Re-Designing the Traditional Residential House in contemporary china

Using a re-interpreted dou-kung to develop a new vernacular typology.

by

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Abstract

This thesis was undertaken to examine traditional wood construction in China. It attempts to reinterpret the traditional bracket set (tou-kung) and translate if this type of timber structures can be built using new modes of fabrication .The goal of the new Tou-kung is to construct a medium height timber structure residential tower to deal with China's growing population. The traditional tou-kung was developed to support the 'flying eave', which protected the structure from inclement weather and reduce the load of the adjacent beams. New wood materials such as glued laminated timbers and the 'camber', a technique for glued laminated beam to counter deflection, is used for the reinterpreted the tou-kung.

The layout of the new medium height timber structure residential tower is designed to retain the traditional courtyard and multi- generational dwelling and deal with the new family structure resulted from one child policy.

Contents:

Introduction

Chinese architecture is facing an issue: contemporary development architecture has lost the connection with tradition building styles. Ssu-ch'eng Liang and Huiyin Ling, famous Chinese architects, raised the call of protecting traditional architecture even before the People Republic of China was established. However, under the pressure of the global modernization, Chinese architecture is losing its identity. Chinese architecture needs to develop, but it should develop baseing on the Chinese tectonics and social relationships.

How can we reconnect the past with the present? This thesis sets out to review Chinese traditional architecture and to find ways to link the characters of contemporary China with its past. Since traditional asian architecture is mainly wooden architecture, this thesis explores Chinese architecture from the perspective of traditional woodcraft. At the same time, it shows the research and the analysis of traditional vernacular dwelling in Ming and Qing period.

The design project for the thisis is a type of residence that can link the traditional architecture to contemporary life. This residence is expected to create a base to the future development of Chinese architecture.

There are many other economically efficient solutions for the housing issue happening in China. However, from the perspective of cultural heritage value, it is a huge loss to solve the issue only by economical efficiency. When a nation loses its identity, the vitality of the nation would vanish with it. Traditional architecture is just an edge of the entire cultural iceberg, but it is an important starting point in the recovery of cultural identity.

Part 1 Chinese traditional wood craft

Chinese traditional architecture is one of the three oriental architectural styles [1]. It is recognized not only for its history and strong influence on other cultures, but also for its independent evolution. Chinese traditional architecture evolved through several important cultural stages along its history and still remained on its own path of development. It reflects the image of Chinese cultures. However, the importance of Chinese traditional architecture was not recognized until Ssu-ch'eng Liang's research was published in the early 1900's He pointed out in his book:

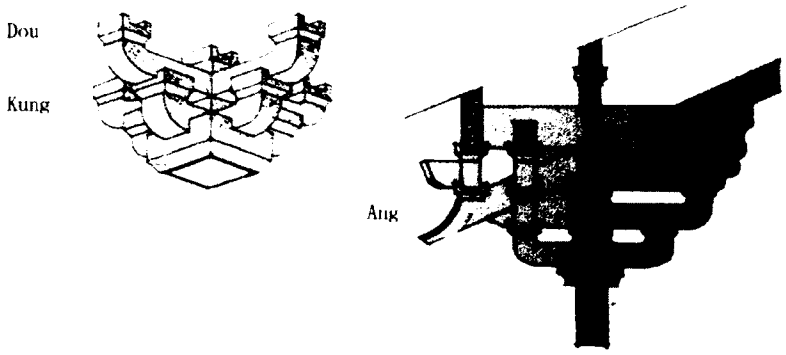
"...the structure has retained its organic qualities which are due to the ingenious and articulate construction of the timber skeleton where the size, shape, and position of every member are determined by structural necessity. Thus the study of the Chinese building is primarily a study of it anatomy"[2].

Huiyin Lin concluded that the Chinese traditional architecture in general consists 3 parts; the platform, the wood frames and the roof. The platform or the building foundation, is constructed with stones and bricks; the roof is made of tiles and mud; the wood frame,or the anatomy of the architecture, is the structure, the unique part[3].

The study of the traditional Chinese architecture has to begin with the wood structure.

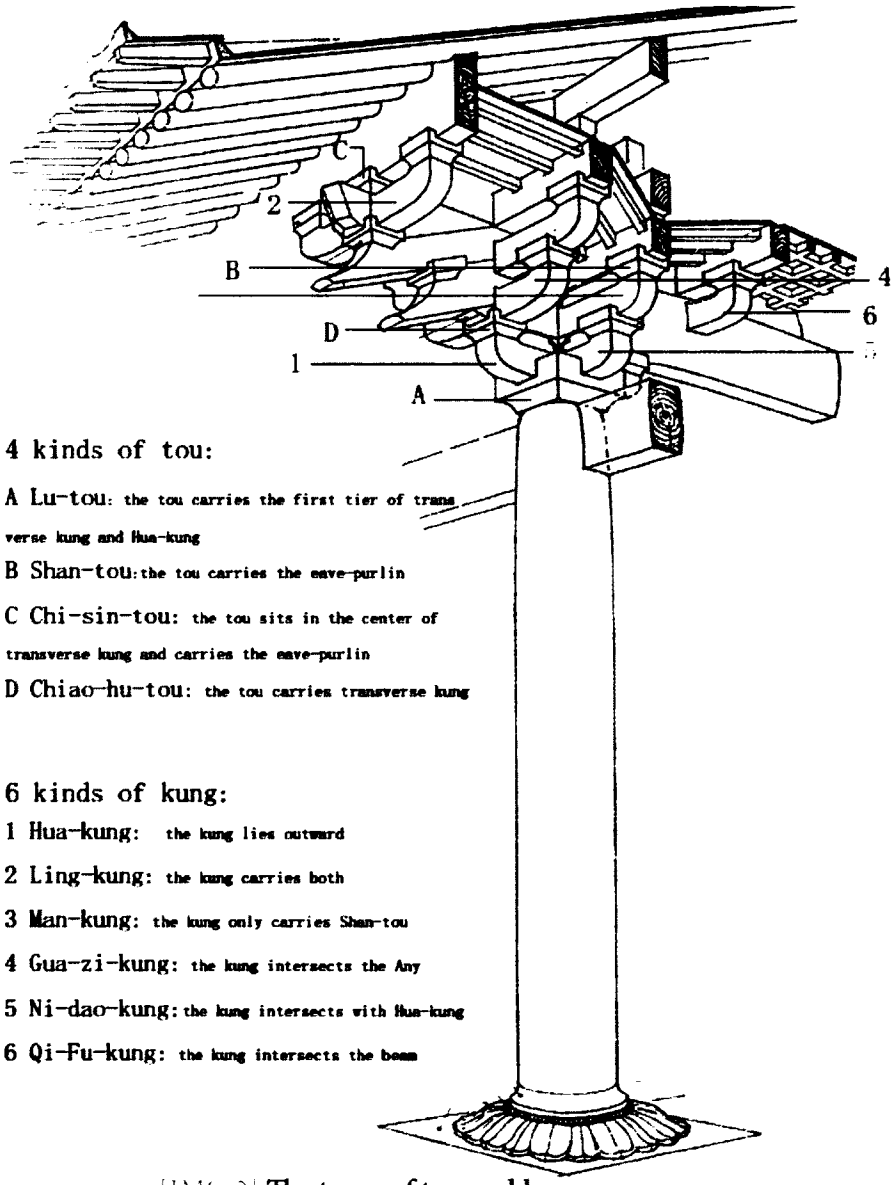
Introductions of Tou-kung:

Tou-kung (the bracket set), in the definition of Western architecture, is the column capital. Tou is the block, carries the weight to the base; Kung is the horizontally projecting arm; the diagonal arm is called Ang. [IMG 1]One bracket set has up to 5 tiers and can appear extremely sophisticated [4]. However, each element carries its own functions. tou-kung is not only an ornament but also a structural system which spreads the load in four directions. The tou-kung successfully reduces the load of beams and allows for a thinner cross section. Further more, the famous "flying eave" roof style is a by-project of tou-kung. The large projection of Tou-kung supports the eave to form a large cantilever which protects the building's foundation from rain damage and give shade from the sun[5]. It is a good example of a system that fulfils both structural and aesthetic purposes.



[IMG 1] Tou, Kung and Ang

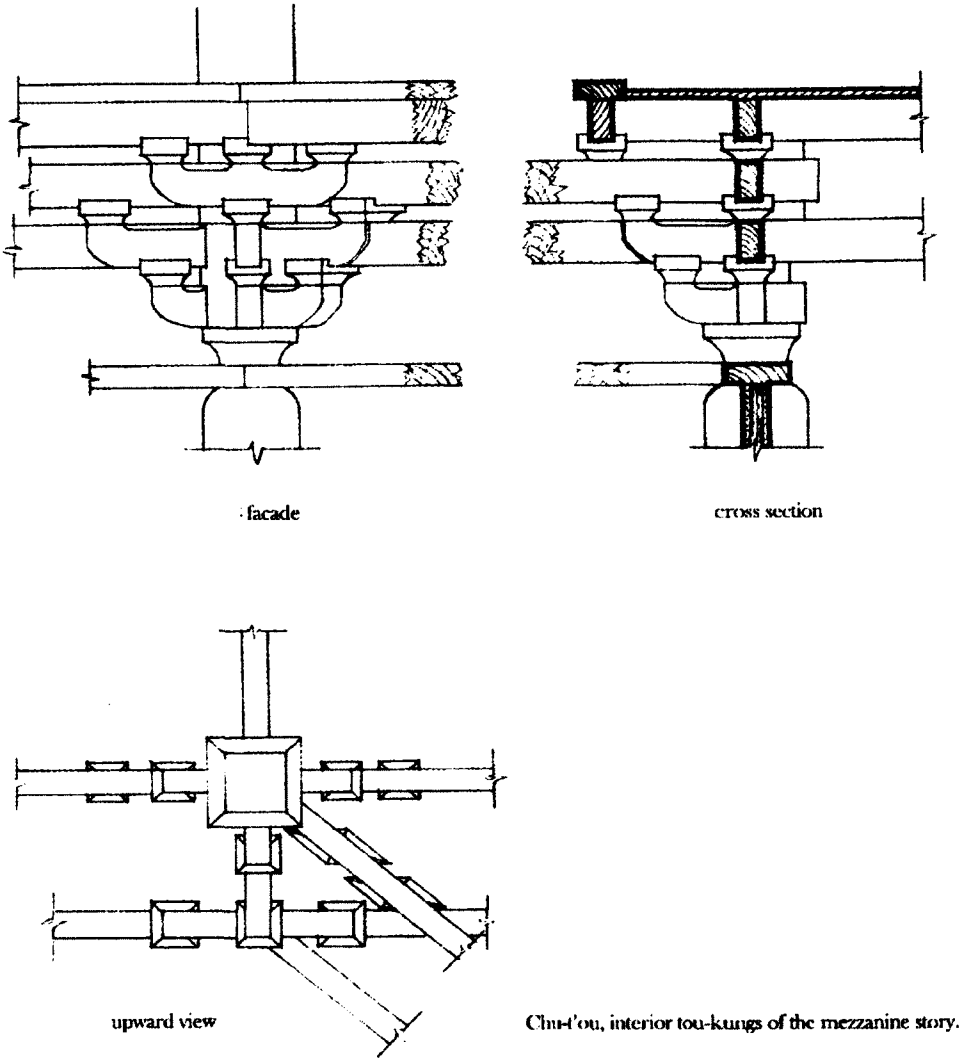
There are 4 kinds of tou: Lu-tou(the tou carries the first tier of transverse kung and Hua-kung), Shan-tou(the tou carries the eave-purlin), Chi-sin-tou (the tou sits in the centre of transverse kung and carries the eave-purlin)and Chiao-hu-tou(the tou carries transverse kung). There are 6 kinds of kung: Hua-kung (the kung lies outward), Ling-kung(the kung carries both Shan-tou and Chi-sin-tou), Man-kung(the kung only carries Shan-tou), Gua-zi-kung(the kung intersects the Any), Ni-dao-kung (the kung intersects with Hua-kung) and Qi-Fu-kung(the kung intersects the beam). [IMG 2] In each tier the tou-kung will extend outward for a distance, which is called a "Jump". Usually, one set of tou-kung will make up to 5 "Jumps"[6].



[IMG 2] The types of tou and kung

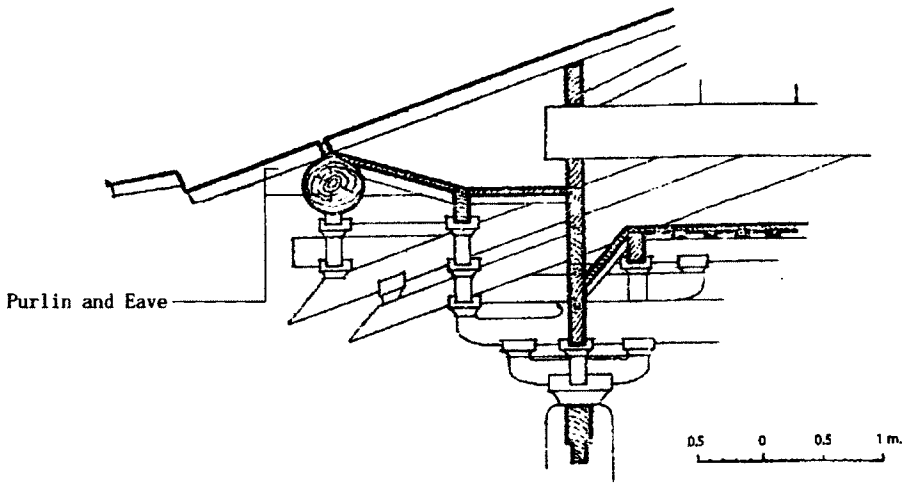
In response to the different structural needs in a building, the tou and kung can be assembled in various arrangements. There are twenty-four different combinations of tou-kung in Kuan-yin Ke, Tu-le Temple, Chi Hsien, Hopei Province, built in 984 A.D. [7]. In general, they can be concluded into 3 types: 1, the set in the corner. 2, the set carrying the eave. 3, the set carrying the beam. [IMG 3, 4, 5]

The tou-kung is a independent modural structural system to assist the whole structural system.

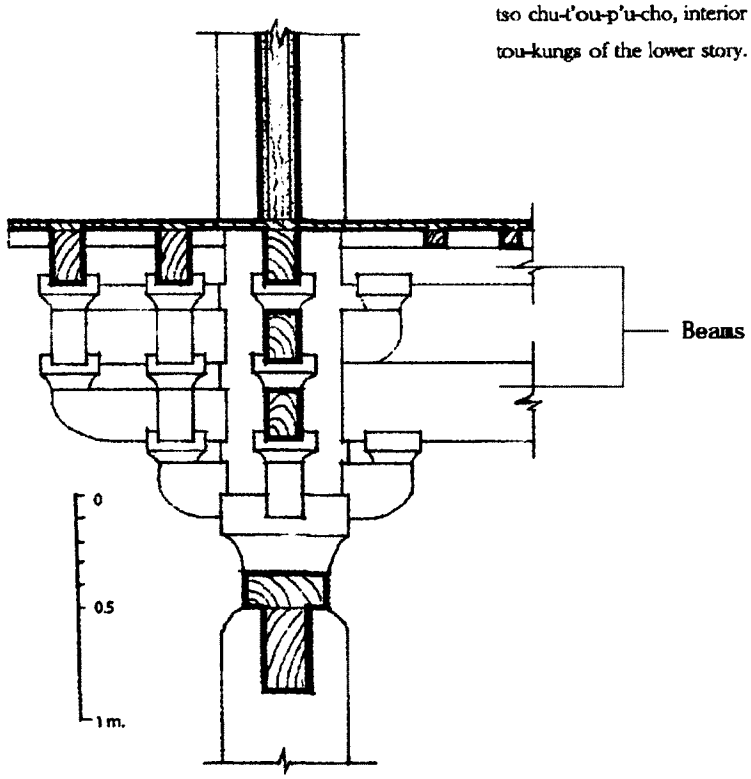


[IMG 3] The set in the corner.

Chu-t'ou-p'u-cho of exterior tou-kungs of the upper story, Kuan-yin Ke.



Cross section of p'ing-tso chu-t'ou-p'u-cho, interior tou-kungs of the lower story.



