weight:fractional))
    sort: weight_lineseg = (lines = [LineSegment]) * (weight = [Fractional])


SDL 6> sort weight_shapes : weight_lineseg + labeled_points;
name 'weight_shapes' is assigned the sort '[LineSegment] * [Fractional] + [Point]
* [Label]'
```

>> sort (weight_shapes): ((weight_lineseg:((lines:lineseg)*(weight:fractional)))
+(labeled_points:((points:point)*(labels:label))))

    sort: weight_shapes = weight_lineseg + labeled_points

SDL 7> sort shapes : weight_shapes + lines + points + labels;

name 'shapes' is assigned the sort '[Label] + [LineSegment] + [LineSegment] *
[Fractional] + [Point] + [Point] * [Label]'

>> sort (shapes): ((weight_lineseg:((lines:lineseg)*(weight:fractional)))
+(labeled_points:((points:point)*(labels:label)))+(lines:lineseg)+(points:point)+
(labels:label))

    sort: shapes = weight_shapes + lines + points + labels

SDL 8>

7.6.5 Creating Instance

The user specifies new instances by following the instance definition. The
instance name is an identifier. If an instance definition already exists, the new
definition will overwrite the old definition. Note that an identifier must be
declared before it is used; otherwise, an error occurs. The following example
specifies four instances of sort *shapes* which was defined above.

SDL 8> instance s1, s2, s3, s4: shapes;

>> instance (s1): (shapes:((weight_lineseg:((lines:lineseg)*(weight:fractional)))
+(labeled_points:((points:point)*(labels:label)))+(lines:lineseg)+(points:point)+
(labels:label)))

>> instance (s2): (shapes:((weight_lineseg:((lines:lineseg)*(weight:fractional)))
+(labeled_points:((points:point)*(labels:label)))+(lines:lineseg)+(points:point)+
(labels:label)))

>> instance (s3): (shapes:((weight_lineseg:((lines:lineseg)*(weight:fractional)))+
(labeled_points:((points:point)*(labels:label)))+(lines:lineseg)+(points:point)+
(labels:label)))

```
>> instance (s4): (shapes:((weight_lineseg:((lines:lineseg)*(weight:fractional)))
+(labeled_points:((points:point)*(labels:label)))+(lines:lineseg)+(points:point)
+(labels:label)))


SDL 9> instance p1, p2, p3, p4: point;
>> instance (p1): point
>> instance (p2): point
>> instance (p3): point
>> instance (p4): point


SDL 10>
```

The instance definition can be used to declare numerical data and individual.

7.6.6 Individuals

An individual can be created by the built-in functions such as point, label, line, etc. The following example specifies a point individual and stores the individual to the variable *current*.

```
SDL 10> point(5, 5, 0, 1);
>> value: (point) position: 5(1,1,0)


SDL 11> print(current);
Instance: current = (point) position: 5(1,1,0)


SDL 12> p1 = point(10,0,0,1);
>> value: (point) position: 10(1,0,0)


SDL 13> p2 = point(15,50,0,1);
>> value: (point) position: 5(3,10,0)
```

SDL 14>

7.6.7 Manipulating Forms

A *form* is a collection of one or more individuals of the same sort. The following examples illustrate how to add individuals to a form. Note that the GRAIL function *form_add* is essential in manipulating a given form. The function *form_add* adds an individual to the given form. The individual that is added must be of the same sort as the form. Once an individual is added, the form will be sorted and maximalized automatically.

The function *attribute_add* is used for adding extra attributes to a given individual. Supposed that *b1* is a form, and *b1.@end* indicates the last individual of the form *b1*. Note that the 'at index' (@) is an integer that indicates the index of an individual in a form. The first individual of the form is indexed as 1. Two special indices are provided. The index first indicates the first individual of the given form, and the index end indicates the last.

```
SDL 14> form_add(s1, (p1, label("a")));
Debug: Add an individual to form s1
begin <1>
   begin <1>
      position: 10(1,0,0)
      begin <1>
         label: a
      end <>
   end <>
end <>

SDL 15> form_add(s1, (p2, {label("abc"), label("b")}));
Debug: Add an individual to form s1
begin <1>
   begin <2>
```

```
      position: 10(1,0,0)
      begin <1>
         label: a
      end <>
      position: 5(3,10,0)
      begin <2>
         label: abc
         label: b
      end <>
   end <>
end <>


SDL 16> p1 = point(40.0, 40.0, 0.0);
>> value: (point) position: 40(1,1,0)


SDL 17> p2 = point(80.0, 40.0, 0.0);
>> value: (point) position: 40(2,1,0)


SDL 18> p3 = point(80.0, 80.0, 0.0);
>> value: (point) position: 80(1,1,0)


SDL 19> p4 = point(40.0, 80.0, 0.0);
>> value: (point) position: 40(1,2,0)


SDL 20> form_add(s2, lineseg(p1, p2));
Debug: Add an individual to form s2
begin <1>
   begin <1>
      direction: (1,0,0) root: 40(0,1,0)
      tail: 40 head: 80
   end <>
end <>
```

```
SDL 21> form_add(s2, lineseg(p2, p3));
Debug: Add an individual to form s2
begin <1>
   begin <2>
      direction: (0,1,0) root: 80(1,0,0)
      tail: 40 head: 80
      direction: (1,0,0) root: 40(0,1,0)
      tail: 40 head: 80
   end <>
end <>

SDL 22> form_add(s2, lineseg(p3, p4));
Debug: Add an individual to form s2
begin <1>
   begin <3>
      direction: (0,1,0) root: 80(1,0,0)
      tail: 40 head: 80
      direction: (1,0,0) root: 40(0,1,0)
      tail: 40 head: 80
      direction: (1,0,0) root: 80(0,1,0)
      tail: 40 head: 80
   end <>
end <>

SDL 23> form_add(s2, lineseg(p4, p1));
Debug: Add an individual to form s2
begin <1>
   begin <4>
      direction: (0,1,0) root: 40(1,0,0)
      tail: 40 head: 80
      direction: (0,1,0) root: 80(1,0,0)
      tail: 40 head: 80
      direction: (1,0,0) root: 40(0,1,0)
```

```
      tail: 40 head: 80

      direction: (1,0,0) root: 80(0,1,0)

      tail: 40 head: 80

    end <>

end <>


SDL 24> form_add(s3, (lineseg(p1, p3), fractional(0.3)));

Debug: Add an individual to form s3

begin <1>

    begin <1>

      direction: (1,1,0) root: (0,0,0)

      tail: 40 head: 80

      begin <>

        value: 0.3

      end

    end <>

end <>


SDL 25> s4 = s1 + s2 + s3;

Debug: Sort of form matched!

 >> value: (form) begin <3>

    begin <4>

      direction: (0,1,0) root: 40(1,0,0)

      tail: 40 head: 80

      direction: (0,1,0) root: 80(1,0,0)

      tail: 40 head: 80

      direction: (1,0,0) root: 40(0,1,0)

      tail: 40 head: 80

      direction: (1,0,0) root: 80(0,1,0)

      tail: 40 head: 80

    end <>

    begin <1>

      direction: (1,1,0) root: (0,0,0)
```

```
        tail: 40 head: 80
        begin <>
            value: 0.3
        end
    end <>
    begin <2>
        position: 10(1,0,0)
        begin <1>
            label: a
        end <>
        position: 5(3,10,0)
        begin <2>
            label: abc
            label: b
        end <>
    end <>
end <>


SDL 26>
```

7.6.8 Graphical Output and Display

Some elementary graphical capacities are provided for graphical output and display. The user can open a display window by typing the function *display_open* after the SDL prompt. A window will display on the screen after the function is executed. The user can request the program to display a form (*display_form*), refresh a display (*display_refresh*), or purge a display (*display_clear*).

```
SDL 26> display_open();


SDL 27> display_origin(50, 50);
```

Debug: Change origin to (50, 50).

SDL 28> display_ratio(2.0,2.0);
Debug: Change display ratio to (2, 2).

SDL 29> display_form(s1);

SDL 30> display_form(s2);

SDL 31> display_form(s2+s3);

SDL 32> display_form(s4);

SDL 33>

A display of form *s4* is shown in Figure 8.1.
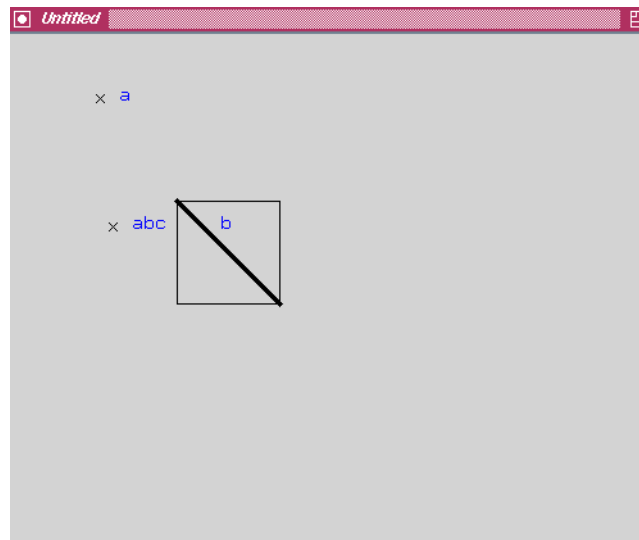
Figure 8.1. Current graphical display of SDL.

7.7 SDL Examples from the Grammar of Chinese Vernacular Houses

Finally, I take a few shape rules from the grammar of Chinese vernacular houses (Section 4.3), and show how these shape rules can be described in the shape description language. The illustrated examples have been tested in SDL. The first step is to specify the following sort definitions.