IMG. 15.5 The set carrying the eave and the set carrying the beam.

Evolution of tou-kung :

The study of Tou-kung cannot be separated from the architecture and time period. It was first developed in the funereal clay house models in the Han Dynasty (568 A.D.)[8]. The earliest surviving example of the tou-kung structure was the Temple Fo-kuang in the WU-t'ai Mountains, Shansi Province, built in 857, from Tang Dynasty [9]. In Ssu-ch'eng Liang's book 'A Pictorial History of Chinese Architecture', he categorized the tou-kang in 3 stages: 1,the period of Vigor, 2, the period of Elegance, 3, the period of Rigidity[10]. In each period Tou-kung is distinct.

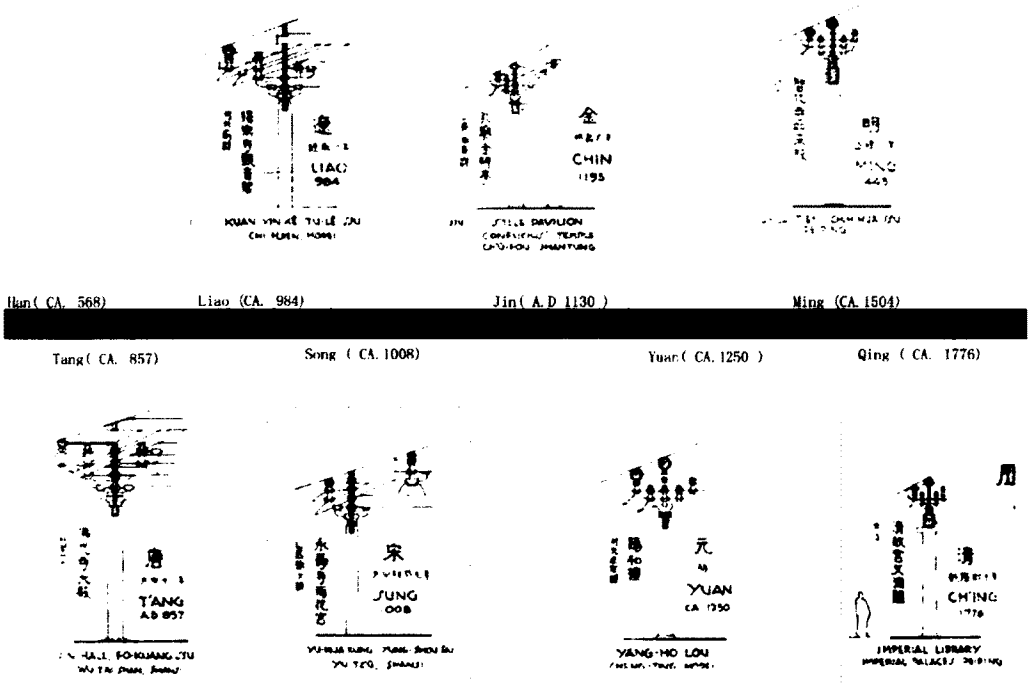


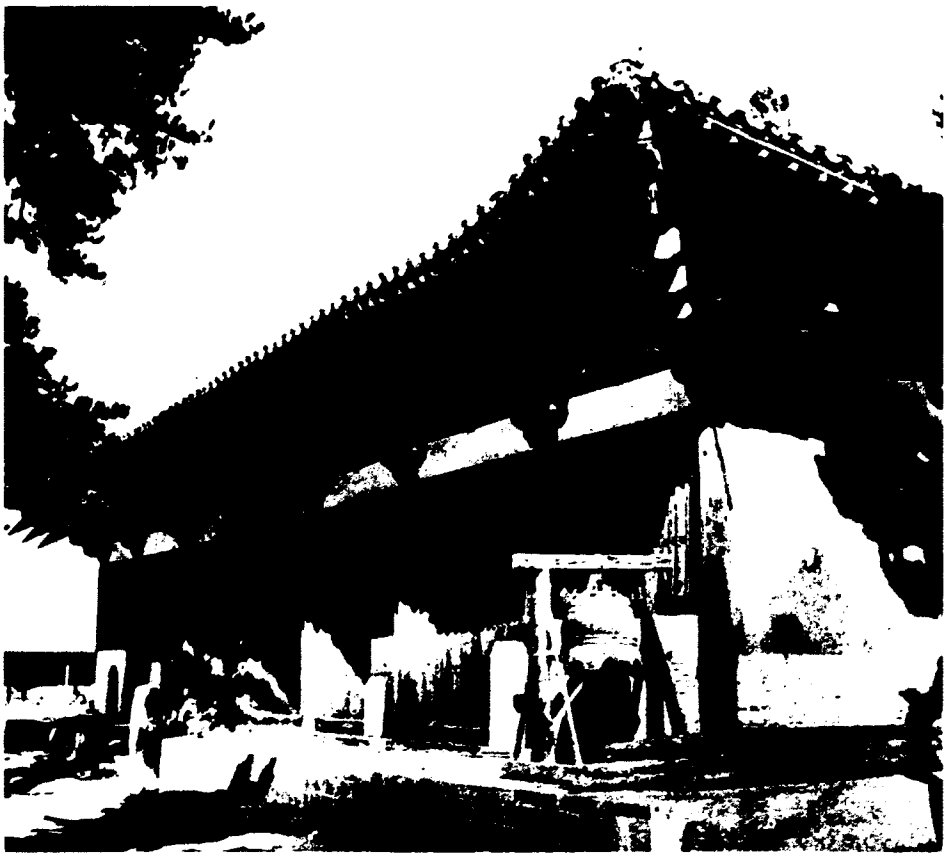
FIG.6 Dou-kong development related to the China Dynasty periods.

The Period of Vigor

The period of Vigor of tou-kung development dated from Tang Dynasty (C.A.. 850-1050). This was an exceedingly wealthy period in the Chinese history. A number of remarkable cultural development happened during this era, such as the development of trading policy and diplomacy with Tibet, Sinkiang and Korea, and the founding of Hanlin Academy. As a result of the rapid development, the capital city Changan, expanded into a city of 1 million inhabitations. The period came to an end during the civil war in 11th century. When the frontier general An Lushan rebelled and captured the capital city, he nearly destroyed all the documents and monumental architectures in the city [11].The wealth in this period produced during Tang dynasty resulted in expressive architecture with luxury proportion and luxurious ornaments, which is well illustrated in the tou-kung designs of this period..

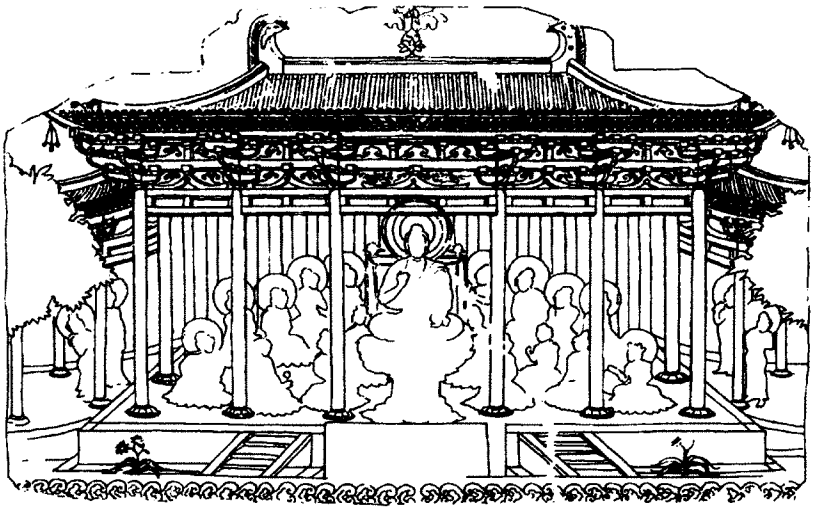
The architecture of this period have to be studied from the engraved reliefs and paintings, because most buildings are no longer standing.[IMG 8]Today, there is only one remaining structure from this period: the temple of Fo-kuang, in the WU-t'ai Mountains, Shansi Province, built in 857 C.A [IMG 7] Although it was partly damaged, it is still possible to gain insight from the remaining architecture and the relief [12].

In the temple of Fo-kuang, the column is straight and slender without entasis. The beams are all crescent-moon beams and all the surfaces of the beam is engraved. The most spectacular feature of this architecture is the tou-kung. There are four tiers for this tou-kung. The ratio of the height to the column is 1:2, giving an overwhelming impression of dignity. The huge tou-kung also gives a long projection for the flying eave. From their the supporting columns, the cantilever of the eave is 14 feet [13].



[IMG 7]The temple of Fo-kuang, in the WU-t'ai Mountains, Shansi Province.

The facade design of this period can be better studied from the relief of Ta-yen T'a (Wild Goose Pagoda). [IMG 8] The facade is symmetrical with the width of the side bays smaller than the central bay. There is 1 intermediate set above the architrave in the side bays and 2 sets in the central bay with extremely rich paintings and engravings on the architrave [14].



[IMG 8] The relief of Ta-yen T'a(WIld Goose Pagoda).

The period of elegance

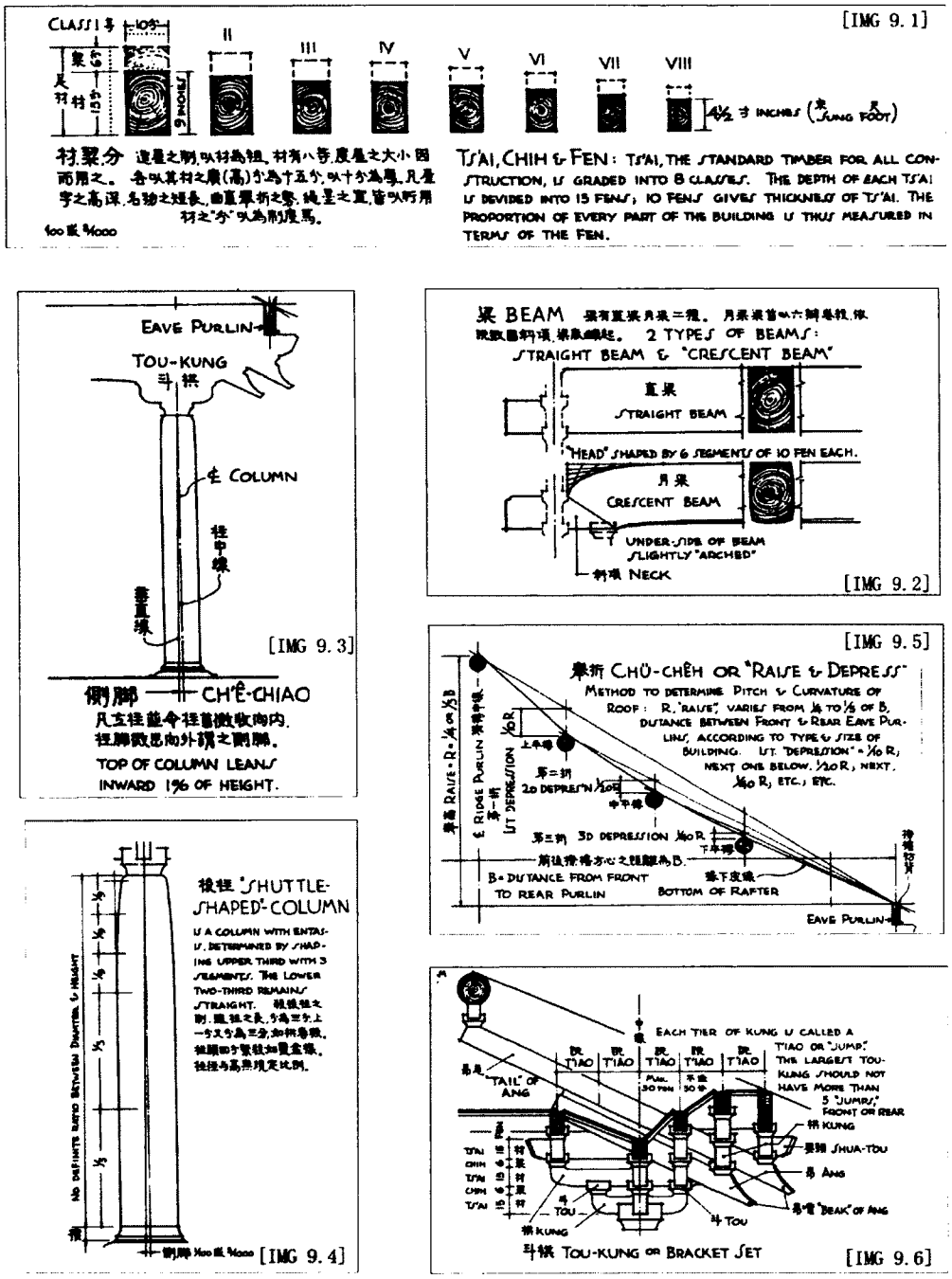
The period of elegance dated from ca.1000-1400. The most symbolic architecture of this period is from the Song Dynasty. Song Dynasty was established after Tang Dynasty , and their architecture is very similar in style. During this period, the book Ying Tsao Fa Shih was written, the Song Dynasty building standard [15]. It offers insight into building methods and form.

Ying Tsao Fa Shih states that there are 8 different standards for timber construction. {IMG 9.1} The measurement is called "Fen", which equals 1 2/3 inches. 15 Fen is called 1 Ts'ai. The standard ratio of the depth to the width of the timber is 3:2. The length of each "jump" varies depending on the need, but it cannot exceed 30 "fen" [16]. {IMG 9.6}

There are two kinds of beams: 1. The straight beam; 2. The crescent-moon beam, which is directly passed down from the Tang Dynasty. {IMG 9.2} The column during this period is quite different. The ratio of the diameter to the height of the column is loose, usually ranges from 1 Ts'ai with 6 Fen to 3 Ts'ai. However, the column now has entasis. The lower 2/3 remains straight, but the upper 1/3 is shaped with 3 segments. {IMG 9.4} In addition, the top of the corner column leans inward, towards the building approx. 1% of the height[17]. {IMG 9.3} This slight leaning creates a visual impression of stability.

an other important architectural development of this period is the roof curvature. Roofs in the Song Dynasty continued the Tang style in general, supported by the tou-kung, with the large cantilevering eaves. However, a formula was used to generate a gentle curve on the roof in Song dynasty, as recorded . In the Ying Tsao Fa Shih (Building Standard). In this formula, the height of the ridge-pole is predetermined. The roof is built from top to the bottom. On every purlin, the roof line will make a Zhe, a "depress" until the roof line is finished [18]. {IMG 9.5}

The architecture is composed of all these elements to give the impression of lightness and elegance. Besides the slight leaning of the corner columns, the entasis, and the gentle curve of the roof, Song architecture carried on with most of the Tang architectural traditions; The side bays were still smaller than central bay and the number of intermediate sets of brackets remained the same as Tang. In addition to the structural changes, another difference between the Tang Dynasty to the Song Dynasty is the removal of rich ornaments. It is elegant only because of the humble proportion and graceful form.



[IMG 9] Song Dynasty rules for structure carpentry.

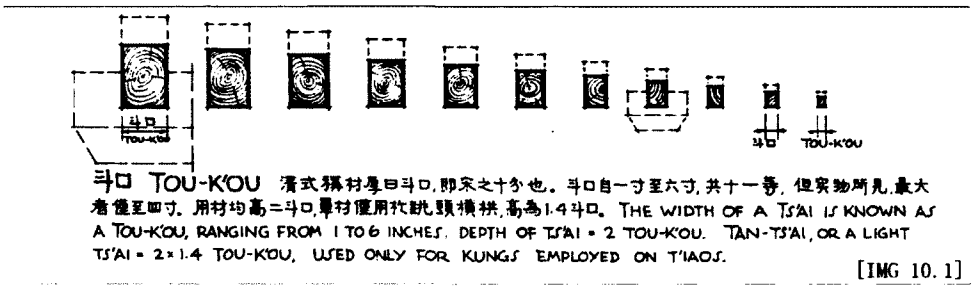
The period of Rigidity

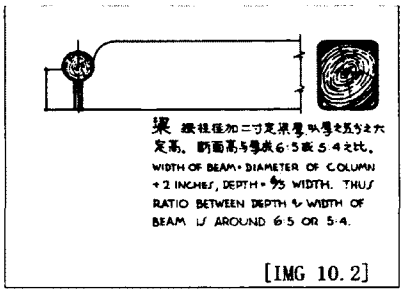
This period dated from C.A 1700 - 1900 . (Qing Dynasty) the study of architecture in the Qing Dynasty is described in a book called the Gong Cheng Fa Shi, a text written to regulate structures. In this book, the measurement and the standard are both different from Song dynasty. The Ts'ai and Fen are abandoned. The new measurement is called tou-kou, or "mortise of the tou", the width for receiving the kung. It ranges from 1 inch to 6 inches and has 11 different standards. The standard of timbers is now expressed in multiples of tou-kou. The ratio of the width to the depth of each timber now is 1:2. {IMG 10.1} The beam changed as well. The ratio of 2:3 in Song Dynasty becomes 4:5 or 5:6. The crescent-moon beam is never used during Qing dynasty [19]. {IMG 10.2} The measurement, tou-kou became a variable unit. As the beam dimension is proportionally expressed in multiples of tou-kou, the building dimension will change proportionally in the same principle. The standards of Tou-kou during this period determined the dimension of the architectures.

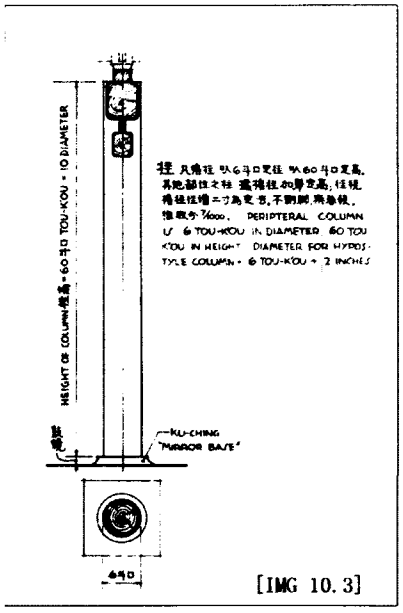
The proportion of the column in this period is strict. The diameter of the column is 6 "tou-kou and the height of the column is 60 tou-kou. There is no entasis on the column and the column has no incline [20]. {IMG 10.3}

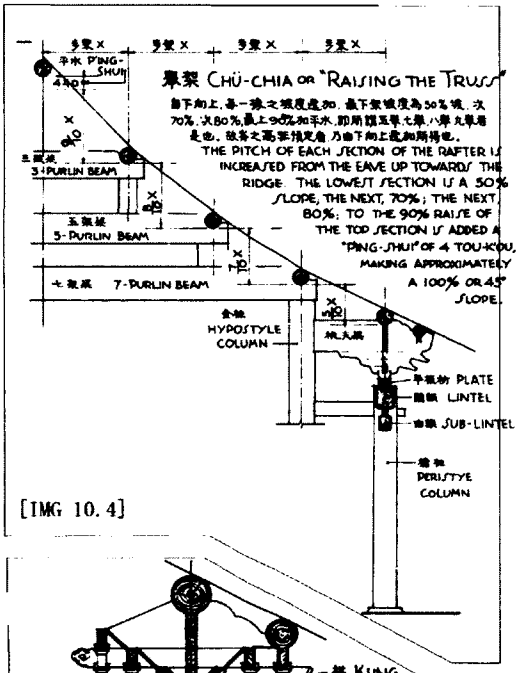
The method to determine the roofline is different from the Song dynasty. The formula appears similar; however, the concept is the opposite. The height of roof is predetermined in Song Dynasty, and the calculation is from top to the bottom. [21]This method allows the builders to have a general idea of the building proportion. In the Qing Dynasty, the calculation begins from the bottom. The width of first side bay is predetermined by the distance of the lower two purlins, and then the purlin to form the roof "raises", instead of "depressing" . [22] {IMG 10.4}

As a result, the roof height of the Qing architecture is unpredictable. In the Song Dynasty, the roof is determined for from an aesthetic propose and the elegant proportion has to be decided first . In comparison, the idea of roof height is quite arbitary during Qing dynasty.



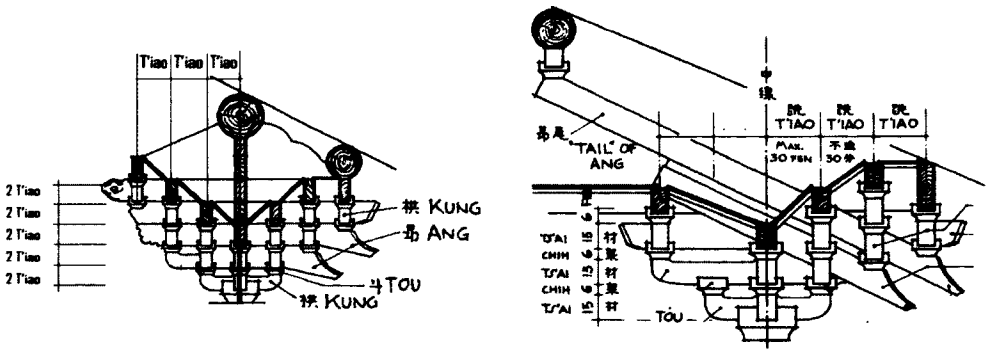






[IMG 10] Qing Dynasty rules for structure carpentry.

For tou-kung, the changes are not only of the dimensions, but also the structural function. In the Song Dynasty, between each tier, the kung would always be supported by the tou, as a cushion. However, in the Qing Dynasty, the kung in the upper tier, is placed directly on the kung in the lower tier without tou. Therefore the structural function of each member in this period is not clear and the resultant bracket set appears solid and heavy. In addition, the projection was proportionally smaller in the Qing Dynasty than it was in the Song Dynasty. For example, the "Jump" was 1 tou-kou in the Qing Dynasty [23]. A 3"jump" tou-kung will project 6 tou-kou. As the timber cross section ratio is 1:2, the tou-kung raises 4x2= 8 tou-kou. The ratio of the projection to the height is 3:4; In the Song Dynasty, for the largest standard timber, when the "jump" is 30 "Fen". A 3 "jump" Tou- kung will project up to 90 "fen". The height raised up is 3 tiers, which is 63 "fen". The ration of the projection to height is 3:2.[IMG 11] While raising the same height, the Tou-kung in the Qing Dynasty projects less than in the Song Dynasty. The rule in the Qing Dynasty really prevents the tou-kung from projecting outward. In conclusion, the structural function of the tou-kung in this period is fading away. The tou-kung became more decorative than structural.

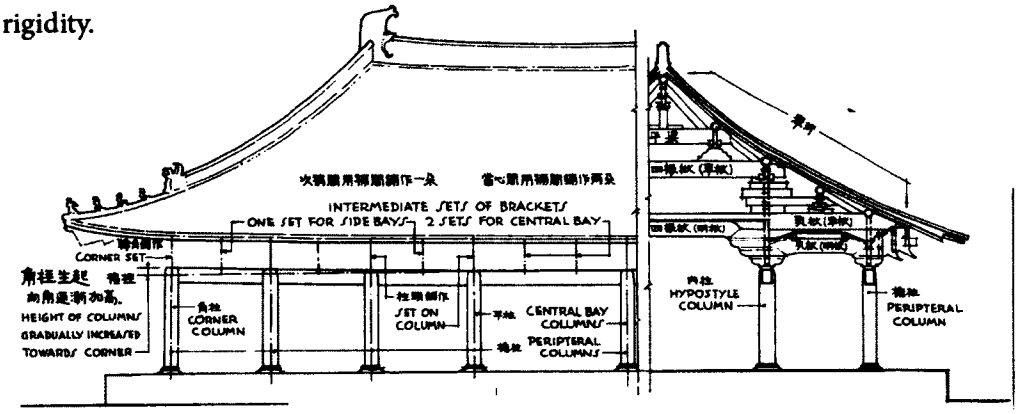


The Qing Dynasty

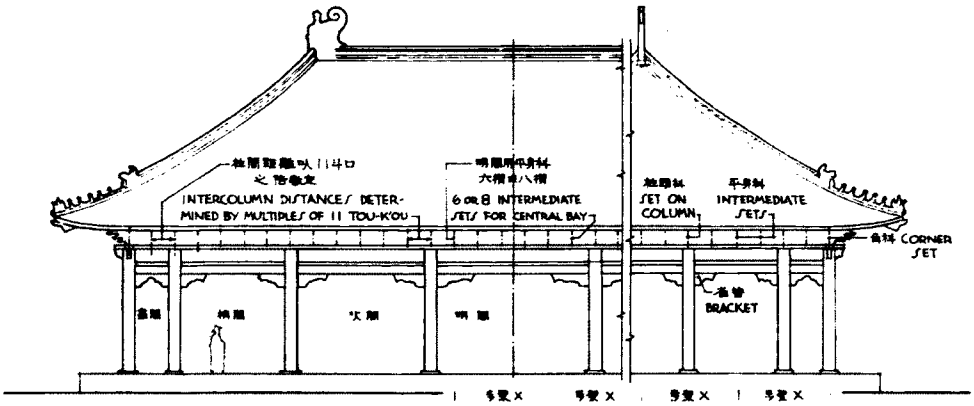
The Song Dynasty

[IMG 11] The Tou-kung in the Qing Dynasty and in the Song Dynasty

All these changes resulted in a different style in the Qing Dynasty. The width of the bays increases gradually from sides to the centre. The number of intermediate sets on the architrave increases. In the Tang and Song Dynasty, there is only one set, but now there are 4 to 6 sets. The architrave is over supported and the dead load of extra sets becomes a structural burden. There were no rules to determine the length of the building facade in the Tang and Song Dynasty. In the Qing Dynasty, a specific rule is set: the distance between the axis of each column equals 11 tou-kou. [IMG 12] All these rules strongly restrains the form of the building. Each building looks standardized. Generally, the roof in Qing Dynasty is proportionally over-sized and the eave projects less than in the Song Dynasty. Columns are elongated and even. Tou-kung is heavy and solid. The entire building gives an impression of rigidity.



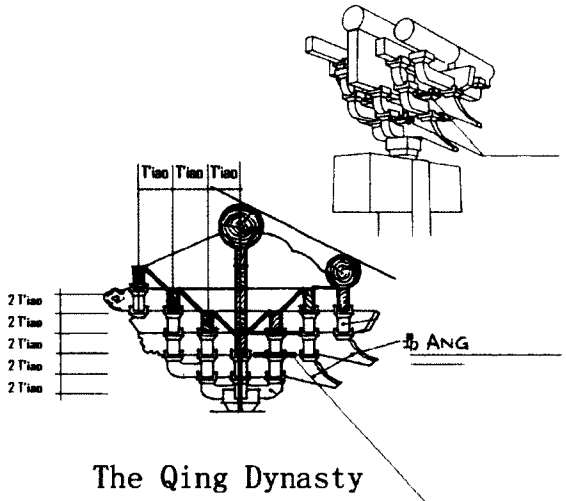
A Facade in the Song Dynasty



A Facade in the QIng Dynasty

[IMG 12] The facade in the Qing Dynasty and in the Song Dynasty

In conclusion, tou-kung in the Tang, Song and Qing dynasty all played important roles in their architectural system. However, the concept of tou-kung is different in each period. In the Tang and Song Dynasty, the tou-kung is a structural element. It extends outward and upward, creating large cantilevers. The Tou-kung is composed of many pieces. , and each of these pieces has different functions and , which be organized to fit different positions. The design of each piece is rational and the aesthetic form is generated from the functioning structure. However, in the Qing Dynasty, the structural function is lessened. The projection of tou-kung is fixed to 6-7 tou-kou, which is close to the diameter of column[24], Ang was a diagonal structural member going through the bracket set and parallel with the eave in the Song dynasty, but it is only kept and attached to the bracket set as a decoration;. Further more, the tou between each tier is removed and the kung is directly placed on top of the lower kung[IMG 13]. Tou-kung became the "instrument of measure" to determine the scale and proportion of the building: The measuring unit becomes tou-kou, the width of opening on tou to receive kung; the "Jump" of each tier is 1 tou-kou; the diameter and height of column is 6 tou-kou and 60 tou-kou; the width of the facade is also decided by tou-kou, which is 11 tou-kou for each bay [25].The tou-kung's structural value has been thrown aside, and the form has become arbitrary, only to follow the will of the designer. The Qing's tou-kung is merely an imitation of Tang and Song's form, predominately adopted as ornament. Architecture is practical art. As Huiying Lin said: "*it is the balance of function, reliability and beauty*"[26]. From the Tang Dynasty to the Qing Dynasty, tou-kung had evolved for hundreds of years. Whether it is a structural system or mere decoration, it was a part of the living architecture. It is a mirror of people's living style, technology and cultures. It should be constantly developing as the Chinese culture develops. However, in the modern world, Chinese traditional architecture is rarely used.

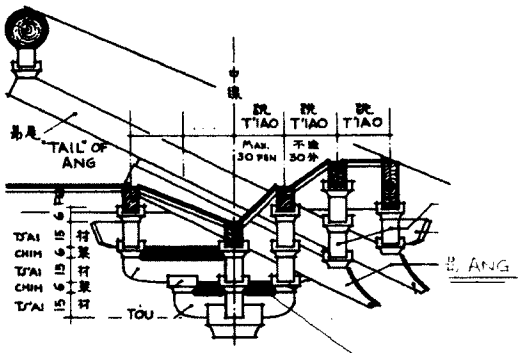


The Qing Dynasty

Dou between each layer is gone.

Horizontal member.
No structural differences from other beams.
The "head", so called "shua tou" as the decorative member.

There is no empty space between each layer. Beams are placed on top of others directly.



The Song Dynasty

Diagonal member.
Different structural functions from other horizontal beams.
The "head", so called "shua tou" as the decorative member.

The empty space between each layer.

FIG. 13 The tou-kung in the Qing Dynasty and in the Song Dynasty

New technology influences.

As aforementioned, the tou-kung in Qing dynasty becomes smaller than in the Song dynasty and gradually loses its structural function . The Song Dynasty was ruled by the Han people, but Qing Dynasty was ruled by Mongolians. The changes of culture can be a critical factor on the development of the tou-kung. What are other influential factors? With new developments in the modern world, how is the new generation of the tou-kung going to function and look ?

The first impact would be are the improvements in wood materials. Glued laminated timber became popular in the early of 20th century. Comparing to the traditional saw timber, it has many advantages, such as better strength and fire-retardant. Specially, it allows engineering to fix natural defects. For example, the glued laminated timber can reorganize the grain direction and the knots to gain more strength. According to the chart [IMG 14] below, at the same length of 18 inches, the saw timber's design load is 574 plf, and deflection is 0.80 in. (A); at the same length, but a thinner depth 5.125 inches, the first glulam's design load is 750 plf and the deflection is 1.25(C). It shows that. Even though the glued laminated timber is capable of taking more load. saw timber is superior to glued laminated timber in term of deflection. However, a wood technique, called 'camber' [IMG 16] is introduced to fix the deflection. The 'camber' of glued laminated timber can improve issue of deflection. [IMG 15] shows that beam C after cambered, the deflection reduced from 1.05(in.) to 0.60(in.), which is less that beam A, the uncambered saw timber. Glued laminated timber may allow the structure of the tou-kung become to more slender and project further.

Table 11.3. Maximum allowable load and deflection at maximum allowable load for solid-sawn and glulam beams of equal board-foot content, 24-ft span

Beam Description	Maximum Design Load (plf)	Deflection (in.)
A. No. 1 Douglas fir B&S, Nominal 8 × 18 in., F_b = 1,350 psi, E = 1,600,000 psi, weight = 32 plf	574	0.80
B. 24F-V4 Douglas fir glulam 6.75 × 13.5 in. F_b = 2,400 psi, E = 1,800,000 psi, weight = 22 plf	562	1.68
C. 24F-V4 Douglas fir glulam 5.125 × 18 in., F_b = 2,400 psi, E = 1,800,000 psi, weight = 22 plf	750	1.25
D. 20F-V4 Douglas fir glulam 5.125 × 18 in., F_b = 2,000 psi, E = 1,600,000 psi, weight = 22 plf	626	1.17

Table 11.4. Net sag of uncambered solid-sawn beams and cambered glulam beams of equal board-foot content at equal load

Beams from Table 11.3	Total Load Deflection (in.)	Dead Load Deflection (in.)	Creep (in.)	Net Sag (in.) Uncambered[a]	Net Sag (in.) Cambered[b]
A	0.75	0.25	0.25	1.00	. . .
B	1.61	0.54	0.27	1.88	1.07
C	0.90	0.30	0.15	1.05	0.60
D	1.01	0.34	0.17	1.18	0.67

Note: Net sag for an applied load of 360 plf live and 180 plf dead. Underlines are explained in Section 11.11.
[a]Total load deflection plus creep.
[b]Uncambered beam deflection minus dead load deflection minus creep.