```
// sort definitions
sort labeled_points : (points : point) * (plabel : label);
sort labeled_lines : (lines : line) * (llabel : label);
sort labeled_linesegs : (linesegs : lineseg) * (lslabel : label);
sort weight_linesegs : (ls : lineseg) * (thickness : fractional);

sort lsshapes : weight_linesegs + labeled_linesegs;
sort labeled_shapes :  lsshapes + labeled_lines + labeled_points;
sort sshapes :  points + lines + linesegs;

sort global : (name : label) * (value : label);
sort shapes : labeled_shapes + sshapes + global;
```

Example 1: initial shape

<div align="center">(0,0)�</div>

```
// example 1 (initial shapes)
instance init_shape : shapes;
form_add(init_shape, point(0,0,0,1));
```

Example 2: shape rule 1
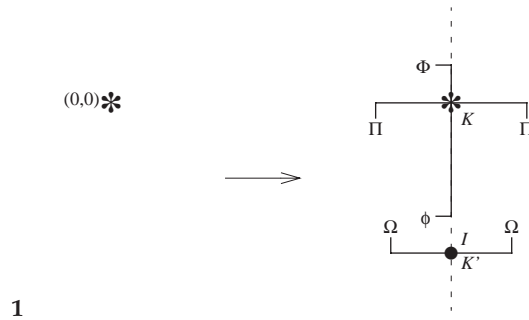

```
// example 2 (rule 1)
instance s1_left, s1_right : shapes;
instance p1, p2 : point;
instance bay, enclosure, route: int;

s1_left = form_duplicate(init_shape);

bay = 5;                    // number of bays in principle building
enclosure = 2;              // number of enclosures
route = 4;                  // number of routes
p1 = point(0,0,0,1);        // key brick position
p2 = point(0,-10,0,1);      // front point of axis

form_add(s1_right, (p1, label("K")));
form_add(s1_right, (p2, {label("K'"), label("I")}));
form_add(s1_right, line(p1, p2));
form_add(s1_right, (label("bay"), label(bay)));
form_add(s1_right, (label("enclosure"), label(enclosure)));
form_add(s1_right, (label("route"), label(route)));
```

Example 3: shape rule 2

2
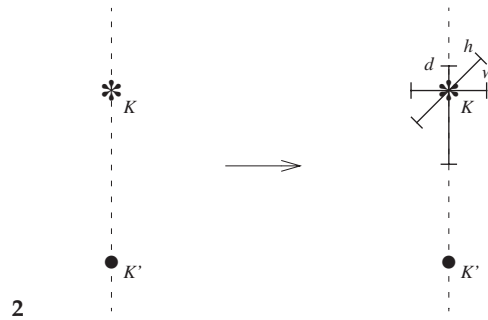
```
// example 3 (rule 2)
instance s2_left, s2_right : shapes;
instance width, depth, height : real;


form_add(s2_left, (p1, label("K")));
form_add(s2_left, (p2, label("K'")));


form_add(s2_left, line(p1, p2));


height = 10.0;                    // the height
depth = 13.0;                     // the depth
width = 10.0;                     // the width
s2_right = form_duplicate(s2_left);
form_add(s2_right, (label("width"), label(width)));
form_add(s2_right, (label("depth"), label(depth)));
form_add(s2_right, (label("height"), label(height)));
```

Example 4: shape rule 3

3
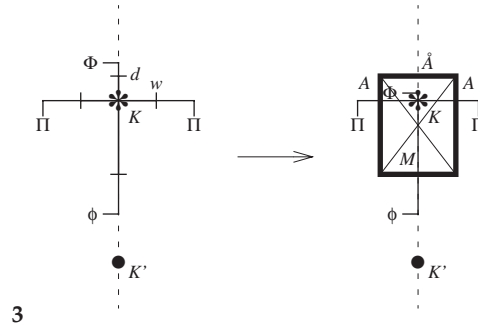
```
// example 4 (rule 3)
instance s3_left, s3_right : shapes;
instance t1, t2, t3, t4 : point;


s3_left = form_duplicate(s2_left);
form_add(s3_left, (label("bay"), label(bay)));
form_add(s3_left, (label("enclosure"), label(enclosure)));
form_add(s3_left, (label("width"), label(width)));
form_add(s3_left, (label("depth"), label(depth)));


t1 = point(-width/2.0, -2.0*depth/3.0, 0.0);
t2 = point(width/2.0, -2.0*depth/3.0, 0.0);
t3 = point(width/2.0, depth/3.0, 0.0);
t4 = point(-width/2.0, depth/3.0, 0.0);
s3_right = form_duplicate(s2_left);
form_add(s3_right, (label("bay"), label(bay)));
form_add(s3_right, (label("enclosure"), label(enclosure)));
form_add(s3_right, (lineseg(t1, t2), {label("cross"), label("M")}));
form_add(s3_right, (lineseg(t2, t3), {label("cross"), label("M"), label("A")}));
form_add(s3_right, (lineseg(t3, t4), {label("cross"), label("M"), label("A'")}));
form_add(s3_right, (lineseg(t4, t1), {label("cross"), label("M"), label("A")}));
```

Example 5: shape rule 4

4
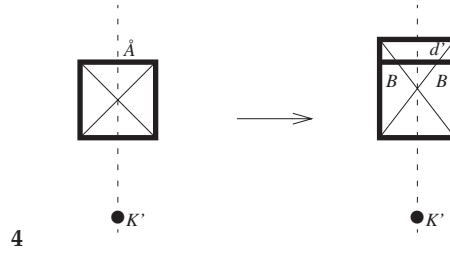
```
// example 5 (rule 4)
instance s4_left, s4_right : shapes;
instance t5, t6 : point;
instance rear : real;


form_add(s4_left, (p2, label("K'")));
form_add(s4_left, line(p1, p2));
form_add(s4_left, (lineseg(t1, t2), label("cross")));
form_add(s4_left, (lineseg(t2, t3), label("cross")));
form_add(s4_left, (lineseg(t3, t4), {label("cross"), label("A'")}));
form_add(s4_left, (lineseg(t4, t1), label("cross")));


rear = 4.0;                          // the depth of rear space
t5 = point(width/2.0, (depth/3.0 + rear), 0.0);
t6 = point(-width/2.0, (depth/3.0 + rear), 0.0);
form_add(s4_right, (p2, label("K'")));
form_add(s4_right, line(p1, p2));
form_add(s4_right, (lineseg(t1, t2), label("cross")));
form_add(s4_right, (lineseg(t2, t5), label("cross")));
form_add(s4_right, (lineseg(t5, t6), label("cross")));
form_add(s4_right, (lineseg(t6, t1), label("cross")));
form_add(s4_right, lineseg(t3, t4));
form_add(s4_right, (t3, label("B")));
form_add(s4_right, (t4, label("B")));
```

Example 6: shape rule 5

5
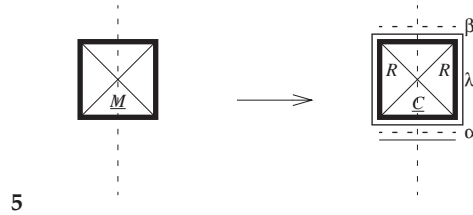
```
// example 6 (rule 5)
instance s5_left, s5_right : shapes;

form_add(s5_left, line(p1, p2));
form_add(s5_left, (lineseg(t1, t2), {label("cross"), label("M")}));
form_add(s5_left, (lineseg(t2, t3), {label("cross"), label("M")}));
form_add(s5_left, (lineseg(t3, t4), {label("cross"), lable("M")}));
form_add(s5_left, (lineseg(t4, t1), {label("cross"), label("M")}));