[IMG 14&15] Saw timber and glued timber design load and deflection statistics

[IMG 15] Wood Engineering and the Design of Structures

$$R = \frac{3L^2}{2\Delta}$$

Where:

R = approximate radius of curvature (ft.)

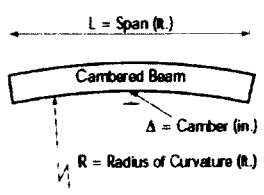
L = span (ft.)

Δ = desired camber (in.)

See Figure 1 for a graphic representation of beam camber parameters.

FIGURE 1

BEAM CAMBER PARAMETERS



[IMG 16] Formula of the Camber

Secondly, the mass production of glued laminated timber is better suited for China's fast construction industry. Traditional handcraft is more personal; however, it is not competitive to the contemporary world of efficiency. Prefabrication and mass productions with high precision has become critical to the Modern construction.

In this thesis, experiments have been completed to produce a traditional tou-kung with the CNC machine [IMG 17&18]. Its purpose is to find out the most efficient way to construct the tou-kung set for mass production. The CNC machine of Carleton University is not designed for right angle cutting which is easier for chisels. As a result, many parts required secondary process in the workshop. The joints of new tou-kung will have to adapt to the new method of production.

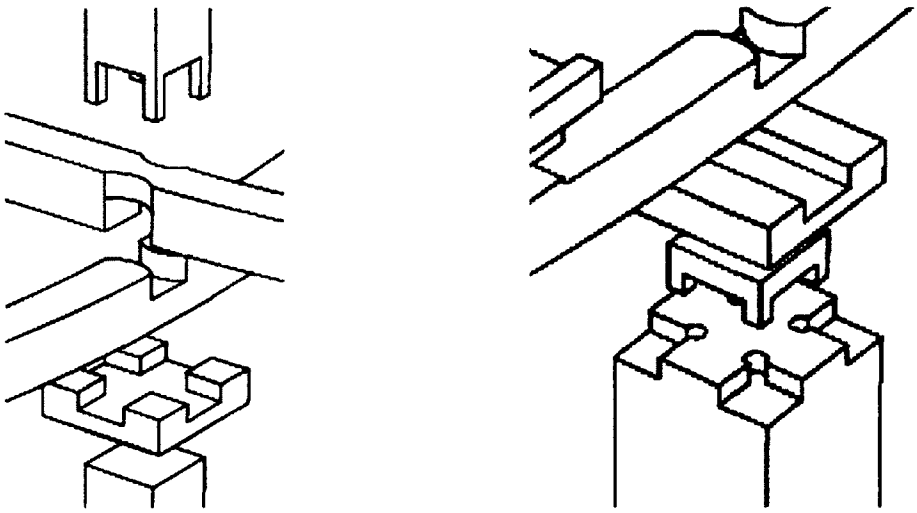
[IMG 17] **Reproduction process with model acquirements.**

[IMG 18] **Reproduction of a Song Dynasty tou-kung**

Lastly, the contemporary world requires a new form and function of architecture. The new technology has allowed varieties of forms to fulfil their functions. In the context of this thesis, tou-kung has given the Chinese traditional architecture "flying eave" because of its cantilevering function capability. Can the new tou-kung keep this function and maximize it?

The new design of the tou-kung aims to achieve 3 goals: 1.Using the new material based on the material's advantages, such as glued laminated timber; 2. Adapting to the mass production; 3. Maximizing the cantilevering function capability.

[IMG 19&20] present the new design of the joints and the new tou-kung.



[IMG 19] The new joints design.

[illegible]

[IMG 20] **The new tou-kung design.**

Part 2 The Chinese vernacular dwellings

The study of Chinese traditional vernacular dwellings cannot be separated from either its historic periods or its geographic regions. Chinese vernacular dwellings have developed over hundreds of years. The earliest record can be dated from Han (3rd B.C. -3rd A.D) [27] [IMG 21], and many of the existing buildings from the Ming and Qing dynasties are still in use, such as dwellings in Yixian County, Anhui [28] [IMG 22]. They greatly vary in style. Over the generations, the Chinese traditional vernacular dwellings came to a standard form: the courtyard house which can vary in styles but has a number of similar elements. It is the vast territory of China that results in different building styles even thought they were from the same period. An indication of this stylish variation in evidence is illustrated in [IMG 23&24][29]. Including [IMG 22], those 3 different style houses are from 3 regions: the houses in [IMG 23] are from Beijing, the capital city, which is a flat land in northern China; the houses in [IMG 24] are from Shanxi, the rural and highland area in the central China; the houses in [IMG 22] are from Anhui, one of the commercial and lake area in the southern China. All these cultural, geographic and climatic factors effect on the styles.

[IMG 21] Tombal pottery model of a Western Han house found near Canton in 1956.

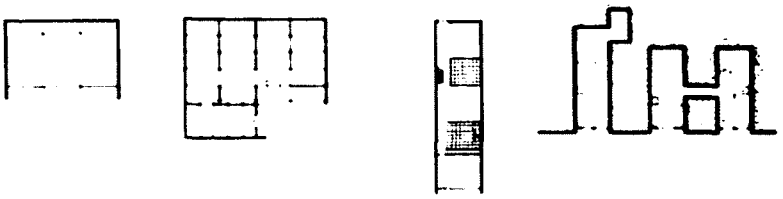
[IMG 22] Hongcun Village, Yixian County ,Anhui

[IMG 23] Residence No. 23 North Third Lane, Xisi, Bejing

[IMG 24] The Jiang Family Mansion at Liujiamao, Mizhi County, Shanxi

This study of vernacular dwellings in China will be focused on the Ming and Qing periods (1368 A.D-1911 A.D)[30]. Prior to this period it is difficult to find sufficient documentations. The residential typology is hard to preserve in the face of progress, especially since wood was the main building material for Chinese traditional vernacular dwellings. Furthermore, the Ming and Qing vernacular architecture is more influential to contemporary architecture. The residential typology changes rapidly since it is the most direct representation of both the period and people's daily life. The styles of the Ming and Qing vernacular dwellings cannot reflect contemporary life in China, but it is the reference of how the next generation of vernacular dwelling will evolve.

Through the research, the classical layouts of Ming and Qing vernacular dwellings are concluded into 9 types [IMG 25] [31]. According to the dwelling characters reflected by territories, China is divided into 13 regions[IMG 26] [32]. Considering both the layouts and the regional characters, it can be categorized into 3 main characters: the modularity of combinations, the multi- generational dwelling, and the inseparable courtyards.

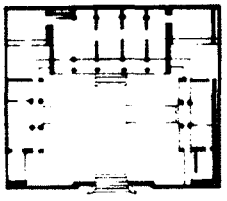


The Lateral-Rectangular Plan

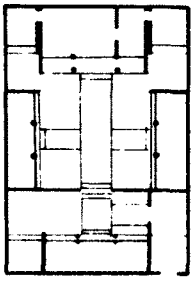
The L-shape Plan

The Longtitudinal Rectangualr Plan

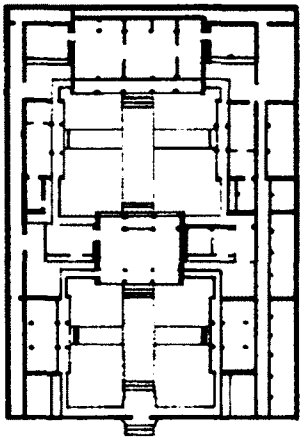
The Cavern plan



The Sanheyuan Plan

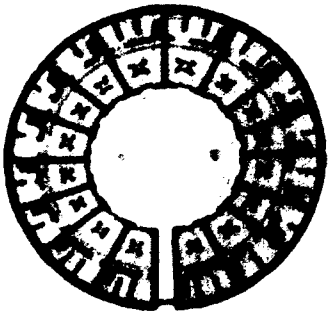


The Siheyuan Plan



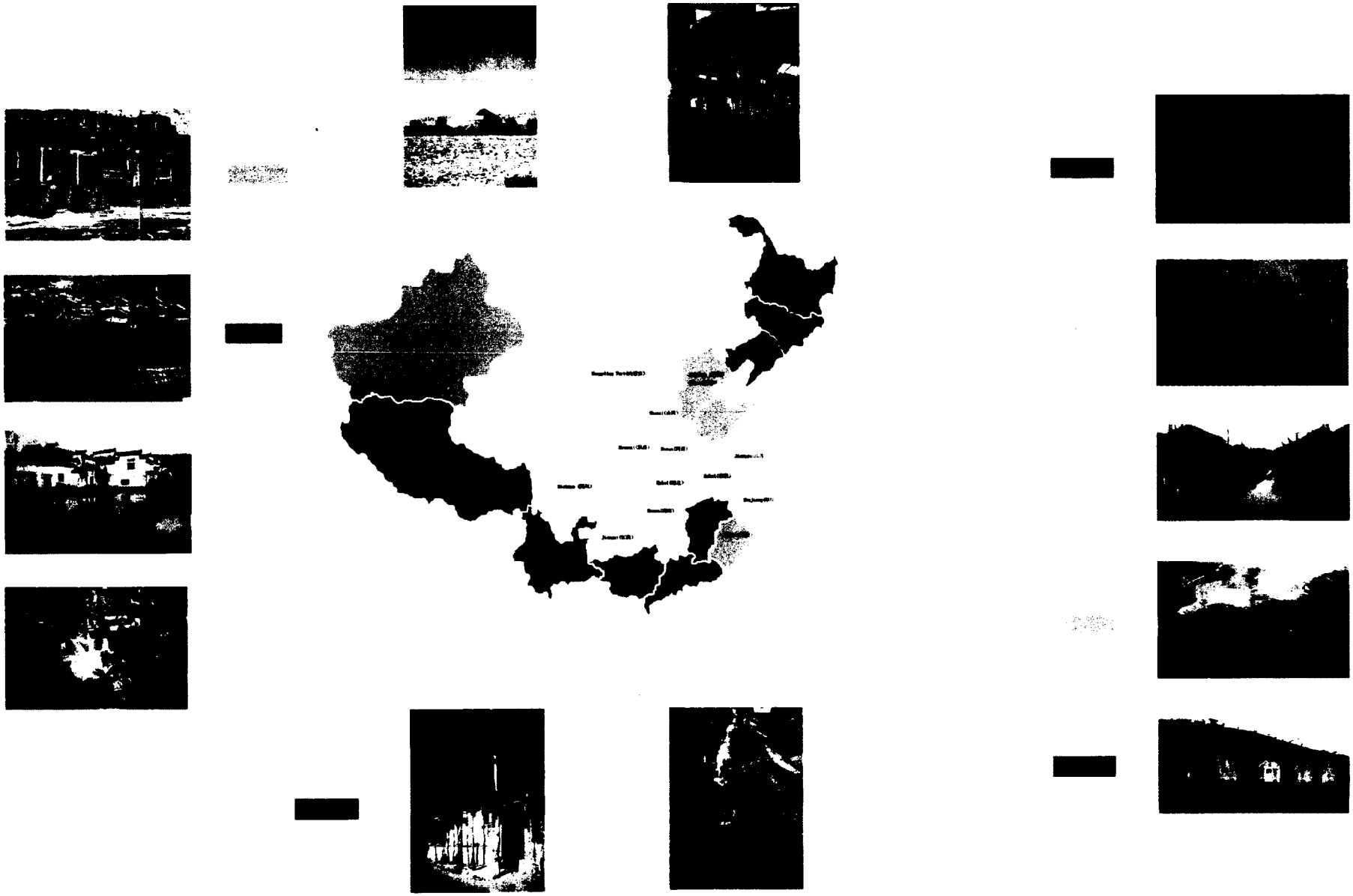
The Mix Sanheyuan and Siheyuan Plan

The Circular Plan



The Ring-Type Plan

[IMG 25] 9 Types of Plans.



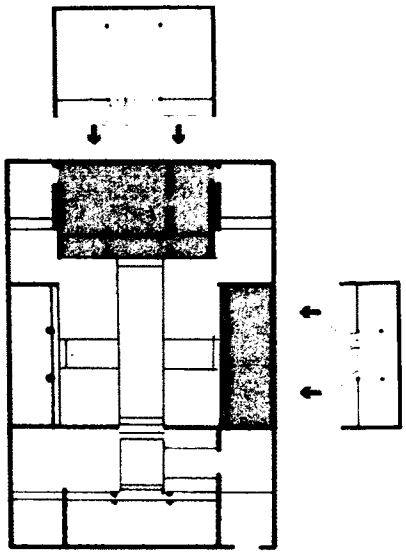
[IMG 26] 13 Rigions of Vernacular dwellings in China

The modularity of combinations

The relationship of dwellings, between a single house and a courtyard house, or even a courtyard house and the town is modular. Among the 9 types of layouts, the lateral rectangular plan and the L plan are the most common. They are generally found in the 13 regions and mostly used in rural area. They usually have 1 to 7 bays , where windows and doors are located on south-facing wall. They can be either open and closed with walls forming private courtyards. [IMG 27], a 3-bays rectangular layout, the central bay is called "Tang", which is the living and reception room; the side bays are called "Jinjian", which are the bedrooms [33]. This is the most basic form of layouts.

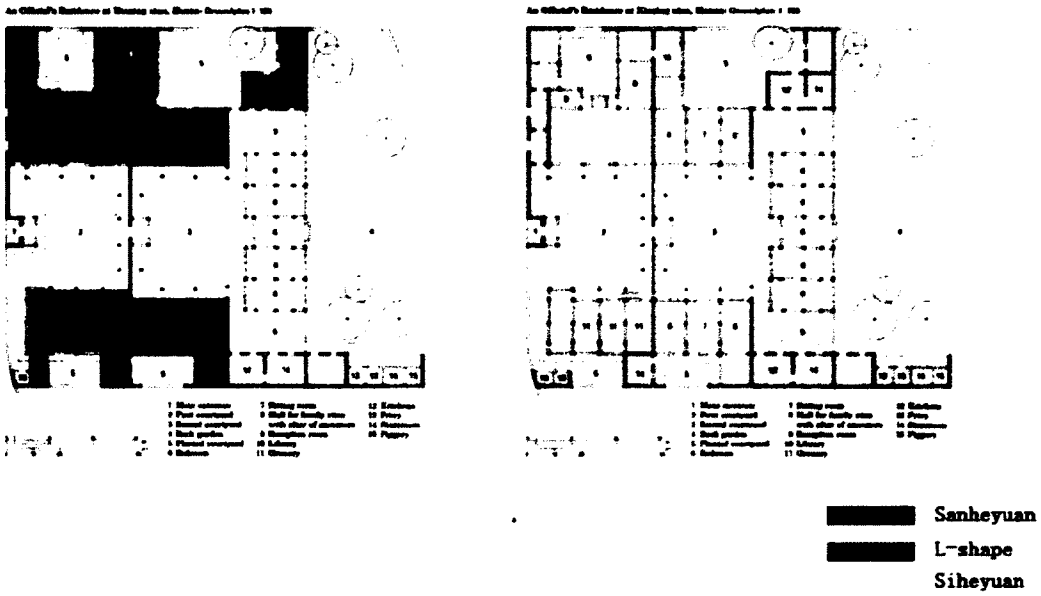
[IMG 27] Three-bay house in Xinlong County, Hebei

The other most common layouts are Sanheyuan (meaning having buildings on all 3 sides of the courtyard) and Siheyuan (meaning having buildings on all 4 sides of the courtyard). The Sanheyuan is found more common in rural areas. Siheyuan is found more commonly in urban areas. Both of their plans are symmetrical, and can have 3-storey, depending on the region. Their doors are located on the southwest or northwest corner, and the living sections are on the northern side [34]. As it is illustrated in [IMG 28], Sanheyuan and Siheyuan are composed of rectangular and L plans. Additionally, when larger scale residence is required, Sanheyhuan and Siheyuan can be assembled to become mixed courtyard houses. IMG 29 shows an official's residence in Xinning Xian, Hunan. Each Sanheyuan and Siheyuan takes the form of the "rectangular plan" and composes more complicated courtyard houses due to the modular mode of construction. The Sanheyuan and Siheyuan used in this mixed-courtyard house still carried their courtyard house character. In the same principle, a modular town can be constructed [IMG 30]. The biggest advantage of the modularity is the flexibility. It can suit different demands and is flexible to expand or shrink as required. It would also keep the overall appearance of the town unified. The modular dwelling character is a remarkable solution for the traditional dense dwellings in urban context.