form_add(s5_right, line(p1, p2));
form_add(s5_right, (lineseg(t1, t2), {label("cross"), label("C"), label("raised"),
                        label("alpha")}));
form_add(s5_right, (lineseg(t2, t3), {label("cross"), label("C"), label("R"),
                        label("raised")}));
form_add(s5_right, (lineseg(t3, t4), {label("cross"), label("C"), label("raised"),
                        label("beta"), label("front")}));
form_add(s5_right, (lineseg(t4, t1), {label("cross"), label("C"), label("R"),
                        label("raised")}));
```

Part III
Conclusion

Chapter 8:
Contributions and
Future Work

It has often been said that a person doesn't really understand
something until he teaches it to someone else. Actually a person
doesn't really understand something until he can teach it to a
computer, i.e. express it as an algorithm. … The attempt to
formalize things as algorithms leads to a much deeper
understanding than if we simply try to understand things in the
traditional way.

Donald Knuth (1973:709)

8.1   Contributions

This following are the contributions of this dissertation.

An approach to the study of historical architecture

Much of the work on historical architecture has been normative, and in the case of Chinese traditional architecture has focused on socio-cultural rituals. Little attempt, if any, has been made to extract the strict – i.e., mathematical and computational – principles that often govern historical architecture. I have done so for Chinese traditional architecture and in this process I have developed an approach – using spatial grammars – for the integration of form, technology, and socio-cultural considerations.

The approach not only deals with form relationships: that is, shape grammars, but also with the relationships between design parameters: that is, fortunate dimensions, orientation, construction date, roof design, purlin design etc. Furthermore, this approach provides the means by which one can explain, interpret, and relate the different types of historical Chinese architecture. The temple grammar is a good example of this. Apart from issues of decoration and other details, the temple grammar clearly illustrates that Chinese traditional buildings derive from the same architectural principles in an explicit computational manner.

The development of a shape grammar is not an original contribution (see Section 1.2.2 for an extensive list of the published grammars). The approach that I have taken might be considered as a novel twist to the popular approach. The typical starting point for most published grammars is an architectural morphology or an analysis of a corpora of existing designs. As such, these grammars tend to emphasize purely form relationships. Although acknowledged, these grammars rarely contain explicit conditions between form and design parameters. On the other hand, historical Chinese architecture was not designed on paper. As such plans were not documented. Moreover, any documentation tended to dwell on the mystical nature of the design and construction process.

The paradigmatic approach that I have developed has three steps.

• The first is to demystify aspects of the design process into principles that lend themselves to computation. In the case of historical Chinese architecture this enabled me to explicitly derive conditions from *fēng-shuǐ* into computational procedures.

• The second is to translate the design process into form rules which incorporate the design parameters and to interrelate these form rules into a system (grammar).

• The third is to generate a corpora of existing designs thereby showing that grammars do indeed offer explanations of historical architecture.

I believe this to be an original way of using grammars for design studies. It can be applied to the grammatical study of any historical or vernacular architecture, and is particularly applicable to designs which have not been documented in any formal way, e.g., African architecture (Deyner, 1978), and to buildings that have long since perished, e.g., Turkish houses (Orhun, et al., 1995). The approach begins with an analysis of an architectural style and ends in generative description. It is my belief that such an approach may promote increased respect for grammars which have yet to find widespread acceptance.

A step towards a computer implementation of shape grammars: the shape description language

The implementation of shape grammar is still a difficult topic. To date, there is still no viable grammar system. The development of a comprehensive parametric grammar system is, of course, an even more difficult proposition. There are a number of issues that have to be resolved (see Section 7.1). In this dissertation, I address one of these issues by focusing on a [programming] language for shape description which will allows user to describe shape rules augmented with non-geometric and other computable information.

The shape description language is important for the following reasons. Firstly, it provides for a natural description for shapes. Secondly, its design is independent of the internal representation for shapes. Thirdly, it is extensible to parametric shapes and weighted shapes.

The shape description language is based on two concepts, *sort* and *form*. Through sorts, characteristic individuals can be specified. Sorts are collections of different individuals each of which share certaincommon features that characteristic of all individuals of the sort. Sorts can be combined algebraically to form other sorts. Forms are collections of one or more individuals from the same sort. Both geometric and non-geometric

information can be forms. In principle, sorts and forms are dynamic constructs.

From the potential for shape grammar implementation, the shape description language provides for the specification of shape rules, interactively, textually and graphically. In the textual mode, the language acts an interpreter. In the graphical mode, the current implementation provides an interface for the user to draw forms (i.e., labeled and weighted shapes). The current implementation does not impose mode restrictions; shapes can be defined textually and graphically with equal facility.

In summary, the shape description language provides a mechanism for representing weighted and augmented shapes; it can be used for purely non-geometric information; its interactive environment offers a potential framework for shape grammar implementation.

Other, implicit, constributions of this dissertation are:

Historic preservation of Chinese buildings

The grammar of Chinese traditional architecture can help with the renovation and restoration of historic Chinese buildings. My own prior experience leads me to believe that grammars provide methods for recovering missing information, and for suggesting alternative design solutions. Moreover, a grammar, in theory, can be used for decomposing or parsing an existing building to explore how it correlates with known architectural principles.

Contemporary Chinese designs

Computer-assisted studies can provide for the design of new buildings based on Chinese culture and style of architecture. The post-modern movement in architecture promotes new buildings to be considered and designed with reference to local context. This has always been a critical issue for architects. The grammars of Chinese traditional architecture might provide a means of resolving some of the problems in contemporary versions of the traditional styles.

Teaching of Chinese architecture and architectural history

I will be returning to Taiwan shortly where I will teach a design studio, and courses in architectural history and computer-aided design. For me , it is important to emphasize the use of computers in teaching traditional fields. Although such use in teaching the principles and various aspects of Chinese architecture is not entirely new, my work in this dissertation will add significantly to the depth and richness of such explorations. Since this dissertation provides a paradigm for integrating computing into architectural historical studies, the same approach may add to the treatment of other styles of architecture, including Western architecture.

8.2   Future Work

These are some possible topics for future work.

The Grammar of Regulation style of Chinese traditional architecture

The northern style of Chinese architecture followed rigid construction rules under the dictates of *zhì-shì*, literally, the regulation style. Two famous books or regulations on Chinese traditional architecture are the *Yíng-zào Fǎ-shì* [*Building Standards*, A.D. 1103] of *Sòng* dynasty and the *Gōng-bù Gōng-chéng Zuò-fǎ Zé-lì* [*Structural Regulations*, A.D. 1734] of *Qīng* dynasty. These have been studied from many different aspects (Chen, 1981; Guo, 1995; Li and Tsou, 1994, 1995a,b; Ma, 1993). However, none of these studies translates the regulations into compositional rules and computer programs. I believe that this is extremely useful, particularly for Northern style palaces. Moreover, this might be the only way for researchers to visually understand how traditional components were assembled into a building.

Integration of multimedia, architectural history, and generation system

Architectural historians may find that they can discover much more if they they try to explain architectural history to computer. It is a belief of mine that if computers becomes the intended targets for the teaching of architectural history, in turn, the computer can then be used to *teach* people. To me the integration of computing and architectural history is about developing computer environments that can facilitate, assist, and in general, help

architectural historians and others in the explanation and interpretation of architectural historic facts. This is one of my longer term ambitions.

Extension to the shape description language

As previously mentioned, the current version of the shape description language is only a step towards a shape grammar interpreter. The next step is to explore matching and recognition problems and develop capabilities for some aspects of thes e problems to be incoporated into the shape description language.

In summary, this dissertation has undertaken a study of an architectural style, extracted from it mathematical and computational principles, formalized into a system of compositional rules, that can be described in a description language – which, ultimately, will provide the means for visual and interactive explorations on a computer.

Bibliography†

† For the Chinese resources, the mark (†) indicate the Chinese author name is transliterated corresponding to the Pinyin system. Furthormore, if the English title is not available in the resource, both Chinese character transliteration and English translation (without italicized) are provided.

Agesen, Ole; Lars Bak; Craig Chambers; Bay-Wei Chang; Urs Hölzle; John Maloney; Randall B. Smith; David Ungar; and Mario Wolczko. 1995. *The SELF 4.0 Programmer's Reference Manual*. Mountain View, California: Sun Microsystems Computer Company.
source: ftp://self.sunlabs.com/release/Self-4.0/manuals/progRef.ps.Z

Aho, Alfred V.; Ravi Sethi; and Jeffrey D. Ullman. 1988. *Compilers: Principles, Techniques, and Tools*. Reading, Massachusetts: Addison-Wesley.

Alkhoven, Patricia. 1992. "The Reconstruction of the Past: the Application of New Techniques for Visualization and Research in Architectural History." *CAAD Futures '91: Computer Aided Architectural Design Futures Education, Research, Application* (edited by Gerhard N. Schmitt). Braunschweig: Vieweg. pp. 549-566. [Proceedings of the *CAAD Futures '91* conference, Zürich, Switzerland, July 1991.]

Ames, Andrea L.; David R. Nadeau; and John L. Moreland. 1996. *The VRML Sourcebook*. New York: John Wiley & Sons, Inc.

Bennett, Charles H.; and Rolf Landauer. 1985. "The Fundamental Physical Limits of Computation." *Scientific American* (Vol. 253, No. 1; July, 1985): 48-56.

Bell, Gavin; Anthony Parisi; and Mark Pesce. 1996. *The Virtual Reality Modeling Language: Version 1.0C Specification*. source: http://vag.vrml.org/vrml10c.html

Bodde, Derk. 1991. *Chinese Thought, Society, and Science: The Intellectual and Social Background of Science and Technology in Pre-modern China.* Honolulu, Hawaii: University of Hawaii Press.

Bredon, Juliet; and Igor Mitrophanow. 1966. *The Moon Year: A Record of Chinese Customs and Festivals*. New York: Paragon.

Boyd, Andrew Charles Hugh. 1962. *Chinese Architecture and Town Planning, 1500 B.C. - A.D. 1911*. Chicago: The University of Chicago Press.

Bussagli, Mario. 1989. *Oriental Architecture/2 : China, Korea, Japan*. Translated by John Shepley. New York: Rizzoli.

Byun, Sang Jae. 1989. *Reinterpretation of Traditional Korean Architectural Spatial Patterns by Shape Grammar*. Master Project. Los Angeles: University of California, Los Angeles.

Carlson, Christopher. 1989. *The Explorer's Guide to discoverForm™*. Version 1.3. Pittsburgh: Center for Arts & Technology, Carnegie Mellon University.

Carr, Edward Hallett. 1961. *What Is History?* New York: Vintage Books.

Chase, Scott Curland. 1987. *Computer Implementations of Shape Grammars*.
        Master Thesis. Los Angeles, California: University of California, Los
        Angeles.

Chase, Scott Curland. 1996. *Modeling Designs with Shape Algebras and
        Formal Logic*. Ph.D. Dissertation. Los Angles, California: University
        of California, Los Angeles.

Chen, Ming-da[†] (陳明達). 1981. 營造法式大木作制度研究 *Yíng-zào Fǎ-shì
        Dà-mù-zuò Zhì-dù Yán-jiù* (A Study on the Structural Carpentry
        System According to the *Yíng-zào Fǎ-shì*). Two Volumes. Beijing,
        China: *Wén-wù* (文物). (in Chinese)

Chiou, Bor-Shuenn. 1991. *"Heaven Round, Earth Square": Architectural
        Cosmology in Late Imperial China*. Ph.D. Dissertation. Scotland:
        University of Edinburgh.

Chiou, Shang-chia (邱上嘉). 1990. 臺灣一般傳統木構造民宅營建技術
        的多樣性研究 —以嘉南平原地區匠師訪談爲例 *Research on the
        Diversity of the Construction Techniques of general Taiwanese Traditional
        Wooden Civilian Habitations: Through Examples of Interviews with Local
        Artisans in the Chia-nan Plain Region*. Master thesis. Taichung,
        Taiwan: Graduate School of Architecture, Tunghai University. (in
        Chinese with English abstraction)

Chiou, Shang-chia, and Ramesh Krishnamurti. 1994. *The Grammar of
        Taiwanese Traditional Vernacular Houses*. Technical Report. Pittsburgh:
        Department of Architecture, Carnegie Mellon University.

Chiou, Shang-chia, and Ramesh Krishnamurti. 1995a. "The Fortunate
        Dimensions of Taiwanese Traditional Architecture." *Environment and
        Planning B: Planning and Design* (Vol. 22, No. 5): 547-562.

Chiou, Shang-chia, and Ramesh Krishnamurti. 1995b. "The Grammar of
        Taiwanese Traditional Vernacular Dwellings." *Environment and
        Planning B: Planning and Design* (Vol. 22, No. 6): 689-720.

Chiou, Shang-chia, and Ramesh Krishnamurti. 1995c. "The Grammatical
        Basis of Chinese Traditional Architecture." *Languages of Design 3*
        (1995): 5-31.

Chiou, Shang-chia, and Ramesh Krishnamurti. 1996a. "Example Taiwanese Traditional Houses." *Environment and Planning B: Planning and Design* (Vol. 23, No. 2): 191-216.

Chiou, Shang-chia, and Ramesh Krishnamurti. 1996b. "Unraveling Fēng-Shuǐ." accepted by *Environment and Planning B: Planning and Design.*

Chiu, Mao-Lin. 1995. "The Wood Structures of Chinese Traditional Architecture and Computer Simulation." *Proceeding of International Conference on Chinese Architectural History: Computing in Architectural Research*. Hong Kong: The Chinese University of Hong Kong. pp. 1-13.

Choi, Jin Won. 1994. "ArchiWAIS: A Multimedia-Based Architectural Information System for Teaching and Learning History and Theory." *ACADIA '94 Proceedings: Reconnecting* (edited by Anton Harfmann and Mike Fraser). Association for Computer Aided-Design in Architecture. pp. 161-169.

Choi, Jin Won. 1995. *The Design and Implementation of a Multimedia Information and Authoring System for Teaching and Learning Architectural History and Theory*. Ph.D. Dissertation. Columbus, Ohio: Ohio State University.

Chomsky, Noam. 1957. *Syntactic Structures*. The Hague, Netherlands: Mouton.

Conway, Hazel. 1987. "Design History Basics." *Design History: A Students' Handbook* (edited by Hazel Conway). London: Allen & Unwin. pp. 3-14.

Conway, Hazel, and Rowan Roenisch. 1994. *Understanding Architecture: An Introduction to Architecture and Architectural History*. London & New York: Routledge.

Cormen, Thomas H.; Charles E. Leiserson; and Ronald L. Rivest. 1992. *Introduction to Algorithms*. Cambridge, Massachusetts: MIT Press.

De Cola, Sergio; Bruno De Cola; and Francesco Pentasuglia. 1990. "Messina 1908: The Invisible City." *The Electric Design Studio: Architectural Knowledge and Media in the Computer Era* (edited by Malcolm McCullough, William J. Mitchell, and Patrick Purcell). Cambridge, Massachusetts: MIT Press. pp. 239-246.

Denyer, Susan. 1978. *African Traditional Architecture: An Historical and Geographical Perspective*. New York: Africana Publishing Co.

Dillingham, Reed (狄瑞德); and Chang-lin Dillingham (華昌琳). 1985. 台灣傳統建築之勘察 *A Survey of Traditional Architecture of Taiwan*. Second Edition. Taipei, Taiwan: *Jìng-yǔ-xiàng* (境與象). (in both Chinese and English)

Downing, F.; and Ulrich Flemming. 1981. "The Bungalows of Buffalo." *Environment and Planning B: Planning and Design* (8): 269-293.

Dye, Daniel Sheets. 1974. *Chinese Lattice Designs*. New York: Dover. (Reprinted from *A Grammar of Chinese Lattice* published in 1937 by Harvard University Press.)

Eberhard, Wolfram; and Rolf Mueller. 1936. "Contributions to the Astronomy of the Han Period III: Astronomy of the Later Han Period." *Harvard Journal of Asiatic Studies*: 194-214.

Fawcett, William. 1987. "A Note on the Logic of Design." *Design Studies* (Vol. 8, No. 2; Apr. 1987): 82-87.

Fei, Hsiao-tung (費孝通). 1943. 鄉土中國 *Xiāng-tǔ Zhōng-guó* (The Rural China). Taipei, Taiwan: *Wén-xiá* (文俠). (in Chinese)

Feuchtwang, Stephan D.R. 1974. *An Anthropological Analysis of Chinese Geomancy*. Laos: Vithagna.

Fleisher, A. 1992. "Grammatical Architecture?" *Environment and Planning B: Planning and Design* (19): 221-226.

Flemming, Ulrich. 1981. "The Secret of Casa Guiliani Frigerio." *Environment and Planning B: Planning and Design* (8): 87-96.

Flemming, Ulrich. 1987a. *A Pattern Book for Shadyside*. Technical Report. Pittsburgh, Peennsylvania: Department of Architecture, Carnegie Mellon University.

Flemming, Ulrich. 1987b. "More Than the Sum of Parts: The Grammar of Queen Anne Houses." *Environment and Planning B: Planning and Design* (14): 323-350.

Flemming, Ulrich. 1987c. "The Role of Shape Grammars in the Analysis and Creation of Designs." in *Computability of Design* (edited by Yehuda E. Kalay). New York: John Wiley and Sons. pp. 245-272.

Fletcher, Banister. 1950. *A History of Architecture on the Comparative Method for Students, Craftsmen & Amateurs*. Fifteenth Edition. New York: Charles Scribner's Sons.

Fletcher, Banister. 1987. *Sir Banister Fletcher's A History of Architecture*. Nineteenth Edition. Edited by John Musgrove; John Tarn; and Peter Willis (consulting editors). London & Boston: Butterworths.

Fo, Yin[†] (佛隱). 1986. 風水講義 *Fēng-shuǐ Jiǎng-yì* (Notebook of Chinese Geomancy). Taipei, Taiwan: *Wǔ-líng* (武陵). (in Chinese)

Freedman, Maurice. 1979. *The Study of Chinese Society: Essays by Maurice Freedman*. Edited by George William Skinner. Stanford, California: Stanford University Press.

Gamel, Leslie D. 1991. *The Formalization of an Architectural Language: A Re-evaluation of the Palladian Grammar*. Master Thesis. Arizona State University.

Gilleard, John; John Myers; and Olugbemiga A. Olatidoye. 1990. "Computer Applications in Architectural Conservation." *ACADIA '90 Proceedings: From Research to Practice* (edited by J. Peter Jordan). Association for Computer Aided-Design in Architecture. pp. 187-199.

Gips, James Elliot. 1975. *Shape Grammars and Their Uses: Artificial Perception, Shape Generation, and Computer Aesthetics*. Birkhaüser, Basel: Birkhaüser.

Gu, Wu-lu[†] (顧吾廬). 1989. 八宅明鏡 *Bā-zhái Míng-jìng* (Book of Eight Buildings). Eleventh Edition. Hsinchu, Taiwan: *Zhú-lín* (竹林). (in Chinese)

Guo, Qinghua. 1995. *The Structure of Chinese Timber Architecture: Twelfth Century Design Standards and Construction Principles*. Ph.D. Dissertation. Gothenburg, Sweden: Department of Building Design, Chalmers University of Technology.

Hamber, Anthony; Jean Miles; and William Vaughan (eds.). 1989. *Computers and the History of Art*. London: Mansell.

Han, Pao-teh (漢寶德). 1983. "風水－中國人的環境觀念架構 A Study of Feng-Shui as a Chinese Concept of the Environment." *Bulletin of*

Architecture and City Planning National Taiwan University (Vol. 2, No. 1; Jun., 1983): 123-150. (in Chinese with English abstract)

Han, Pao-teh (漢寶德). 1987. "風水宅法中禁忌的研究 A Study of Taboos in Feng-Shuei Practice of Home Building." *Bulletin of Architecture and City Planning National Taiwan University* (Vol. 3, No. 1; Sep., 1987): 5-55. (in Chinese with English abstract)

Harper, Robert. 1993. *Introduction to Standard ML*. Technical Report. Pittsburgh, Pennsylvania: School of Computer Science, Carnegie Mellon University.
source: http://afs/cs.cmu.edu/project/fox/mosaic/intro-notes.ps

Heisserman, Jeff A. 1991. *Genesis Reference Manual*. Technical Report. Pittsburgh, Pennsylvania: Engineering Design Research Center, Carnegie Mellon University. [EDRC 48-23-91]

Heng, Chye Kiang. 1995. "Visualising the Tang Western Capital Chang'an." *Proceeding of International Conference on Chinese Architectural History: Computing in Architectural Research*. Hong Kong: The Chinese University of Hong Kong. pp. 41-55.

Hersey, George, and Richard Freedman. 1992. *Possible Palladian Villas (Plus a Few Instructively Impossible Ones)*. Cambridge, Massachusetts: MIT Press.