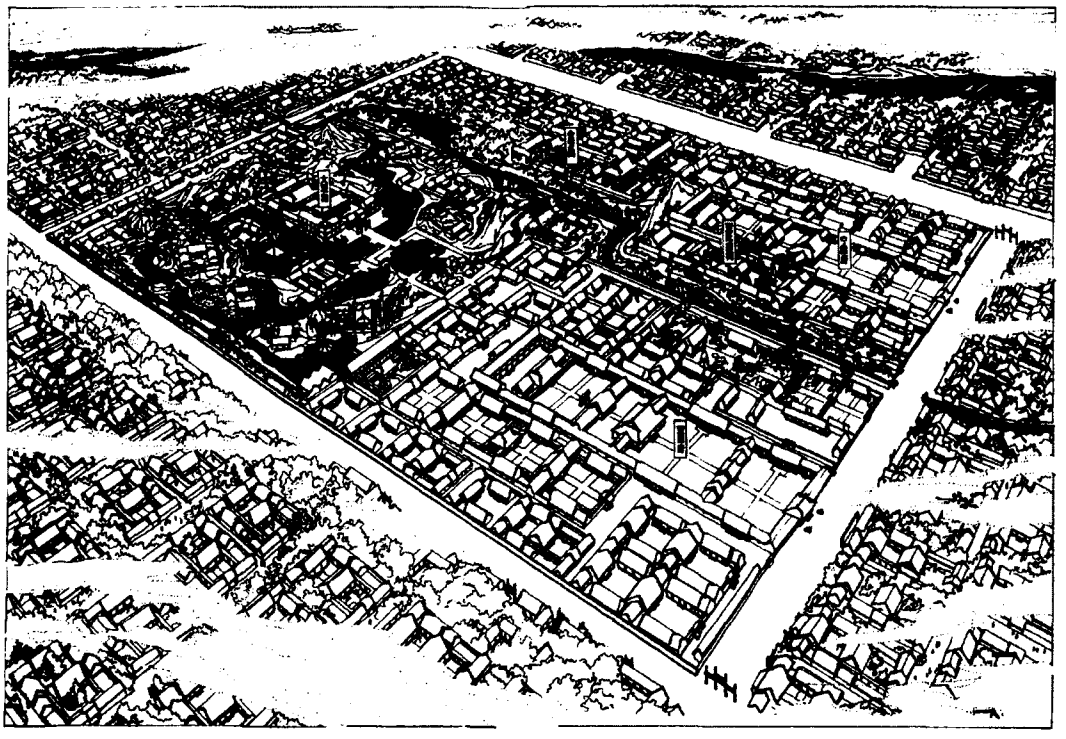


Siheyuan

[IMG 28] The Combination of a Siheyuan



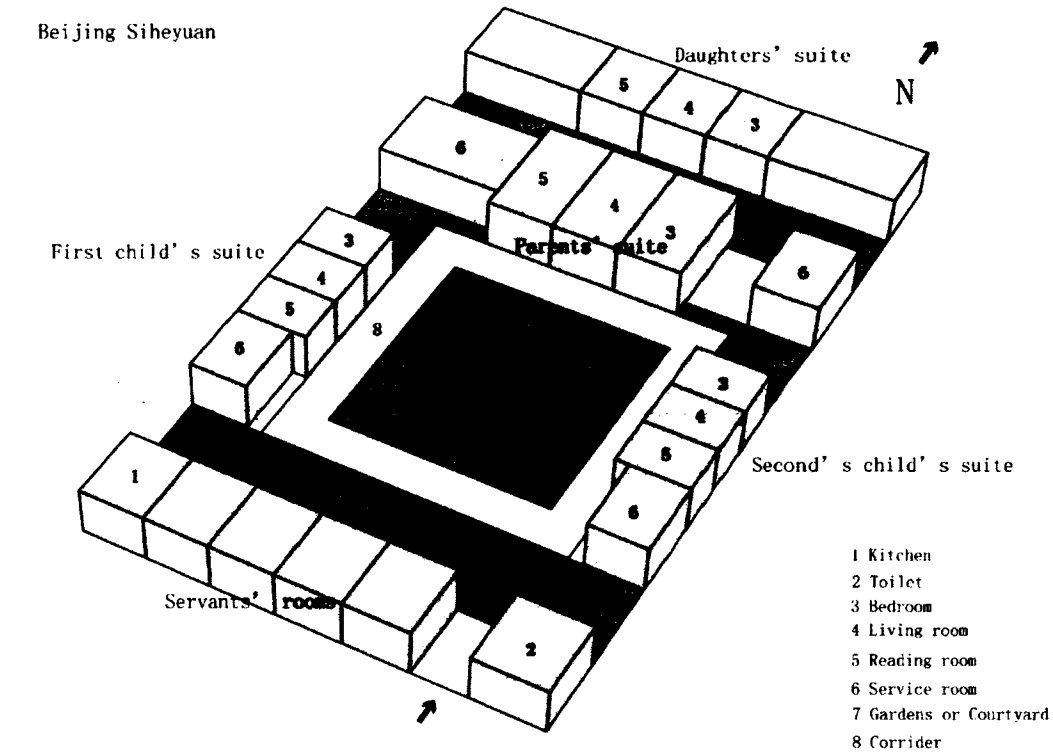
[IMG 29] A Mixed-Siheyuan : a official's residence in Xinning xian,Hunan

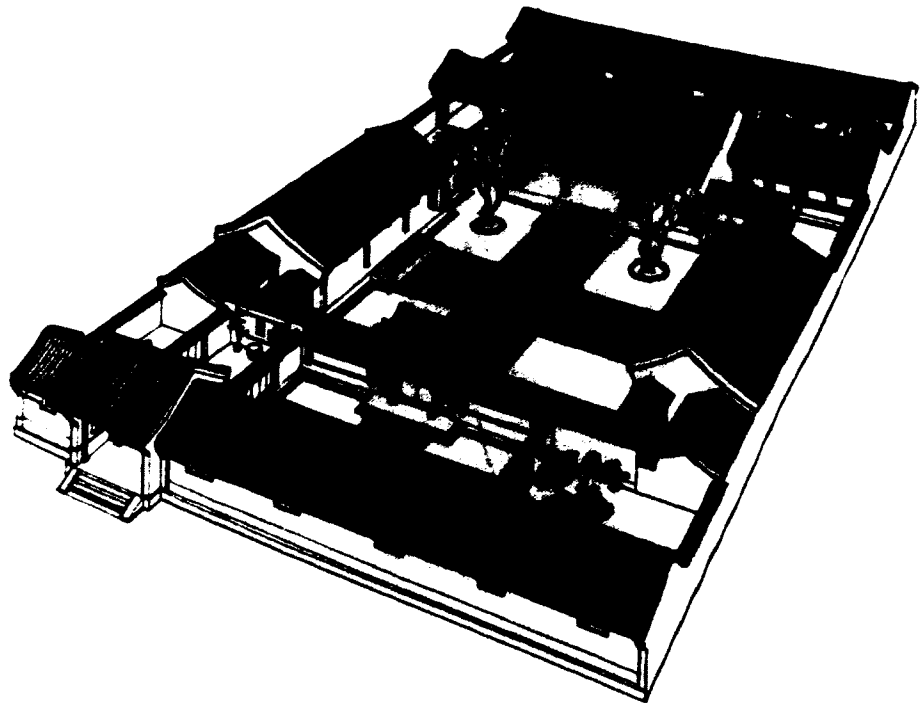


[IMG 30] **A restored drawing of Nanjing in Ming and Qing period from a Chinese novel: The dream of Red Chamber**

Multi- generational dwellings

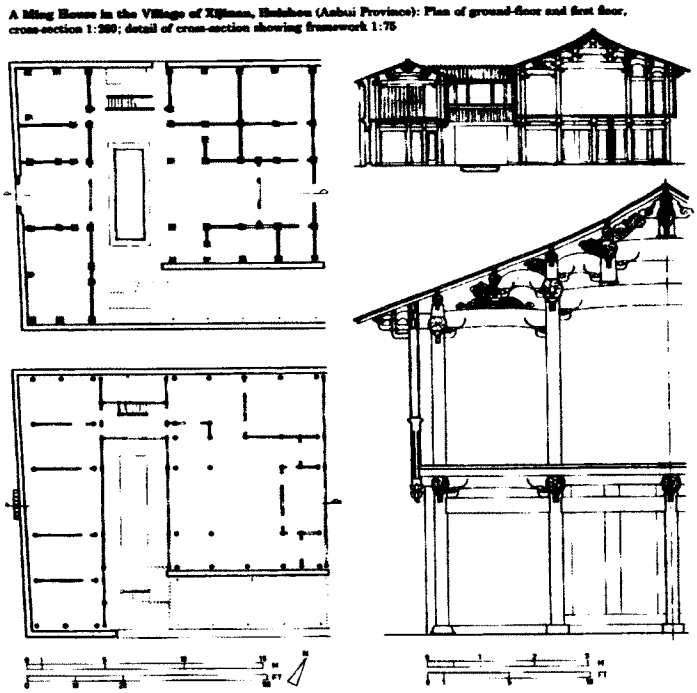
In the Chinese tradition, the dwelling is designed to house a multi-generational family. Based on Confucian principles, all the family members have to live under one 'roof'. This includes the parents, their unmarried children, and their married sons with their families. Married daughters leave their families and live with their husbands and families of their own. In one house, there might be up to 4 generations with their servants [35]. This family structure results in the hierarchy of the dwellings arrangement. In a Beijing Siheyuan[IMG 31], the courtyard house, which the parents dwells in,is located on the central axis and facing south; the sons' houses are located on the side; the daughters' houses are located at the very north of the courtyard house, since they are not permitted to meet strangers and will leave their families after married; the servants' rooms are located in the north as well[36]. The family hierarchy is obvious: parents are the head of the family and have the authority to look over their children; the sons have the right to stay with the family and join the family council; In the Ming house,example, a two–storey courtyard house in the village of Xijinan, Huizhou, Anhui province [IMG 32], the servants' rooms and reception room are on the first floor, the ancestor's room is on the axis of the courtyard house on the second floor, which is the largest room and has a higher ceiling than the other rooms. The parents' room is behind the ancestor's room. The children' rooms are on the side of it [37]. This tradition is the main cause for the modularity of courtyard dwellings. The flexibility makes the adjustment of the family possible.



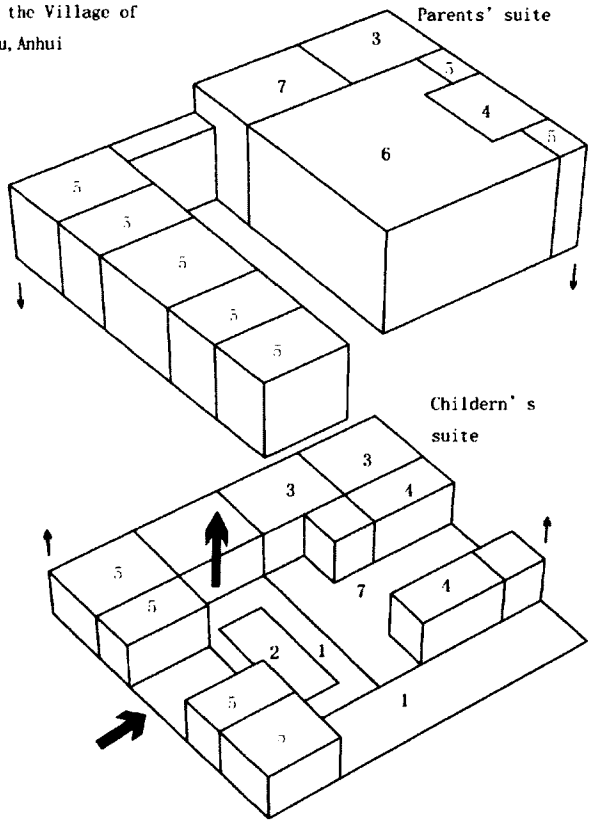


[IMG 31]**A Siheyuan in Beijing**

A Ming House in the Village of Xijinan, Huizhou (Anhui Province): Plan of ground-floor and first floor, cross-section 1:200; detail of cross-section showing framework 1:75



A Ming house in the Village of Xijianan, Huizhou, Anhui



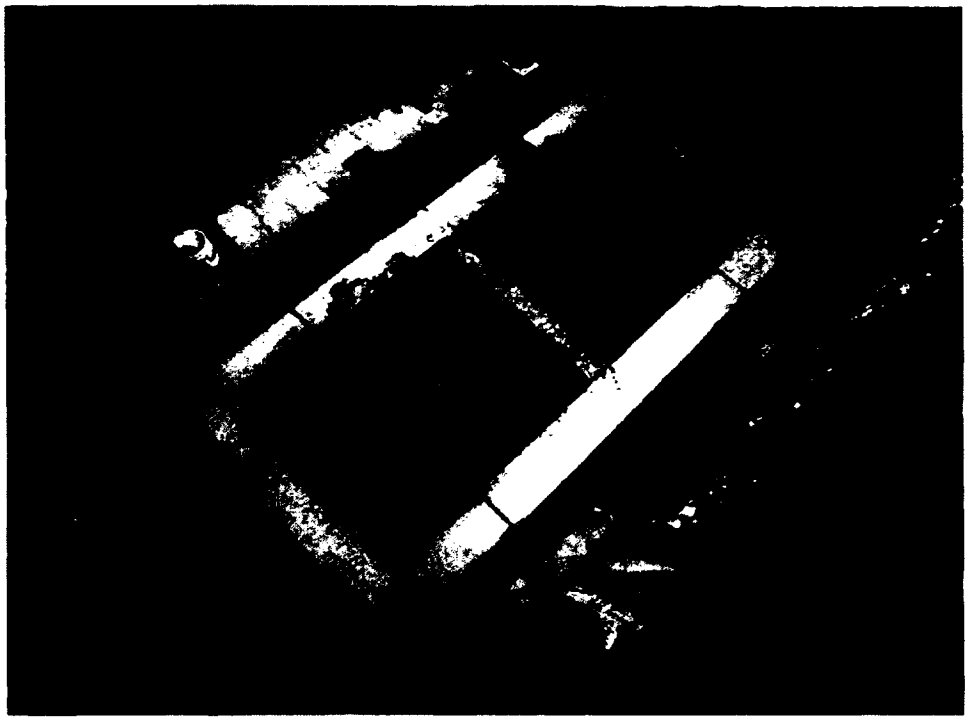
1 Courtyard
2 Pool
3 Bedroom
4 Living room
5 Storeroom
6 Ancestors' room
7 Reception room

[IMG 32] **A two-storey courtyard house in village of Xijinan, Huizhou, Anhui province**

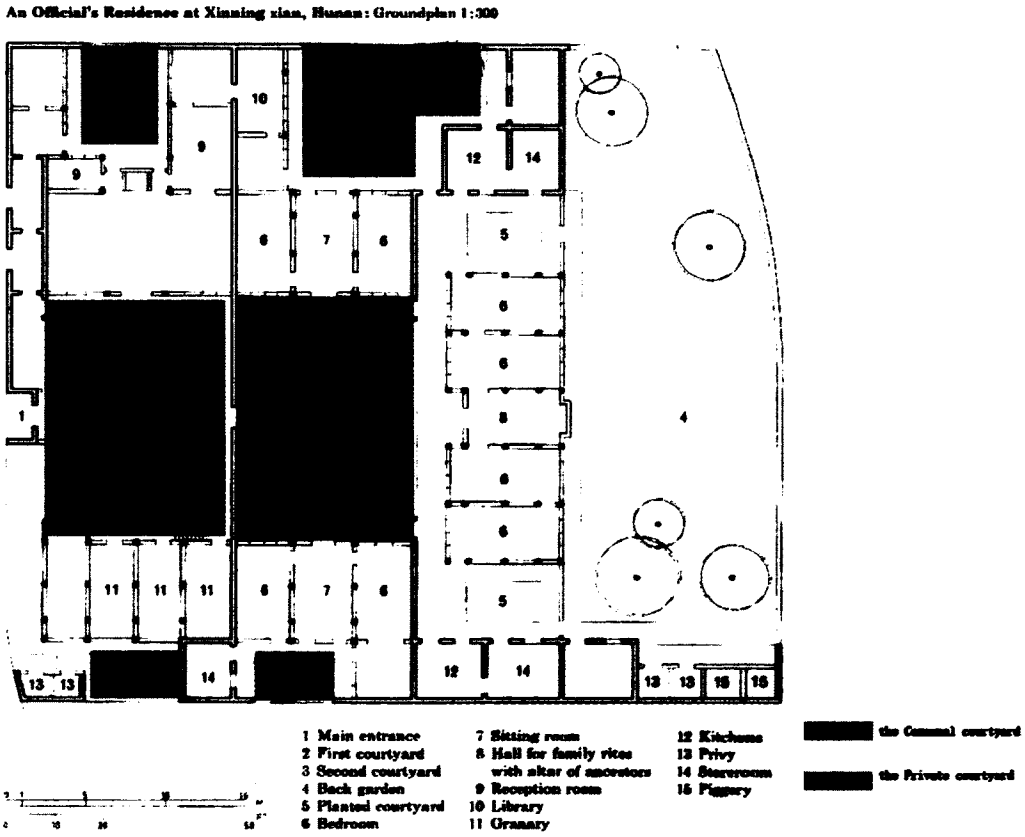
The inseparable courtyards

The courtyard is inseparable from the residence in Chinese traditional dwellings. In the Chinese culture, the relationship with nature is critical. The poems and paintings about nature and garden design are highly valued in Chinese culture. The romance of nature is directly reflected in the garden design in China. For example, the Suzhou garden is an imitation of nature and the owner's imagination. It is a microcosm in a defined space, the owner's personal world. No matter what scale the garden is, the idea has never changed. The garden requires seclusion from the world outside. It is a refuge place for leisure, conversation and mediation. At a larger scale, the garden becomes a park , such as Beihai Park in Imperial City in Beijing [IMG 33]; at a minimum scale, it could be an open air space with a pool surrounded by local stone pavements covered by mosses [IMG 34]. For the basic courtyard dwellings, the courtyards have two types. The first one is the communal courtyard. , which is still considered a refuge from the outside world, but a shared space for the family. The second one is the private courtyard, which is even private from other family members, only open to the owner of the courtyard house. As illustrated in [IMG 35], the communal courtyard locates in the centre of mixed-siheyuan, it is the circulation core as well. The courtyard houses on both sides of the communal courtyard all have their own private courtyards. Instead of connecting to the communal courtyard, these private courtyards are hidden behind the houses. The second type of courtyard is never open to the outside world, but to nature. In the house in Hangzhou [IMG 36], it is located on a hill [38]. The courtyard on the northeast corner is not closed by wall, but opened widely to the woods. Nature, to the Chinese, is just as close as a family member.

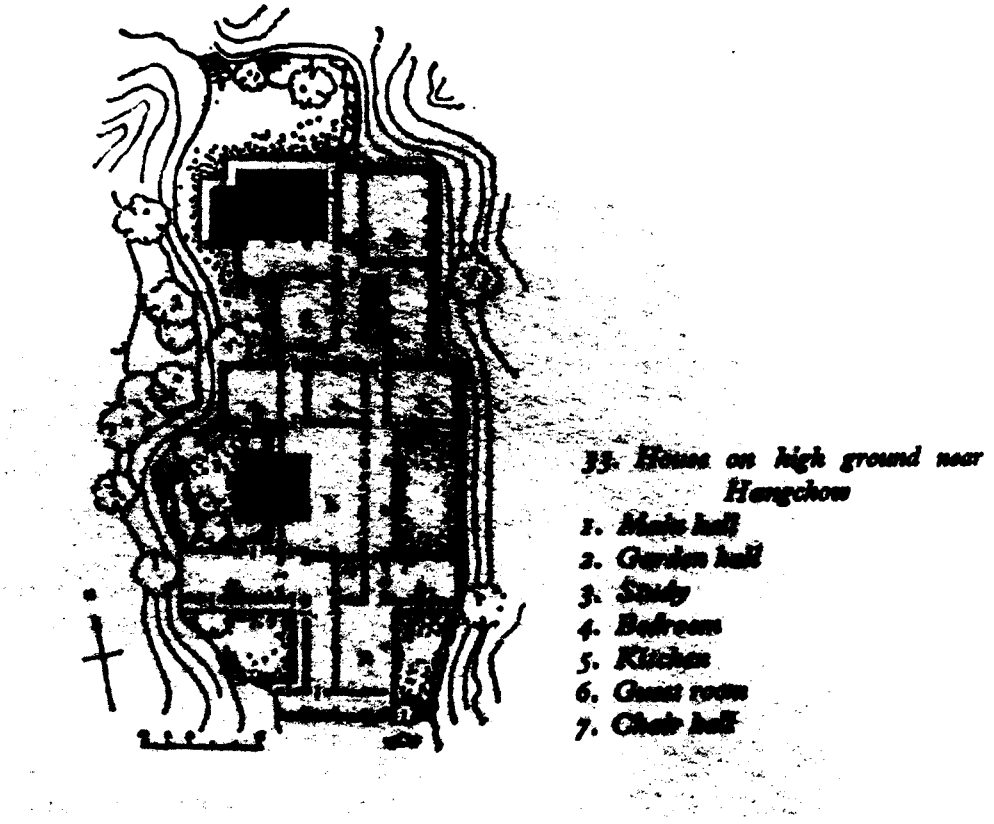
[IMG 33] **Beihai Park in Imperial City**



[IMG 34] A courtyard pool in the residence of Jiangxi,



[IMG 35] A Mixed-siheyuan : a official's residence in Xinning xian,Hunan

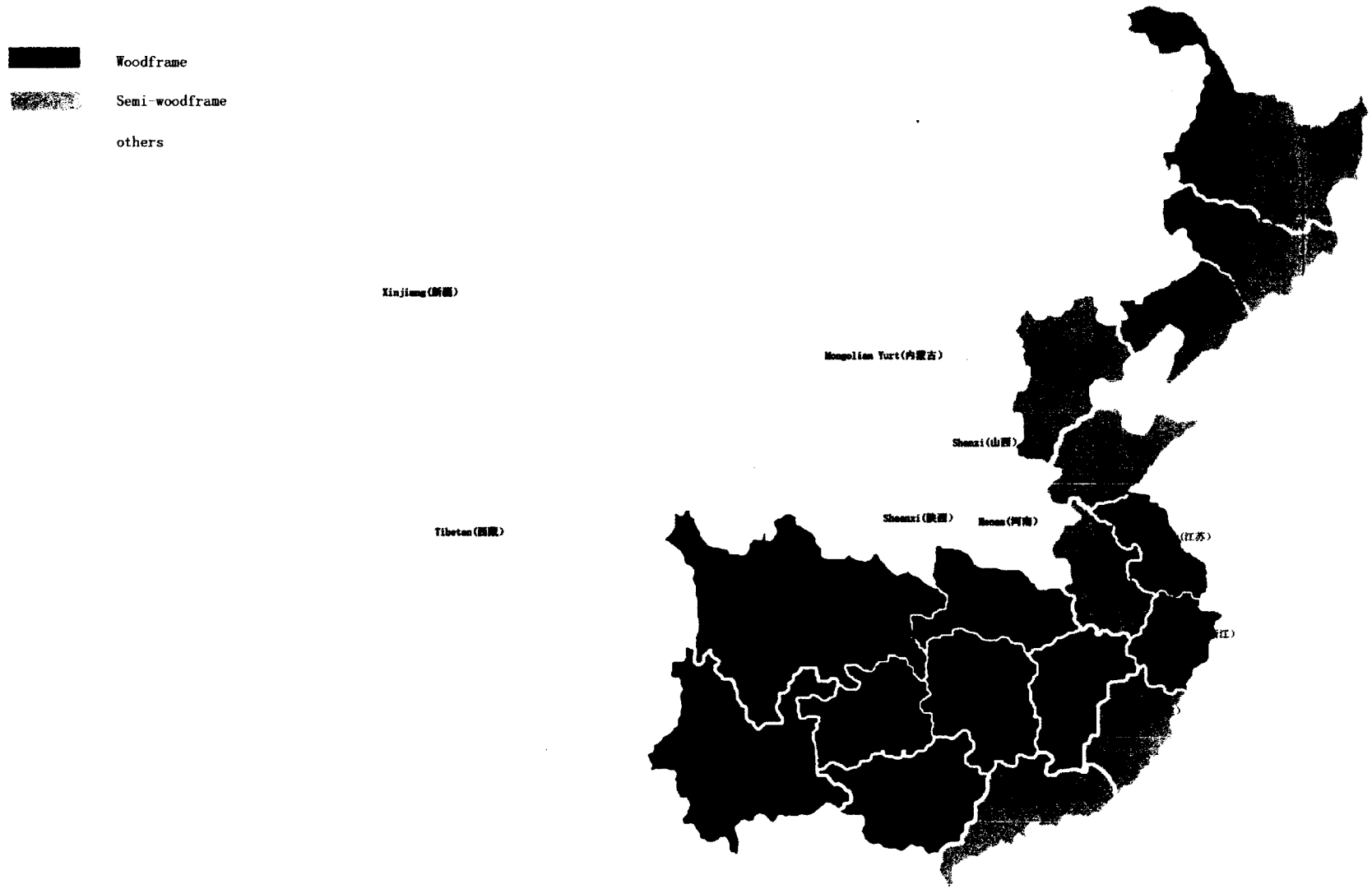


[IMG 36]The house located on a hill in Hangzhou

Part 3 Design strategies

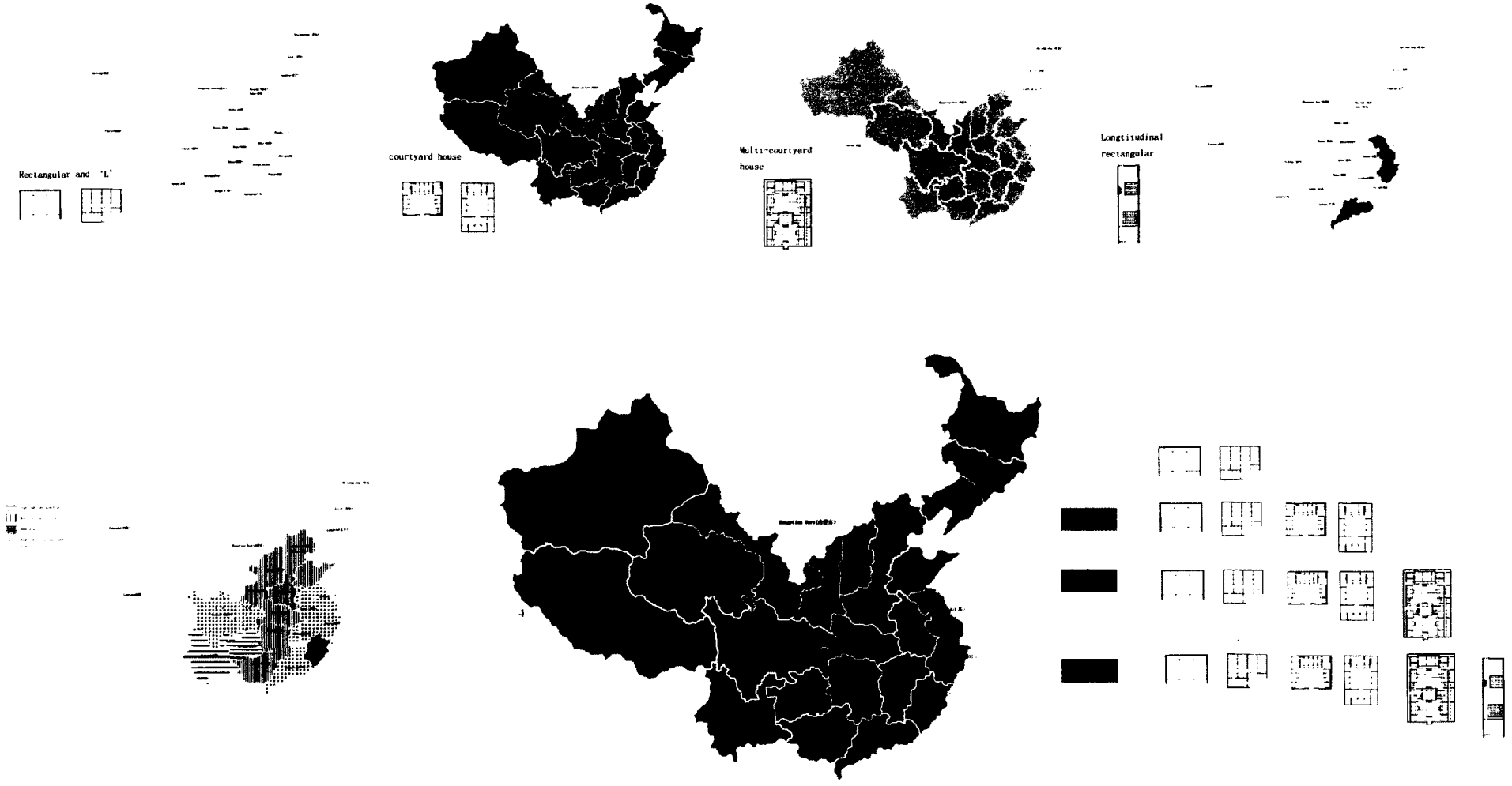
Site selection--Chongqing:

In viewing the different typologies and researching the various regions in China, Chongqing was chosen as the site to experiment with the a new residential typology. It is a unique model perfectly suited for this project for 4 important reasons. Firstly, the vernacular dwellings are wooden structure as illustrated in [IMG 37]. Secondly, the vernacular dwellings in Chongqing cover most of the Chinese common vernacular dwelling characters, such as the typical layout which illustrated in [IMG 38]. Thirdly, Chongqing has variable landforms, especially hills and rivers. Many traditional Chinese vernacular dwellings styles accommodate the variable landforms. And lastly, the growing population of the city makes high density residential development.