Hoang, Peter. 1904. *A Notice of the Chinese Calendar and a Concordance with the European Calendar*. Second Edition. Zi-Ka-Wei: The Catholic Mission Press.

Hopcroft, John E.; and Jeffrey D. Ullman. 1979. *Introduction to Automata Theory, Languages, and Computation*. Reading, Massachusetts: Addison-Wesley.

Hung, Jr-ywan (洪志遠). 1995. *形狀文法的意義描述系統初探 -以台灣傳統書院建築爲例 A Primary Research on the Meanings Description System of Shape Grammar: A Study of Traditional "Shu-Yuan" Architecture in Taiwan*. Master Thesis. Taichung, Taiwan: Graduate School of Architecture, Tunghai University. (in Chinese with English abstract)

Jiang, Jin-cai[†] (江錦財). 1992. *金門傳統民宅營建計劃之研究 Jīn-mén Chuán-tǒng Mín-zhái Yíng-jiàn Jì-huà zhī Yán-jiù* (A Preliminary Study

on the Processes of Constructing Traditional Houses at *Jīn-mén*).
Master Thesis. Tainan, Taiwan: National Cheng-kung University. (in
Chinese with English abstract)

Kahn, Louis I. 1965. "Remarks." *Perspeca: The Yale Architectural Journal* (9/
10): 303-335.

Kernighan, Brian W.; and Dennis M. Ritchie. 1988. *The C Programming
Language*. Second Edition. Englewood Cliffs, New Jersey: Prentice
Hall.

Kirsch, J. L.; and R. A. Kirsch. 1986. "The Structure of Paintings: Formal
Grammars and Design." *Environment and Planning B: Planning and
Design* (13): 163-176.

Kirsch, J. L.; and R. A. Kirsch. 1990. "Storing Art Images in Intelligent
Computers." *Leonardo* (23): 99-106.

Knapp, Ronald Gary. 1986. *China's Traditional Rural Architecture: A Cultural
Geography of the Common House*. Honolulu, Hawaii: University of
Hawaii Press.

Knapp, Ronald Gary. 1989. *China's Vernacular Architecture: House Form and
Culture.* Honolulu, Hawaii: University of Hawaii Press.

Knapp, Ronald Gary. 1990. *The Chinese House: Craft, Symbol, and the Folk
Tradition.* Hong Kong: Oxford University Press.

Knapp, Ronald Gary. (ed.) 1992. *Chinese Landscapes: The Village as Place*.
Honolulu, Hawaii: University of Hawaii Press.

Knight, Terry Weissman. 1980. "The Generation of Hepplewhite-style
Chair Back Designs." *Environment and Planning B: Planning and
Design* (7): 227-238.

Knight, Terry Weissman. 1981. "The Forty-one Steps: The Language of
Japanese Tea-room Designs." *Environment and Planning B: Planning
and Design* (8): 87-114.

Knight, Terry Weissman. 1986. *Transformations of Languages of Designs.*
Ph.D. Dissertation. Los Angeles, California: Department of
Architecture, University of California, Los Angeles.

Knight, Terry Weissman. 1986b. "Transformations of the Meander Motif on
Greek Geometric Pottery." *Design Computing* (1): 29-67.

Knight, Terry Weissman. 1989. "Color Grammars: Designing with Lines and Colors." *Environment and Planning B: Planning and Design* (16): 417-449.

Knight, Terry Weissman. 1990. "Mughal Gardens Revisited." *Environment and Planning B: Planning and Design* (17): 73-84.

Knuth, Donald E. 1973. "Computer Science and Mathematics." *American Scientist* (Vol. 61, No. 6): 707-713.

Koning, Hank; and Julie Eizenberg. 1981. "The Language of the Prairie: Frank Lloyd Wright's Prairie Houses." *Environment and Planning B: Planning and Design* (8): 295-323.

Kostof, Spiro. 1995. *A History of Architecture: Setting and Rituals*. Second Edition. New York & Oxford: Oxford University Press.

Krishnamurti, Ramesh. 1981. "The Construction of Shapes." *Environment and Planning B: Planning and Design* (8): 5-40.

Krishnamurti, Ramesh. 1982. "SGI: an interpreter for shape grammars." Research Report. Milton Keynes, England: Centre for Configurational Studies, The Open University.

Krishnamurti, Ramesh. 1992a. "The Maximal Representation of a Shape." *Environment and Planning B: Planning and Design* (19): 267-288.

Krishnamurti, Ramesh. 1992b. "The Arithmetic of Maximal Planes." *Environment and Planning B: Planning and Design* (19): 431-464.

Krishnamurti, Ramesh; and C. F. Earl. 1992. "Subshape Recognition in Three Dimensions." *Environment and Planning B: Planning and Design* (19): 595-603.

Krishnamurti, Ramesh; and Rudi Stouffs. 1993. "Spatial Grammars: Motivation, Comparison and New Results." in *CAAD Futures '93: Proceedings of the Fifth International Conference on Computer-Aided Architecture Design Futures* (edited by Ulrich Flemming and Skip Van Wyk). Amsterdam, The Netherlands: North-Holland. pp. 57-74. [Proceedings of the *CAAD Futures '93* conference, Pittsburgh, Pennsylvania, U.S.A., July 7-10 1993.]

Krishnamurti Ramesh; and Rudi Stouffs. 1996. "Spatial Change: Continuity, Reversibility, and Emergent Shapes." To appear in *Environment and Planning B: Planning and Design*]

Kumar, Ram; and Rakesh Agrawal. 1992. *Programming in ANSI C*. St. Paul, Minnesota: West Publishing Co.

Kwan, Hua-shan (關華山). 1989. "談臺灣傳統民宅所表現的空間觀念 Spatial Concepts Shown in the Traditional Houses of Taiwan"). in 民居、社會與文化 *Mín-jū, Shè-huì yǔ Wén-huà* (Habitations, Society, and Culture). Taipei, Taiwan: *Míng-wén* (明文). pp 27-64. (in Chinese with English abstract)

Le Corbusier, Charles-Édouard. 1986. *Towards a New Architecture*. New York: Dover.

Lee, Chien-lang. 1983. "A Study of Taiwan Temple by Wang I-Shun." *Bulletin of Architecture and City Planning National Taiwan University* (Vol. 2, No. 1; Jun., 1983): 87-122.

Lee, Chien-lang (李乾朗). 1980. *臺灣建築史 A History of Taiwan Architecture (1600-1945)*. Taipei, Taiwan: *Běi-wū* (北屋) Co. (in Chinese)

Lee, Chien-lang (李乾朗). 1983. *廟宇建築 Miào-yǔ Jiàn-zhú* (Temple Architecture). Taipei, Taiwan: *Běi-wū* (北屋) Co. (in Chinese)

Lee, Chien-lang (李乾朗). 1986. *臺灣的寺廟 Tái-wān de Sì-miào* (Taiwan's Temples). Taichung, Taiwan: Department of Information, Taiwan Provincial Government. (in Chinese)

Lee, Sang Hae. 1986. *Feng-Shui: Its Context and Meaning*. Ph.D. Dissertation. New York: Cornell University.

Levine, John R.; Tony Mason; and Doug Brown. 1992. *lex & yacc*. Sebastopol, California: O'Reilly & Associates, Inc.

Lewis, Harry R.; and Christos H. Papadimitriou. 1981. *Elements of the Theory of Computation*. Englewood Cliffs, New Jersey: Prentice Hall.

Li, Andrew I-kang, and Jin-Yeu Tsou. 1994. "A Computer-Based Teaching Tool for Traditional Chinese Wood Construction." Preconference Proceedings. *Focus Symposium on Advances in Computer-Based Building Design System*. 7th International Conference on System

Research, Informatics and Cybernetics, Baden-Baden, Germany, August 15-21, 1994, pp. 149-159.

Li, Andrew I-kang and Jin-Yeu Tsou. 1995a. "Virtual Modelling and Traditional Chinese Wood Construction." sources: <http://www.arch.cuhk.hk/yzfs/> and <http://www.arch.cuhk.hk/yzfs/paper.htm>

Li, Andrew I-kang and Jin-Yeu Tsou. 1995b. "The Rule-Based Nature of Wood Frame Construction of the *Yingzao fashi* and the Role of Virtual Modelling in Understanding It." *Proceeding of International Conference on Chinese Architectural History: Computing in Architectural Research*. Hong Kong: The Chinese University of Hong Kong. pp. 25-40.

Liang, Ssu-ch'eng. 1984. *A Pictorial History of Chinese Architecture: A Study of the Development of Its Structural System and the Evolution of Its Types*. Edited by Wilma Fairbank. Cambridge, Massachusetts: MIT Press.

Lin, Hui-cheng[†] (林會承). 1990. 〔臺灣〕傳統建築手冊 *[Tái-wān] Chuán-tŏng Jiàn-zhú Shŏu-cè* (Handbook of Taiwanese Traditional Architecture). Taipei, Taiwan: Artist (藝術家). (in Chinese)

Lindsey, Bruce and Paul Rosenblatt. 1993. "Cutting Up Time: Craft and Technology in the Niches Project." *CAAD Futures '93: Proceedings of the Fifth International Conference on Computer-Aided Architecture Design Futures* (edited by Ulrich Flemming and Skip Van Wyk). Amsterdam, The Netherlands: North-Holland. pp. 523-541. [Proceedings of the *CAAD Futures '93* conference, Pittsburgh, Pennsylvania, U.S.A., July 7-10 1993.]

Liou, Shuenn-Ren; Emmanuel-George Vakalo; and Yung-Chia Lee. 1990. "The Si He Yuan of Beijing." *Proceedings of the IAPS 11th International Conference* (Vol. 2). pp. 362-371.

Lip, Evelyn. 1979. Feng Shui: A Layman's Guide to Chinese Geomancy. Singapore: Times Editions Pte Ltd.

Lip, Evelyn. 1995. *Feng Shui– Environments of Power: A Study of Chinese Architecture*. Great Britain: Academy Editions.

Liu, Feng. 1993. *4D Grammar of Chinese Gardens*. Master Project. Los Angeles, California: University of California, Los Angeles.

Liu, Dun-zhen† (劉敦楨). 1990. *中國古代建築史 Zhōng-guó Gǔ-dài Jiàn-zhú-shǐ* (Chinese Ancient Architecture History). Taipei, Taiwan: *Míng-wén* (明文). (in Chinese)

Liu, Laurence G. 1989. *Chinese Architecture*. New York: Rizzoli.

Liu, Zhi-ping† (劉致平). 1984. *中國建築類型及結構 Zhōng-guó Jiàn-zhú Lèi-xíng jí Jié-gòu* (The Prototypes and Structures of Chinese Architecture). Taipei, Taiwan: *Shàng-lín* (尚林). (in Chinese)

Lu, Ban† (魯班公). 1985. *魯班寸白簿 Lǔ-bān Cùn-bái-bù* (Carpenter's Handbook). Tenth Edition. Hsinchu, Taiwan: *Zhú-lín* (竹林). (in Chinese)

Luo, Qi-ming† (駱啓明). 1985. *眞傳地理祕訣 [Zhēn-chuán] Dì-lǐ Mì-jué* (Secrets of Geomancy). Third Edition. Hsinchu, Taiwan: *Zhú-lín* (竹林). (in Chinese)

Ma, Bin-jian† (馬炳堅). 1993. *中國古建築木作營造技術 Zhōng-guó Gǔ-jiàn-zhú Mù-zuò Yíng-zào Jì-shù* (Carpentry Technology in Chinese Traditional Architecture). Taipei, Taiwan: *Bó-yuǎn* (博遠). (in Chinese)

Mahoney, Diana Phillips. 1994. "A New Look at Ancient Treasures: Using PC-based Drafting and Modeling Software, a Scottish Designer Re-creates Greek History." *Computer Graphics World* (Vol. 17, No. 9): 61-62.

Millet, Marietta S.; Grant Hildebrand, Peter Cohan; and Michael Read. 1991. "ArchiMedia Case Studies: Integrative Architectural Education." *ACADIA '91 Proceedings: Reality and Virtual Reality* (edited by Glenn Goldman and Michael Stephen Zdepski). Association for Computer Aided-Design in Architecture. pp. 127-134.

Mitchell, William John. 1989. *The Logic of Architecture: Design, Computation, and Cognition.* Cambridge, Massachusetts: MIT Press.

Mitchell, William John; Robin S. Liggett. 1990. "Top-Down Knowledge-Based Design." in *The Electronic Design Studio: Architectural Knowledge and Media in the Computer Era* (edited by Malcolm McCullough, William John Mitchell, and Patrick Purcell). Cambridge, Massachusetts: MIT Press. pp. 137-148.

Nagakura, Takehiko. 1990. "Shape Recognition and Transformation: A Script-Based Approach." in *The Electronic Design Studio: Architectural Knowledge and Media in the Computer Era* (edited by Malcolm McCullough, William John Mitchell, and Patrick Purcell). Cambridge, Massachusetts: MIT Press. pp. 149-170.

Needham, Joseph. 1956. *Science and Civilisation in China: Vol. 2 History of Scientific Thought*. Cambridge, England: Cambridge University Press.

Needham, Joseph. 1959. *Science and Civilisation in China: Vol. 3 Mathematics and the Sciences of the Heavens and the Earth.* Cambridge, England: Cambridge University Press.

Needham, Joseph. *1971. Science and Civilisation in China: Vol. 4 Physics and Physical Technology: Part 3 Civil Engineering and Nautics.* Cambridge, England: Cambridge University Press.

Ni, Han-zhong (倪漢忠). 1995. 鹿港傳統街屋的形態構成 *The Grammar of the Traditional Street-Houses in Lukang*. Master Thesis. Taichung, Taiwan: Graduate School of Architecture, Tunghai University. (in Chinese with English abstract)

Orhun, D.; B. Hillier; and J. Hanson. 1995. "Spatial Types in Traditional Turkish Houses." *Environment and Planning B: Planning and Design* (22): 475-498.

Paakki, Jukka. 1995. "Attribute Grammar Paradigms– A High-Level Methodology in Language Implementation." *ACM Computing Surveys* (Vol. 27, No. 2; June, 1995): 196- 255.

Pevsner, Nikolaus. 1985. *An Outline of European Architecture*. New York: Penguin Books.

Porphyrios, Demetri (ed.). 1981. *On the Methodology of Architectural History.* London: Architectural Design.

Rapoport, Amos. 1969. *House Form and Culture*. Englewood Cliffs, New Jersey: Prentice-Hall.

Rollo, J. 1995. "Triangle and T-square: The Windows of Frank Lloyd Wright." *Environment and Planning B: Planning and Design* (22): 75-92.

Ropp, Paul S. (ed.) 1990. *Heritage of China: Contemporary Perspectives on Chinese Civilization.* Berkeley, California: University of California Press.

Roth, Leland M. 1993. *Understanding Architecture: Its Elements, History, and Meaning.* New York: IconEditions.

Ruitenbeek, Klass. 1996. *Carpentry & Building in Late Imperial China: A Study of the Fifteenth-Century Carpenter's Manual Lu Ban Jing.* Second Revised Edition. Leiden, The Netherlands: E. J. Brill.

Sangren, Paul Steven. 1987. *History and Magical Power in a Chinese Community.* Stanford, California: Stanford University Press.

Schirokauer, Conrad. 1991. *A Brief History of Chinese Civilization.* San Diego, California: Harcourt Brace Gap College.

Schmitt, Gerhard. 1988. *Microcomputer Aided Design: For Architects and Designers.* New York: John Wiley & Sons.

Scruton, Roger. 1979. *The Aesthetics of Architecture.* Princeton, New Jersey: Princeton University Press.

Seebohm, Thomas. 1990a. "Deconstructing the Constructivist Drawing of Iakov Chernikhov." *ACADIA '90 Proceedings: From Research to Practice* (edited by J. Peter Jordan). Association for Computer Aided-Design in Architecture. pp. 61-77.

Seebohm, Thomas. 1990b. "CAD and the Baroque." *ACADIA '90 Proceedings: From Research to Practice* (edited by J. Peter Jordan). Association for Computer Aided-Design in Architecture. pp. 79-97.

Seebohm, Thomas. 1991. "A Possible Palladian Villa." *ACADIA '91 Proceedings: Reality and Virtual Reality* (edited by Glenn Goldman and Michael Stephen Zdepski). Association for Computer Aided-Design in Architecture. pp. 135-166.

Seebohm, Thomas. 1992. "Discoursing on Urban History Through Structured Typologies." *ACADIA '92 Proceedings: Computer Supported Design in Architecture — Mission•Method•Madness* (edited by Karen M. Kensek and Douglas Noble). Association for Computer Aided-Design in Architecture. pp. 157-175.

Sethi, Radi. 1990. *Programming Languages: Concepts and Constructs*.
        Reading, Massachusetts: Addison-Wesley.

Shi, Jun[†] (石峻, ed.). 1992. 中國哲學名著選讀 *Selected Readings from Famous
        Chinese Philosophers with Annotations and English Translation*. Taipei,
        Taiwan: *Shū-lín*. (in both Chinese and English)

Shyu, Yue-jiann (徐裕健). 1983. "台灣傳統建築架構設計原則之 探討 The
        Study of Chinese Traditional Construction Design Principles in
        Taiwan." *Bulletin of Architecture and City Planning National Taiwan
        University* (Vol. 2, No. 1; Jun., 1983): 71-85. (in Chinese with English
        abstract)

Skinner, Stephen. 1989. *The Living Earth Manual of Feng-Shui: Chinese
        Geomancy*. England: Arkana(Penguin).

Smith, Richard Joseph. 1992. *Chinese Almanacs.* Hong Kong: Oxford
        University Press.

Steinhardt, Nancy Shatzman. 1984. *Chinese Traditional Architecture*. New
        York: China Institute in America, China House Gallery.

Stenvert, Ronald. 1991. *Constructing the Past: Computer-assisted
        Architectural-historical Research*. Ph.D. Dissertation. Utrecht, The
        Netherlands: State University of Utrecht (Rijksuniversiteit te
        Utrecht).

Stiny, George. 1977. "Ice-ray: A Note on Chinese Lattice Designs."
        Environment and Planning B: Planning and Design (4): 89-98.

Stiny, George. 1980a. "Introduction to Shape and Shape Grammars."
        Environment and Planning B: Planning and Design (7): 343-351.

Stiny George. 1980b. "Kindergarten Grammars: Designing with Froebel's
        Building Gifts" *Environment and Planning B: Planning and Design* (7):
        409-462.

Stiny George. 1985. "Computing with Form and Meaning in
        Architecture." *Jurnal of Architectural Education* (Vol. 39, No. 1): 7-19.

Stiny George. 1990. "What Designers Do That Computers Should." in *The
        Electronic Design Studio: Architectural Knowledge and Media in the
        Computer Era* (edited by Malcolm McCullough, William John

Mitchell, and Patrick Purcell). Cambridge, Massachusetts: MIT Press. pp. 17-30.

Stiny George. 1993. "Emergence and Continuity in Shape Grammars." in *CAAD Futures '93: Proceedings of the Fifth International Conference on Computer-Aided Architecture Design Futures* (edited by Ulrich Flemming and Skip Van Wyk). Amsterdam, The Netherlands: North-Holland. pp 37-54. [Proceedings of the *CAAD Futures '93* conference, Pittsburgh, Pennsylvania, U.S.A., July 7-10 1993.]

Stiny George. 1994. "Shape Rules: Closure, Continuity, and Emergence." *Environment and Planning B: Planning and Design* (21): s49-s78.

Stiny George; and James Gips. 1972. "Shape Grammars and the Generative Specification of Painting and Sculpture." in *Information Processing 71* (edited by C V Freiman). Amsterdam, The Netherlands: North-Holland. pp 1460-1465.

Stiny George; and James Gips. 1978. *Algorithmic Aesthetics: Computer Models for Criticism and Design in the Arts.* Berkeley, California: University of California Press.

Stiny, George; and William John Mitchell. 1978a. "The Palladian Grammar." *Environment and Planning B: Planning and Design* (5): 5-18.

Stiny, George; and William John Mitchell. 1978b. "Counting Palladian Plans." *Environment and Planning B: Planning and Design* (5): 189-198.

Stiny George; and William John Mitchell. 1980. "The Grammar of Paradise: On the Generation of Mughal Gardens." *Environment and Planning B: Planning and Design* (7): 209-226.

Stouffs, Rudi. 1994. *The Algebra of Shapes.* Ph.D. dissertation. Pittsburgh, Pennsylvania: Department of Architecture, Carnegie Mellon University.

Stouffs, Rudi; and Ramesh Krishnamurti. 1996. "An Algebraic Approach to Comparing Representation." manuscript. Zurich, Switzerland: Architecture and CAAD, Swiss Federal Institute of Technology Zurich and Pittsburgh, Pennsylvania: Department of Architecture, Carnegie Mellon University.

Stouffs, Rudi; and Ramesh Krishnamurti. 1996a. "An Architecture for Adaptability for Knowledge Intensive Environment."

Stouffs, Rudi; and Ramesh Krishnamurti. 1996b. "The Extensibility and Applicability of Geometric Representations."

Stouffs, Rudi; and Ramesh Krishnamurti. 1996c. "On A Query Language For Weighted Geometries."

Sudkamp, Thomas A. 1991. *Languages and Machines: An Introduction to the Theory of Computer Science*. Reading, Massachusetts: Addison-Wesley.

Sullivan, Louis Henry. 1918. *Kindergarten Chats and Other Writings*. New York: Dover.

Sun, Frank Chi-Hsien. 1995. "The Courtyard House in Beijing: A Multimedia Approach." *Proceeding of International Conference on Chinese Architectural History: Computing in Architectural Research*. Hong Kong: The Chinese University of Hong Kong. pp. 56-64.

Tan, Milton. 1990. "Saying What It *Is* by What It Is *Like*– Describing Shapes Using Line Relationships." in *The Electronic Design Studio: Architectural Knowledge and Media in the Computer Era* (edited by Malcolm McCullough, William John Mitchell, and Patrick Purcell). Cambridge, Massachusetts: MIT Press. pp. 201-214.

Tapia, Mark Andrew. 1996. *From Shape To Style – Shape Grammars: Issues in Representation and Computation, Presentation and Selection*. Ph.D. Dissertation. Toronto, Canada: Graduate Department of Computer Science, University of Toronto.

Thompson, Laurence G. 1989. *Chinese Religion: An Introduction*. Fourth Edition. Belmont, California: Wadsworth Publishing Company.

Tofte, Mads. 1989. *Four Lectures on Standard ML*. UK: Laboratory for Foundations of Computer Science, Department of Computer Science, Edinburgh University.
source: /afs/cs.cmu.edu/project/fox/mosaic/doc/FourLectures.[1-3].ps

Ullman, Jeffrey D. 1994. *Elements of ML Programming*. Englewood Cliffs, New Jersey: Prentice Hall.

Ungar, David. 1995. *How to Program Self 4.0*. Mountain View, California: Sun Microsystems Computer Company.
source:

van Plet, Robert Jan, and Thomas Seebohm. 1990. "Of Computer Memory and Human Remembrance: History of Urban Form Through Three-Dimensional Computer Modeling." *ACADIA '90 Proceedings: From Research to Practice* (edited by J. Peter Jordan). Association for Computer Aided-Design in Architecture. pp. 45-59.

Wang, Ming-Hung. 1986. *Ways of Arrangement– The Basic Operations of Form-making*. Ph.D. Dissertation. Cambridge, Massachusetts: Massachusetts Institute of Technology.

Wang, Qiheng (王其亨, ed.). 1992. *風水理論研究 Research of Fengshui Theory*. Tianjin, China: Tianjin University Press. (in Chinese)

Weller, Robert Paul. 1980. *Unity and Diversity in Chinese Religious Ideology*. Ph.D. Dissertation. Baltimore, Maryland: Department of Anthropology, The Johns Hopkins University.

Wilhelm, Hellmut. 1977. *The I Ching or Book of Changes*. Princeton, New Jersey: Princeton University Press.

Will, Barry F.; John Bradford; Waycal C.H. Wong; and Matchy J.M. Ma. 1995. "Temple Tutor." Hong Kong: Department of Architecture, The University of Hong Kong.
source: <http://arch.hku.hk/research/TempleT/index.html>

Williams, C. A. S. 1976. *Outlines of Chinese Symbolism & Art Motives: An Alphabetical Compendium of Antique Legends and Beliefs, as Reflected in the Manners and Customs of the Chinese*. Third Revised Edition. New York: Dover.

Wong, Chi Kui, and Wah Nan Chung (trans.). 1986. *Classical Chinese Architecture*. Second Edition. Compiled by Chinese Academy of Architecture. Hongkong: Joint Publishing Co.; Beijing, China: China Building Industry Press.

Wright, Frank Lloyd. 1954. *The Natural House*. New York: Horizon Press.

Wu, Nelson Ikon. 1963. *Chinese and Indian Architecture: The City of Man, the Mountain of God, and the Realm of the Immortals*. New York: George Braziller.

Wu, Rong[†] (午榮). 1986. *繪圖魯班經 [Huì-tú] Lǔ-bān-jīng* (Carpenter's Bible). Ninth Edition. Hsinchu, Taiwan: *Zhú-lín* (竹林). (in Chinese)

Yang, Ren-jiang[†] (楊仁江). 1984. *臺灣傳統民居建築（二）：摘星山莊 Tái-wān Chuán-tǒng Mín-jū Jiàn-zhú 2: Zhāi-xī Shān-zhuāng* (Taiwanese Traditional Vernacular Dwellings 2: *Zhāi-xī Shān-zhuāng*). Taipei, Taiwan: Taipei Architects Association. (in Chinese)

Yang, Ren-jiang[†] (楊仁江). 1985. *臺灣傳統民居建築（三）：敦本堂 Tái-wān Chuán-tǒng Mín-jū Jiàn-zhú 3: Dūn-běn-táng* (Taiwanese Traditional Vernacular Dwellings 2: *Dūn-běn-táng*). Taipei, Taiwan: Taipei Architects Association. (in Chinese)