[IMG 37] **The analysis of types of structure related to the location**

The structure types of vernacular dwellings are concluded into wood frame, Semi-wood frame and others (such as mud, masonry and bamboo). Chongqing belongs Sichuan Province which is in the wood frame zone



[IMG 38] **The analysis of types of plans related to the location.**

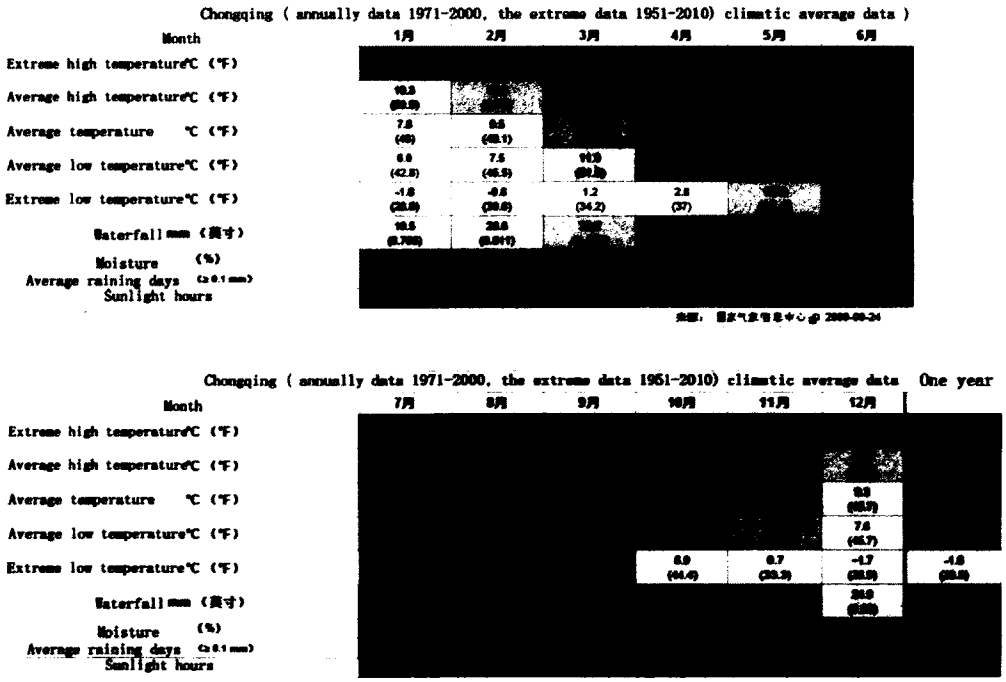
Choingqing includes 5 typles of layouts. addtionally, Chongqing covers 3 different landforms

Chongqing's local characters.

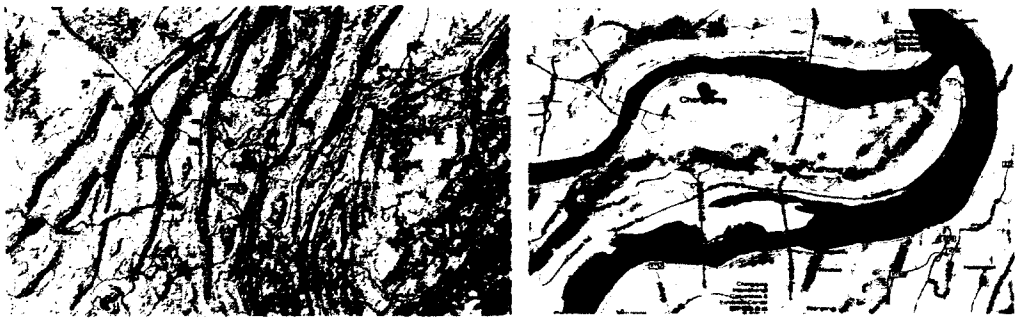
Geography, Climate and Population:

The climate in Chongqing is humid with a high temperature. According to the chart [IMG 39], the average temperature in the summer is up to 26-29 degrees, and the average rainfall is up to 1300-1500mm. In addition, Chongqing is foggy. Typically fog covers the city approximately 104 days a year. Other days are very sunny.

Chongqing is called the city of hills and rivers. The area is a part of the Karst Landform. Hilly area takes 84.5% of the entire city [38]. [IMG 40] Long River and Jialing River flows cross the urban area and join in the central business district. According to the population census in 2008, it has 28,900,000 permanent residents and 3,633,200 migrates [39]. The total city area is 84,000 square kilometre and the average density is 378 person /kilometre square. However, the main population concentrates in the western habitable plain[40]. For example, in the downtown region, such as the Yuzhong Distract, the density is up to 27,391 person /square kilometres square.



[IMG 39] The annual temperature and rainfall report chart.



[IMG 40] The topographic map of Sichuan Province and Chongqing City

Vernacular dwelling characters in Chongqing:

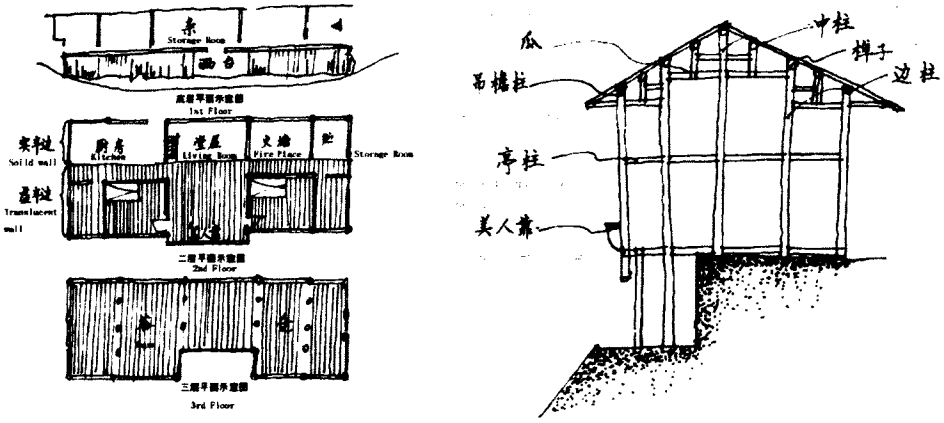
Chongqing is one of the largest cities in Sichuan Province. The vernacular architecture is mainly wooden structure with courtyards. The vernacular dwellings adapt to the hilly characters and the dense population. The most famous vernacular dwelling type is call "Diaojiao" house, or 'the house with legs'. It has advantages in adapting to the landscape and increased ventilation in such a humid climate. [IMG 41&42]

[IMG 41&42] Chongqing "Diaojiao" houses on slopes and on the riverside

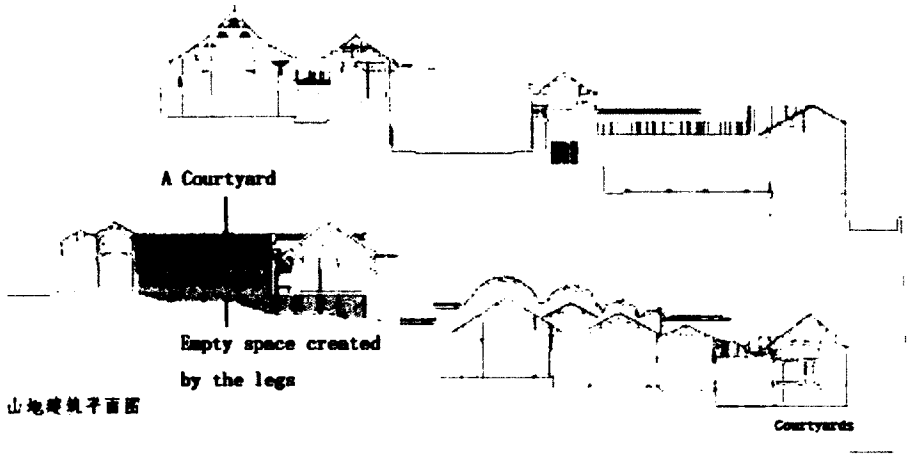
The basic Diaojiao house has 3 bays and 3 levels: on the main level, the living room is in the centre, the kitchen and storage are on the sides. [IMG 43&44] The lowest level is for animals and the top level is for bedrooms [41].

It is the same principle as the Siheyuan, it is also a traditional residential typological character in Chongqing that 4 Diaojiao houses will form a court yard

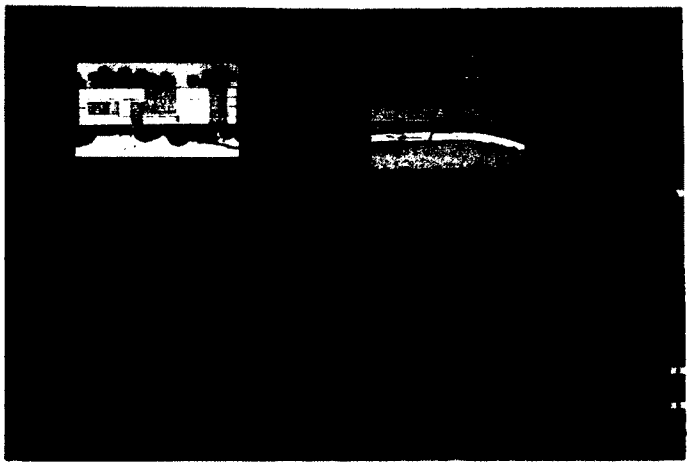
As illustrated in [IMG 45&46], instead of flattening the landscape for the foundation, the legs lift up the platform to build to the higher ground level. The empty space underneath of the building becomes an opportunities for ventilation and circulation.



[IMG 43&44] The plan and the section of a Diaojiao house.



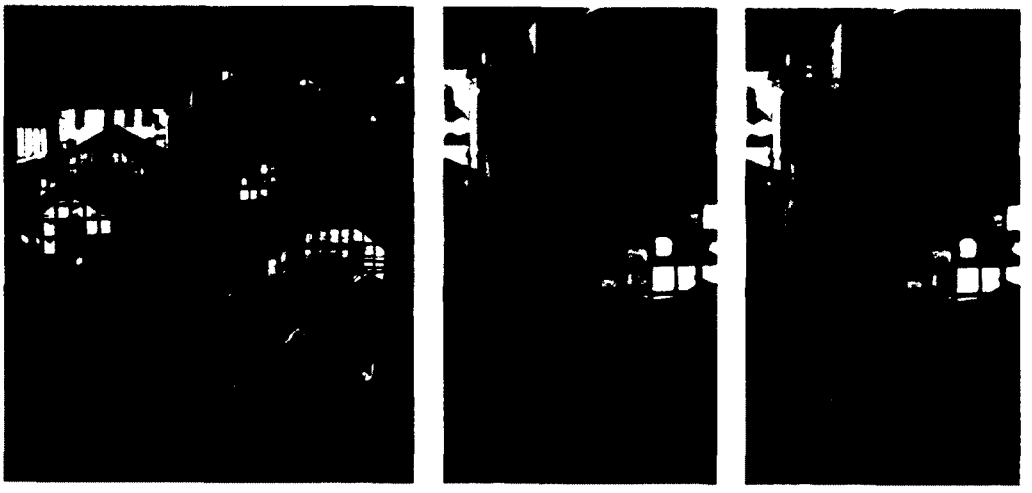
[IMG 45] A section of A Diaojiao house with a courtyard



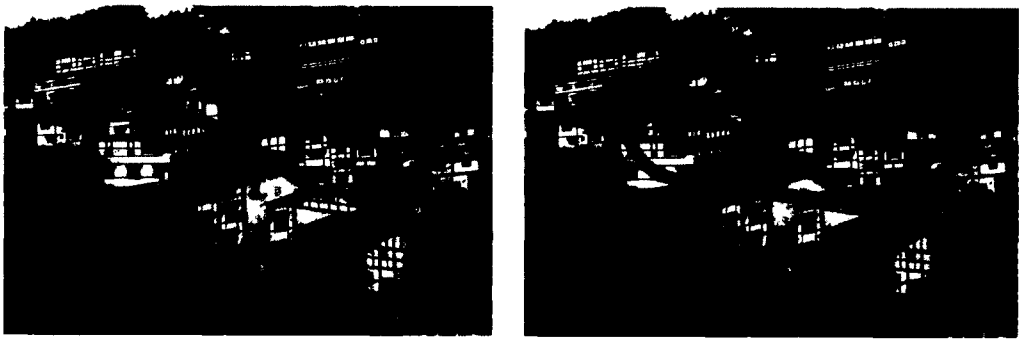
[IMG 46] A Diaojiao house with a courtyard

Chongqing is also characterized for its unique city layout, which adapts to the hills. In Chongqing, the traffic influences the layouts because of the hilly terrain. In a village, the road is placed first to avoid the steep slope, and then the buildings are constructed to follow the road. Due to the extreme high temperature it is undesirable to have large amounts of sunlight enter the

room. The roads are laid out to allow flexible orientation of the buildings. The dwellings along the road sides develop into shops at the street level. To protect the street from the strong sunlight and rainfall, the eaves of dwellings extend to form canopies [IMG 47&48] . Eventually, it develops into a system: in hilly area, layouts of dwellings follows the road and buildings provide cover to protect the traffic from the weather.



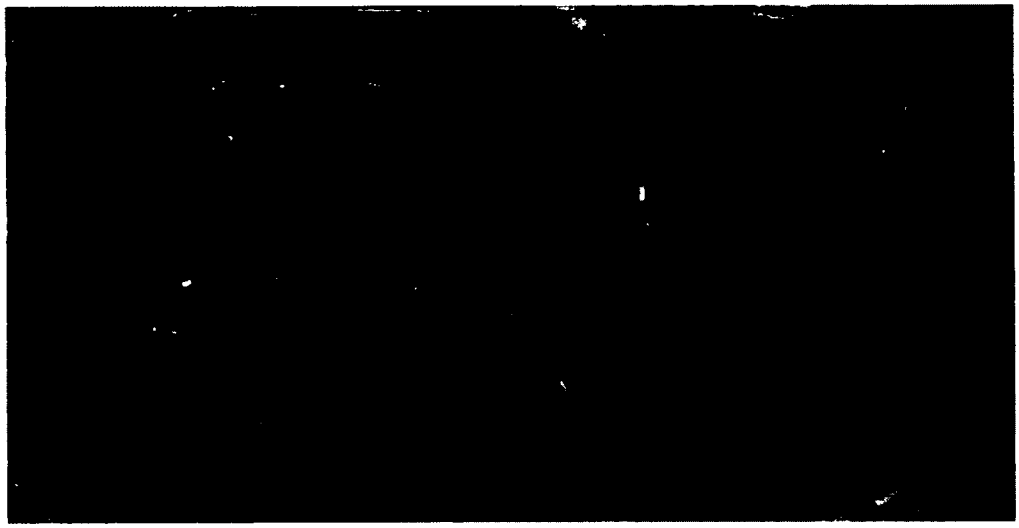
[IMG 47] **Longzhong town, Sucking.**



[IMG 48] **Hongyandong ,Chongqing, Sichuan.**

Site analysis

The site chosen is in Yuzhong district of Chongqing downtown.



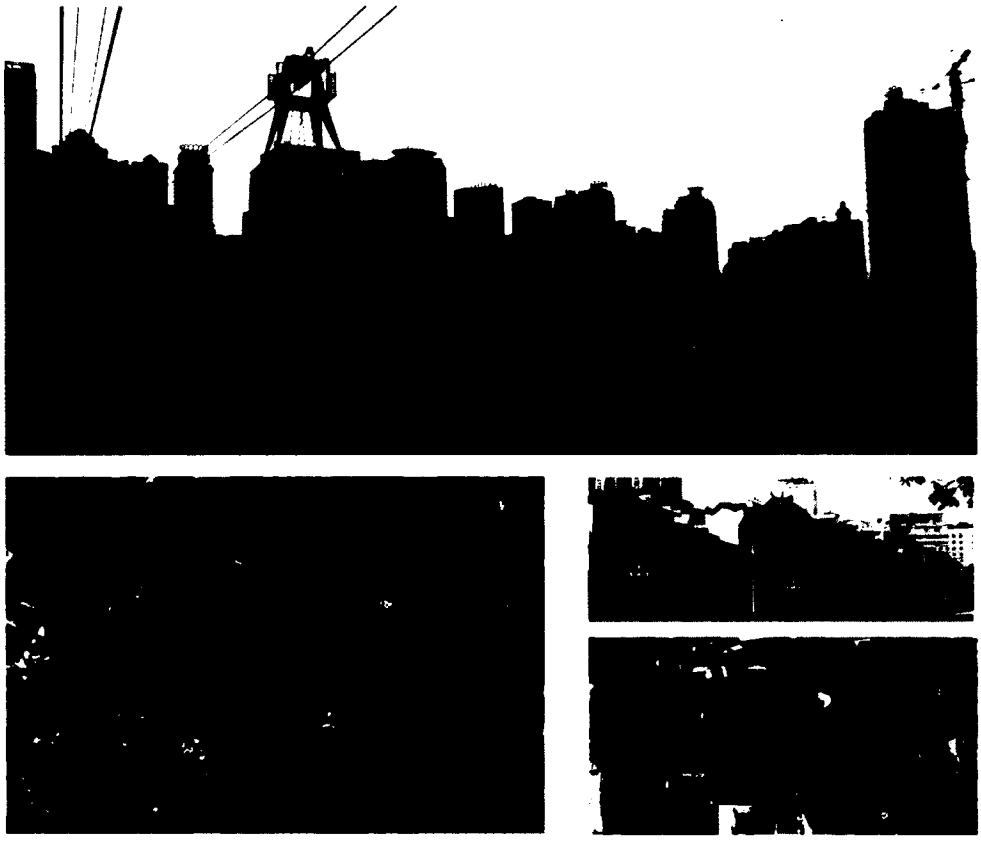
[IMG 49] Satellite map of Yuzhong District ,Chongqing

The site chosen is in Yuzhong district of Chongqing downtown.