Zamanian, Mohammad S. Kiumarse. 1991. *Modeling and Communicating Spatial and Functional Information about Constructed Facilities.* Ph.D. Dissertation. Pittsburgh, Pennsylvania: Department of Civil Engineering, Carnegie Mellon University.

Zhang, Frank Zhihui. 1994. "Feng Shui and GIS." The original paper title "New Challenges in GIS: An International Perspective" presented in *The 1994 CPGIS Annual Conference*, Calgary, Canada, June 13-15, 1994. source: <http://www.geoplan.ufl.edu/~frankz/paper/fengshui.html>

Zheng, Ding-bang[†] (鄭定邦). 1978. *臺灣傳統民居建築 Tái-wān Chuán-tǒng Mín-jū Jiàn-zhú* (Taiwanese Traditional Vernacular Dwellings). Taipei, Taiwan: Taipei Architects Association. (in Chinese)

—. 1985. *玉匣記 Yù-xiá-jì* (*Handbook of Schedules*). Eleventh Edition. Hsinchu, Taiwan: *Zhú-lín* (竹林). (in Chinese)

—. 1988. *Collier's Encyclopedia.* Volume 5. New York: Macmillan Educational Company.

—. 1990. *Learner's Chinese-English Dictionary.* Eighth Edition. Singapore: Nanyang Siang Pau & Umum Publisher Pte. Ltd.

—. 1993. "Ancient Celestical Sign Started Chinese Calendar." *Sky & Telescope* (Vol. 18, No. 6; December, 1993): 13-14.

—. 1994. *The New Encyclopedia Britannica.* Volume 15. Chicago: Encyclopedia Britannica Inc.

—. 1995. *The Java Language Environment: A White Paper.* Mountain View, California: Sun Microsystems Computer Company. source:

—. 1995. *The Java™ Language Specification*. Mountain View, California: Sun Microsystems Computer Company.
source:

—. 1996. *VRML Frequently Asked Questions*. Version 2.0 (Feb. 28, 1996).
source: <http://www.oki.com/vrml/VRML_FAQ.html>

Glossary

fen 35, 36
feng 23
feng-shui 13, 16, 17, 21, 22, 23, 24, 26, 28, 31, 32, 44, 65, 68, 69, 72, 74, 80, 81, 84, 88, 106, 252
Feng-shui Jiang-yì 32
fù 80
Fú-dé 185
Fú-jiàn 3, 24, 68, 98, 99, 153, 158, 164, 171, 179, 181, 199
fú-luán 45, 188
fú-wèi 71
Fú-xi 27
fú-yuán 64, 69

G

gao-chi 45
Gao-shan-zú 99
gèn 27, 28, 29, 72, 75, 83, 84, 85, 86
geng 59, 60, 67, 68, 84, 85
geng-chén 60, 67, 68
geng-shen 60, 67, 68
geng-wu 60, 67, 68
geng-xu 60, 67, 68
geng-yín 60, 67, 68
geng-zi 60, 67, 68
gong 36, 69
Gong-bù Gong-chéng Zuò-fa Zé-lì 36, 255
guan 78, 79, 159
Guang-dong 3, 98, 99, 179, 181
gui 59, 60, 67, 68, 84, 85
guì 80
gui-chou 60, 67, 68
gui-hài 60, 67, 68
gui-mao 60, 67, 68

gui-sì 60, 67, 68
gui-wèi 60, 67, 68
gui-you 60, 67, 68
Guo, Pú 22, 23
guò-shui 55
gu-yu 61, 67

H

hài 59, 60, 67, 68, 79, 84, 85
hài (harm) 78
Hàn 12, 22, 40, 59, 61, 62, 64, 77, 79, 179
hán-lù 61, 67
héng 38
hé-tú 25, 26, 28, 30
hé-yuàn 15, 40, 44, 81, 100, 177, 184
hé-zhuan 83
Hóng-fàn-pian 25
hòu-tian ba-guà 28, 84
Huáng 101
Huáng-dì 65
Huí 12
huì 62, 63
Hui-zong 35
hù-lóng 99, 100, 101, 121
huo 84
huò-hài 71

J

ji 59, 60, 66, 67, 68, 84
jí 63
jì 63
jia 59, 60, 66, 67, 68, 84, 85
jià 34, 35, 36, 49, 50, 54, 182
jia-chén 60, 67, 68
jian 32, 33, 34, 35, 36, 37, 38, 43,

Z

Part IV
Appendices

Appendix 1: Chronology of Chinese Dynasties

Primitive . . . . circa **600000 -** circa **2100 B.C.**

Xìa (夏) . . . . circa **2100 -** circa **1600 B.C.**

Shāng (商) . . . . circa **1600 -** circa **1100 B.C.**

Zhōu (周) . . . . circa **1100 - 256 B.C.**

    Western *Zhōu* (西周)   circa 1100 - 771 B.C.

    Eastern *Zhōu* (東周)   770 - 256 B.C.

        Chūn-qīu (春秋, Spring and Autumn Period)   770 - 476 B.C.

        Zhàn-guó (戰國, Warring States Period)   475 - 221 B.C.

Qín (秦) . . . . **221 - 207 B.C.**

Hàn (漢) . . . . **206 B.C. - A.D. 220**

    Western *Hàn* (西漢)   206 B.C. - A.D. 8

    Xīn (新)   9 - 23

    Líu, Xuán (劉玄): *Gēng-shǐ* (更始)   23 - 25

    Eastern *Hàn* (東漢)   25 - 220

Sān-guó (三國, **Three Kingdoms**) . . . . **220 - 265**

    Wèi (魏)   220 - 265

    Shǔ (蜀)   221 - 263

    Wú (吳)   222 - 280

Jìn (晉) . . . . **265 - 420**

    Western *Jìn* (西晉)   265 - 316

    Eastern *Jìn* (東晉)   317 - 420

Nán-běi-cháo (南北朝, **Northern and Southern Dynasties**) . . . . . **420 - 589**

    Nán-cháo (南朝, Southern Dynasties)   420 - 589

        Sòng (宋)   420 - 479

        Qí (齊)   479 - 502

        Liáng (梁)   502 - 557

        Chén (陳)   557 - 589

    Běi-cháo (北朝, Northern Dynasties)   386 - 581

        Northern *Wèi* (北魏)   386 - 534

        Eastern *Wèi* (東魏)   534 - 550

        Western *Wèi* (西魏)   535 - 557

        Northern *Qí* (北齊)   550 - 577

        Northen *Zhōu* (北周)   557 - 581

Suí (隋) . . . . **581 - 618**

Táng (唐) . . . . **618 - 907**

Wǔ-dài Shí-guó (五代十國, **Five Dynasties and Ten Kingdoms**)   **907 - 979**

Sòng (宋) . . . . **960 - 1279**
    Northern *Sòng* (北宋) 960 - 1127
    Southern *Sòng* (南宋) 1127 - 1279

Liáo (遼) . . . . **916 - 1125**

Jīn (金) . . . . **1115 - 1234**

Yuán (元) . . . . **1271 - 1368**

Míng (明) . . . . **1368 - 1644**

Qīng (清) . . . . **1644 - 1911**

Appendix 2:
Shape Description
Language

I   BNF Grammar for SDL

This section describes the grammar of shape description language using a variant of the BNF (Backus-Naur form). The grammar described here will be used for parser-generator, YACC, and forms the primary design of the shape description language.

The grammar has undefined terminal symbols *Abort*, *Nil-constant*, *Boolean-constant*, *Int-constant*, *Real-constant*, *Char-constant*, *String-constant*, *Identifier*; and *Identifier-predicate*, the **typewriter** style words and symbols are terminals given literally.

I.1   Interpreter Basic

Interpreter-unit ::=
      External-declaration |
      Interpreter-unit External-declaration **>**

External-declaration ::=
      Type-definition |
      Sort-definition |
      Function-definition |
      Statement |
      Comment |
      Abort

I.2   Type Definitions

Type-definition ::=
      type *Type-name* **:** *Init-type-list* **;** |
      type *Type-name* **:** *Init-type-list Type-condition* **;**

Init-type-list ::=
      Init-type-tuple |
      Init-type-alternative

Init-type-tuple ::=
      Init-types |
      (*Init-types* **)** *List-specifier*

Init-types ::=
      Init-type |
      Init-types ***** *Init-type*

Init-type ::=
      (*Type-name* **:** *Type-value-type* **)**

Init-type-alternative ::=
      Type-name |
      Init-type-alternative **+** *Type-name*

Type-value-type ::=
      Type-specifier |
      Type-specifier List-specifier

Type-specifier ::=
      Primary-value-type |
      Primary-basic-sort |
      Type-name

Primary-value-type ::=
      boolean |

Primary-basic-sort ::=

    int |
    real |
    char |
    string |
    nil

Primary-basic-sort ::=

    point |
    line |
    lineseg |
    boundary |
    plane |
    shell |
    volume |
    label |
    Fractional

Type-name : :=

    Identifier

List-specifier ::=

    [ ] |
    [*Expression* **]**

Type-condition ::=

    { *Condition-expression* **}** |
    { }

I.3   Sort Definitions

Sort-definition ::=

    sort *Sort-name* **:** *Init-sort-list* **;**

Init-sort-list ::=

    Init-simple-sort |
    Init-composite-sort

Init-simple-sort ::=

    Init-sort |
    Init-simple-sort ***** *Init-sort*

Init-sort ::=

    (*Sort-name* **:** *Sort-specifier* **)**

Init-composite-sort ::=

    Sort-specifier |
    Init-composite-sort **+** *Sort-specifier*

Sort-specifier ::=
        Primary-basic-sort |
        Sort-name

Sort-name : :=
        Identifier

I.4   **Function Definitions**

Function-definition ::=
        function *Function-name* **( ) :** *Value-type* **{** *Compound-statement* **} ;** |
        function *Function-name* **(** *Argument-declaration-list* **) :** *Value-type*
        { *Compound-statement* **} ;**

Argument-declaration-list ::=
        Argument-declaration |
        Argument-declaration-list Separator Argument-declaration

Argument-declaration ::=
        Identifier **:** *Value-type*

Function-name ::=
        Identifier

Separator ::=

        ,

Value-type ::=
        Type-value-type |
        Sort-specifier

I.5   **Statements**

Statement ::=
        Compound-statement |
        Expression-statement |
        Selection-statement |
        Iteration-statement |
        Comment

Compound-statement ::=
        Instance-declaration-list Statement-list |
        Instance-declaration-list |
        Statement-list

Statement-list ::=
        Statement |
        Statement-list statement

Expression-statement ::=
    Expression **;**

Selection-statement ::=
    if { *Expression* **} then {** *Compound-statement* **} ;**
    if { *Expression* **} then {** *Compound-statement* **} else {** *Compound-statement* **} ;**

Iteration-statement ::=
    while { *Expression* **} {** *Compound-statement* **} ;**
    for { *Expression*_{opt} **;** *Expression*_{opt} **;** *Expression*_{opt} **} {** *Compound-statement* **} ;**

I.6   Instance Declarations

Instance-declaration-list ::=
    Instance-declaration-list Instance-declaration

Instance-declaration ::=
    instance *Identifier-list Init-value-type-declarator* **;**

Init-value-type-declarator ::=
    : *Value-type*

Identifier-list ::=
    Identifier |
    Identifier-list Separator Identifier

I.7   Expressions

Expression ::=
    Assignment-expression |
    Expression Separator Assignment-expression

Assignment-expression ::=
    Condition-expression |
    Unary-expression **=** *Assignment-expression*
    default *Unary-expression* **=** *Assignment-expression*

Condition-expression ::=
    Logical-OR-expression

Logical-OR-expression ::=
    Logical-AND-expression |
    Logical-OR-expression **||** *Logical-AND-expression*

Logical-AND-expression ::=
    Equality-expression |
    Logical-AND-expression **&&** *Equality-expression*

Equality-expression ::=
>   *Relational-expression* |
>   *Equality-expression* **==** *Relational-expression* |
>   *Equality-expression* **!=** *Relational-expression*

Relational-expression ::=
>   *Additive-expression* |
>   *Relational-expression* **<** *Additive-expression* |
>   *Relational-expression* **<=** *Additive-expression* |
>   *Relational-expression* **>** *Additive-expression* |
>   *Relational-expression* **>=** *Additive-expression*

Additive-expression ::=
>   *Multiplicative-expression* |
>   *Additive-expression* **+** *Multiplicative-expression* |
>   *Additive-expression* **-** *Multiplicative-expression*

Multiplicative-expression ::=
>   *Unary-expression* |
>   *Multiplicative-expression* ***** *Unary-expression* |
>   *Multiplicative-expression* **/** *Unary-expression* |
>   *Multiplicative-expression* **%** *Unary-expression* |
>   *Multiplicative-expression* **^** *Unary-expression* |
>   *Unary-expression* **::** *Multiplicative-expression*

Unary-expression ::=
>   *Postfix-expression* |
>   *Unary-operator Unary-expression*

Unary-operator ::=
>   **+** |
>   **-** |
>   **!**

Postfix-expression ::=
>   *Primary-expression* |
>   *Postfix-expression* **[** *Expression* **]** |
>   *Postfix-expression* **.** **@** *Expression*
>   *Postfix-expression* **.** *Identifier* |
>   *Postfix-expression* **( )** |
>   *Postfix-expression* **(** *Argument-expression-list* **)** |

Primary-expression ::=
>   *Identifier* |
>   *Constant* |
>   *Primary-value-type* |

Primary-basic-sort |
Identifier-predicate |
(*Expression* **)** |
{ *Expression* **}**

Argument-expression-list ::=
Condition-expression |
Argument-expression-list Separator Assignment-expression

Constant ::=
Nil-constant |
Boolean-constant |
Int-constant |
Real-constant |
Char-constant |
String-constant

II   Built-in Functions of SDL

This section summarizes and gives a brief description of currently built-in functions in SDL. The underscore (_) symbol indicates the sort or type is arbitrary, and void indicates no return value for that function. Note that the latestest version of GRAIL kernel only privdes point, line, line segment, label, and fractional.

II.1   File I/O

source (*file-name* : string) : void
This function reads the *file-name* which is specified a string as a source if the file exists.

II.2   Output and Purge

print (*v* : _) : void
This function prints a given value to the standard output. If the given parameter is a variable, it retrieves the variable's value (instance value or sort/type definition) and print it.

purge (*instance* : _) : void
This function purges an instance definition and its value form the program.

II.3 Numerical Functions

boolean (v : _) : boolean
This function casts a value to a boolean value. If the given value is int or real, it returns 0 when the given value is 0; otherwise, it returns 1. For the other value type, it returns 1 if it is not null; otherwise, it returns 0.

int (v : boolean + int + real + char) : int
This function casts a value which is type boolean, int, real, or char to an integer. The conversion of char to int is based on the ASCII.

floor (v : int + real) : int
This function returns the largest integer which is not greater than v.

ceil (v : int + real) : int
This function returns the smallest integer which is not less than v.

round (v : int + real) : int
This function returns the closest integer of v.

real (v : boolean + int + real) : real
This function casts a value which is type boolean, int, or real to a real.

char (v : int) : char
This function casts an integer to a character based on the ASCII.

char (s : string , *index* : int) : char
This function return the *index*-th character of the given string s. The index starts from 1.

string (c : char) : string
This function casts a character to a string.

string (s : string , *begin* : int , *end* : int) : string
This function returns a sub-string of the given string s from the *begin*-th to the *end*-th characters. The index of the first character is 1.

slength (s : string) : int
This function returns the length of a given string s.

The following functions detect if a given value is that type, and return a boolean value as the result.

nil? (v : _) : boolean

boolean? (v : _) : boolean

int? (v : _) : boolean

real? (v : _) : boolean

char? (v : _) : boolean

string? (v : _) : boolean

II.4   List and Tuple Functions

head (v : _) : _
  This function returns the first element of a given list.

tail (v : _) : _
  This function returns a list without the first element of a given list.

llength (v : _) : int
  This function returns the length of a list.

tlength (v : _) : int
  This function returns the length of a tuple.

list? (v : _) : boolean
  This function checks if the given value is a list, and returns a boolean value.

tuple? (v : _) : boolean
  This function checks if the given value is a tuple, and returns a boolean value.

II.5   Default Functions

rdefault (*instance* : _) : _
  This function retrieves an instance's default value if it exists.

has_default? (*instance* : _) : boolean
  This function checks if an instance has default value set, and returns a boolean value.

II.6   Individual Functions

point (x : int , y : int , z : int , w : int) : point
  This function specifies an individual of points by the homogeneous coordinates.

point (x : real , y : real , z : real) : point
  This function specifies an individual of points by the Cartesian coordinates.

line (*p1* : *point* , *p2* : *point*) : line
  This function specifies an individual of infinite lines by two reference points. The sort/type of these two parameters (*point*) can be an individual of points, Cartesian coordinates, or homogeneous coordinates.

lineseg (*p1* : *point* , *p2* : *point*) : lineseg
  This function specifies an individual of line segments by two ending points. The sort/type of these two parameters (*point*) can be an individual of points, Cartesian coordinates, or homogeneous coordinates.

label (*l* : int + real + char + string) : label
  This function specifies an individual of labels which can be an integer, real, character, or string.

fractional (*v* : real) : fractional
  This function specifies a fractional value which is real greater than 0 and less than or equal to 1.

The following functions check if the given instance value is an individual of that sort, and return a boolean value.

point? (*instance* : _) : boolean

line? (*instance* : _) : boolean

lineseg? (*instance* : _) : boolean

label? (*instance* : _) : boolean

fractional? (*instance* : _) : boolean

II.7   Form Functions

In the followings, *form* indicates the collection of a sort, and *individual* represents an individual of a sort.

form_add (*f* : *form* , *i* : *individual*) : void
  This function adds an individual (*i*) to a form (*f*) which is an instance with the same sort of the instance *i*. The form *f* is sorted and maximalized automatically after a new individual is added.

The following four functions may be redundant.

form_sort (*f* : *form*) : void
  This function sorts the individuals of a given form (*f*) in order.

form_maximal (f : _form_) : void
This function maximalizes the individuals of a given form (f).

form_print (f : _form_) : void
This function prints the information (all individuals) of a given form f.

form_sum (f_1 : _form_ , f_2 : _form_) : void
This function takes the sum of two discrete forms of the same sort f_1 and f_2. The result is stored in f_1, and f_2 is purged.

form_difference (f_1 : _form_ , f_2 : _form_) : void
This function takes the difference of two discrete forms of the same sort f_1 and f_2. The result is stored in f_1, and f_2 is remained.

form_product (f_1 : _form_ , f_2 : _form_) : void
This function takes the product of two discrete forms of the same sort f_1 and f_2. The result is stored in f_1, and f_2 is purged.

form_sym_difference (f_1 : _form_ , f_2 : _form_) : void
This function takes the symmetric difference of two discrete forms of the same sort f_1 and f_2. The result is stored in f_1, and f_2 is purged.

form_partition (f_1 : _form_ , f_2 : _form_ , f_{common} : _form_) : void
This function makes the partition of two discrete forms of the same sort f_1 and f_2. The common part is stored in f_{common}; f_1 and f_2 are the original forms without the common part.

form_purge (f : _form_) : void
This function purges a form f.

form_recycle (f : _form_) : void
This function clears the contents of the form f.

form_duplicate (f_{from} : _form_ , f_{to} : _form_) : void
This function duplicates the form f_{from} to the form f_{to}.

form_duplicate (f : _form_) : _form_
This function makes a duplication of the form f and returns it.

form_part_of? (f_1 : _form_ , f_2 : _form_) : boolean
This function checks if the form f_1 is part of form f_2, and returns a boolean value.

form_equals? (f_1 : _form_ , f_2 : _form_) : boolean
This function checks if forms f_1 and f_2 are equal, and returns a boolean value.

II.8   Individual Modification Functions

The individual modification functions are provided for adding extra attributes to an individual or editing an individual's value. A vector value is defined as the following:

$vector$:= (v_x : int , v_y : int , v_z : int, v_w : int) + (v_x : real , v_y : real , v_z : real)

attribute_add (i : $individual$, a : $form$) : void
  This function adds an attribute (a) to the individual (i).

individual_remove (i : $individual$) : void
  This function deletes an individual and its attributes if any from the
  form.

edit_coord (i : $individual$, pos : $vector$) : void
  This function changes a point individual to a new coordinate.

edit_label (i : $individual$, l : label) : void
  This function edits a label individual's value.

II.9   Transformation Functions

The transformation functions are provided for manipulating the transformation of form or individual.

translate (obj : $form$ + $individual$, v : $vector$) : void
  This function translates a entire form or single individual by a vector
  value.

rotate (obj : $form$ + $individual$, v : $vector$) : void
  This function rotates a entire form or single individual by a vector
  value. The vector will be translated as r_x, r_y and r_z in degree.

scale (obj : $form$ + $individual$, v : $vector$) : void
  This function scales a entire form or single individual by a vector
  value. The vector will be translated as s_x, s_y and s_z.

II.10   Graphical Functions

display_open ( ) : void
  This function launches the graphic capacity to the SDL, and open a
  simple window for display.

display_close ( ) : void
  This function disconnects the graphics and closes the window from the screen.

display_clear ( ) : void
  This function clears the current display from the window.

display_refresh ( ) : void
  This function refreshes the window with the same contents.

display_form (f : _form_) : void
  This function notices the graphic to display a new contents, namely, form f.

display_ratio (s_x : real , s_y : real) : void
  The ratios s_x and s_y must not be 0. This function changes the display ratio to the new value, and refresh the display.

display_origin (x_{new} : int , y_{new} : int) : void
  x_{new} and y_{new} are the new origin coordinate of display. This function change the display origin coordinate to the new value, and refresh the display.

II.11 Interactive Function

interactive_form (f : _form_) : void
  This function activates the interactive mode from the graphic window which allows user to define form from the window, and all of interactive results are added to form f if the user commits it.

III   Keywords in SDL

This section describes the keywords which are reserved for the SDL.

Abort

quit — quit the program
exit — quit the program

Definition and Setting

sort — define a sort definition
type — define a type definition
instance — define instances

default — set an instance's default
function — define a function

Basic Types and Sorts

nil — empty

point — simple sort of points
line — simple sort of infinite lines
lineseg — simple sort of line segments
boundary — simple sort of boundaries
plane — simple sort of planes
shell — simple sort of shells
volume — simple sort of volumes
label — simple sort of labels
fractional — simple sort of fractional

boolean — data type boolean
int — data type integer
real — data type real
char — data type character
string — data type string

Special Instance

current — current value of any instance

Selection and Iteration

if — define logical condition
then — statements for true
else --— statements for false
while — define while loop
for — define for loop