It is chosen for 3 major reasons:1. The historical background; 2. The mid-rise and low-rise zone of downtown area; 3. The hilly landscape.

1.Historical background.

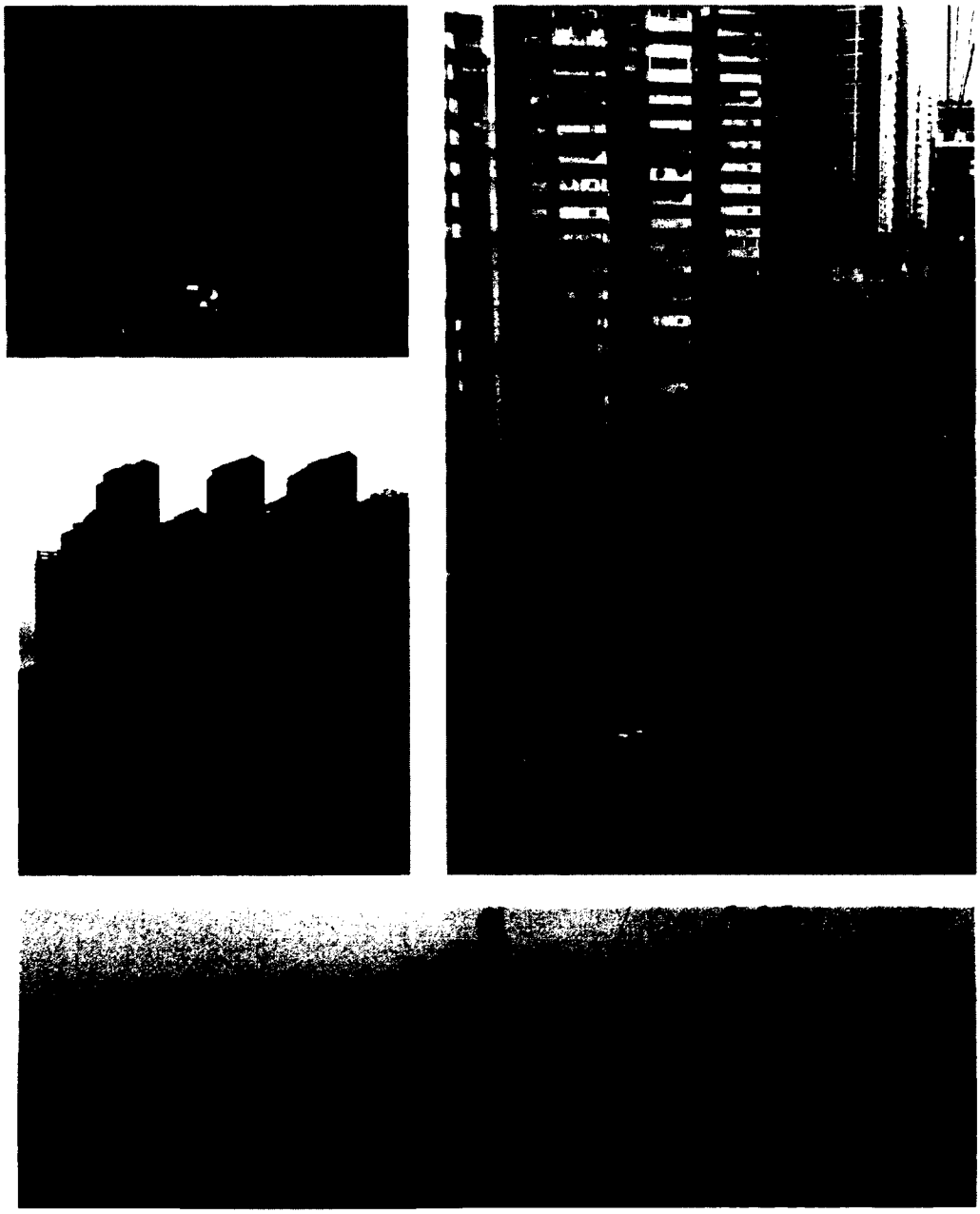
The site chosen is located next to Huguang Club. Huguang Club is a historical business club founded in CA. 1759, Qing Dynasty [42]. It is a well preserved historical building complex and still in use. It is a historical reminder of the historic city. The surrounding residences are 3-6 stories old apartments. These buildings generally follow the historical architectural footprint, in this case the courtyard vernacular dwellings.



[IMG 50] Satellite map of Yuzhong District ,Chongqing

2.The mid-rise and low-rise zone of downtown area

Chongqing is a vertical city, especially the Yuzhong District. The chosen site is one of the few zones still filled with mid-rise and low-rise buildings. The site is already under stress of being replaced by high-rise apartment. To keep the historical architectural footprint, and the diversity of a city skyline, it is necessary to preserve the mid-rise and low-rise zone.

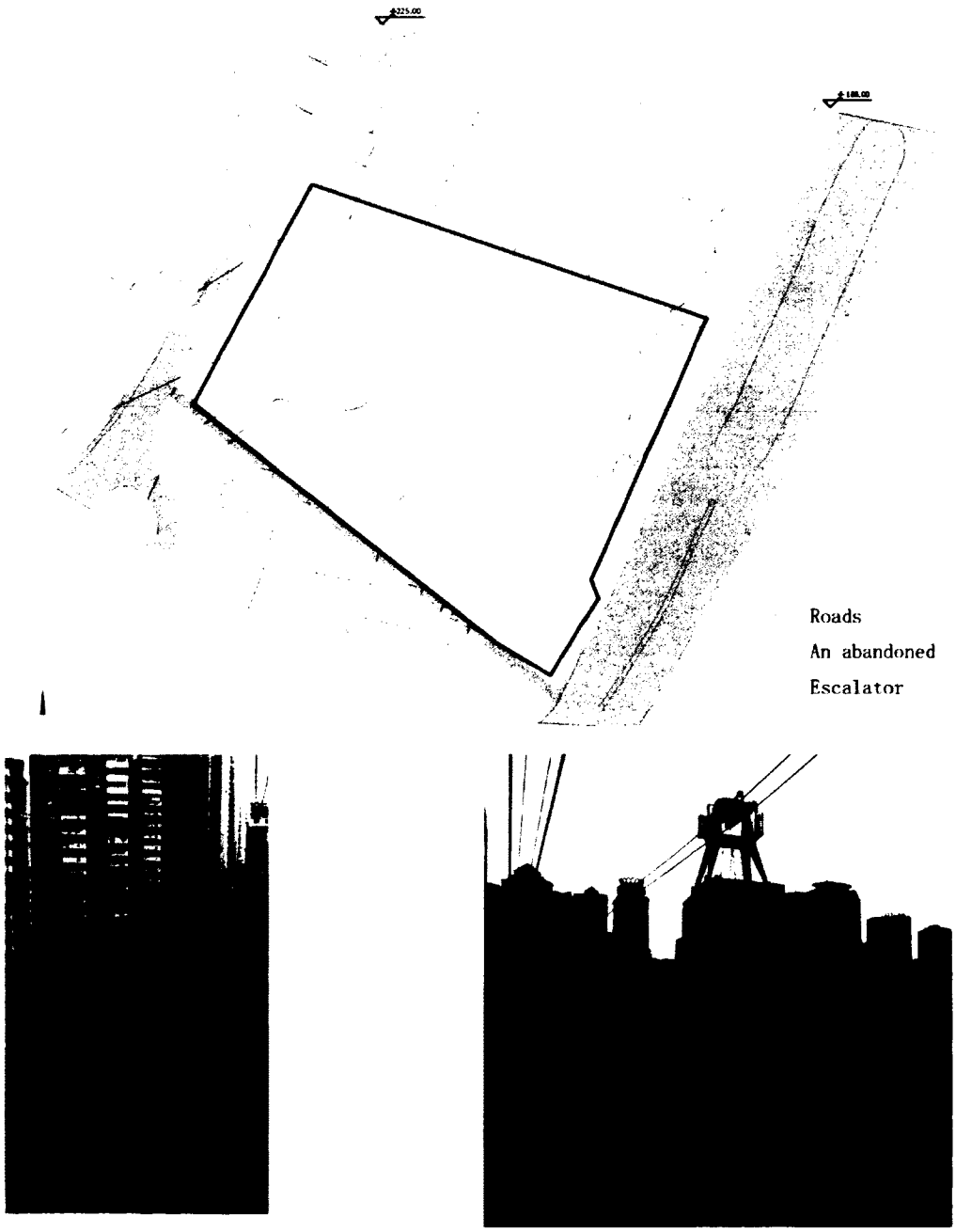


[IMG 51] The high-rise apartments and the city skyline.

3.The landscape.

The site is located on a slope. It is a representative typography of Chongqing vernacular dwelling. It is a proper location to apply the proposed design.

The existing traffic relies on foot. There is no vehicular accessibility. There is a lift connecting the higher ground, and the old escalator through the site is now abandoned.



[IMG 52] The attitude and traffic conditions of the site.

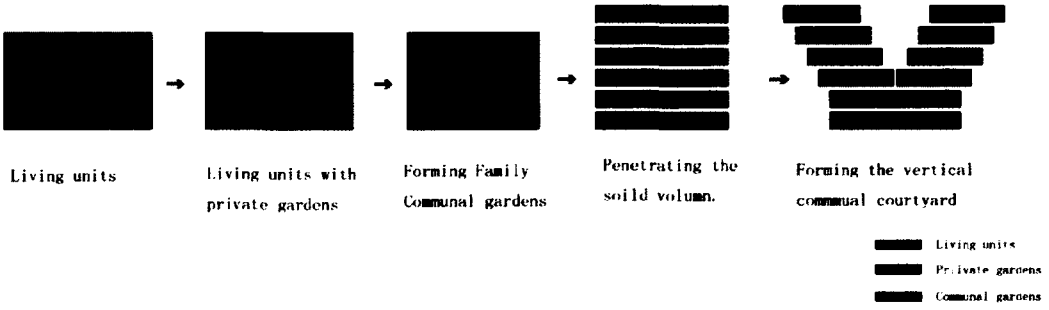
Design process

Design concept:

The design should respond to the characteristics of traditional Chinese architecture, especially the local vernacular dwellings. In addition, it should adopt and improve the contemporary living condition in Chongqing. The capacity of new designed residences may not exceed the existing apartments; however, it has to exceed the average population density of Yuzhong District., which is 27,391 person /square kilometres and provide better social living environments, such as multi-generational living units and the private gardens.

This design facilitates 6 features. The most important feature of all is to restore the multi-generational living while retaining high population density. The other 5 features are: 1.Using wood as main construction; 2. Providing private gardens; 3. Respecting the vernacular dwelling style as 'Diaojiao" house; 4. Shading of street; 5. Using new tou-kung to aid the structure system.

The design concept is derived from the characters of tou-kung: the cantilever, and the layers .Tou-kung is a distinct symbol of Chinese traditional architecture and the structural characters of tou-kung are practical for residences. The cantilever is adaptive to the landscape; the layers penetrate the solid volume of buildings.



[IMG 53] The concept development.

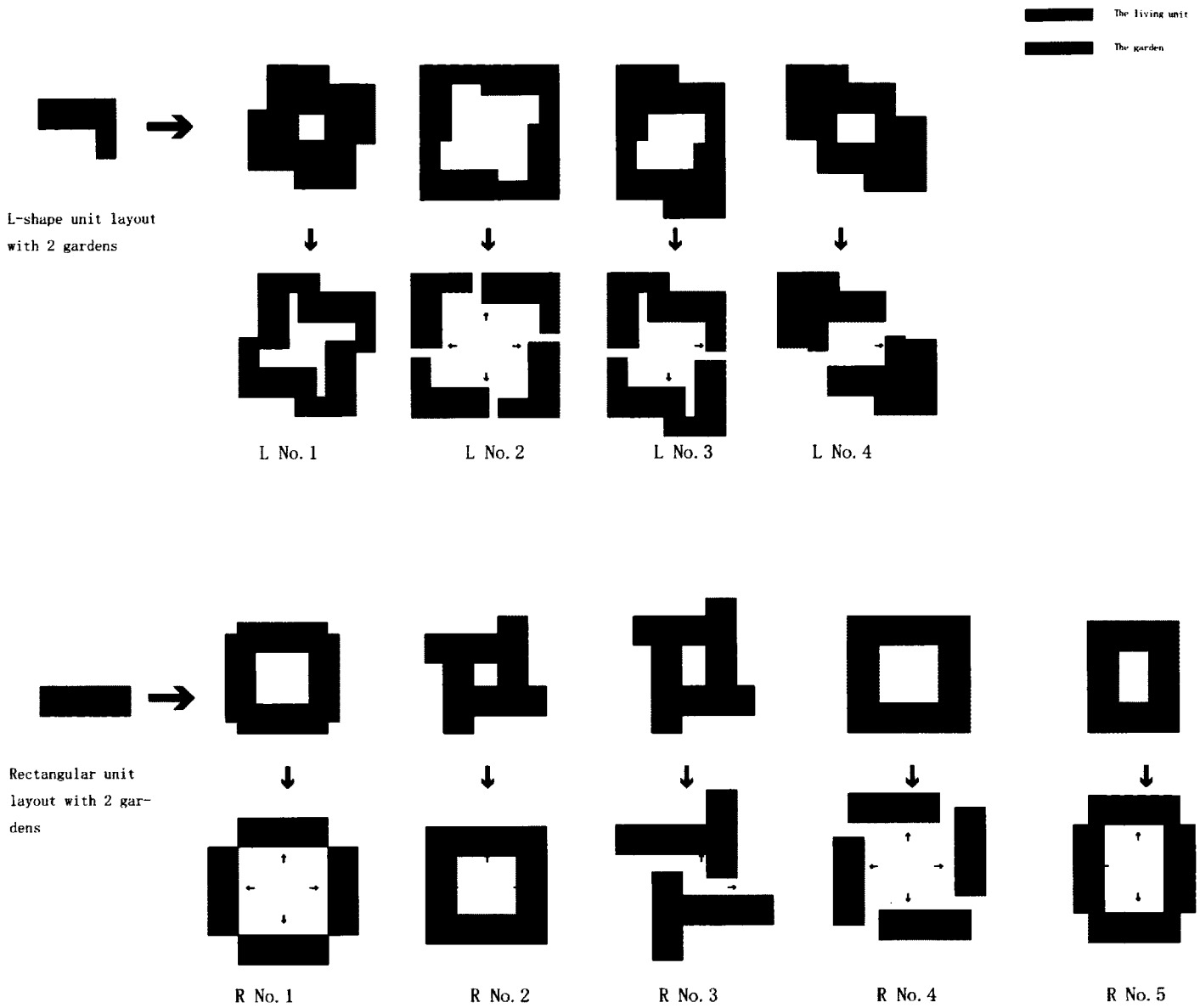
[IMG 54] Mockup models on a slope and the top view and side views .

Common vernacular dwelling characters consideration

The 3 general characters of Chinese vernacular dwellings are, the modularization, , the multi-generational dwelling, and the inseparable gardens. Each unit is designed as a modular. , and each is considered as a layout with 2 private gardens. It guarantees every unit with a private garden for a 3-person family, even after the unit is combined with another unit.

Modular study

The modular study tested the rectangular layout and L-shape layout, the most basic layouts of traditional Chinese vernacular dwellings as the modular unit of the design. The study aims to find out the best combination which guarantees two gardens for each unit, has a balanced form, uses space efficiently and has as many connected gardens as possible for communal gardens while the layout expands outward.



[IMG 55] The combination study of the modular unit.

The L-shape layout No.1 was finally chosen as the modular unit because it fulfils all the requirements, at the same time it forms the most efficient sized courtyard (every unit has 2 gardens and the courtyard can be used for circulation and as a light well) and can be combined to expands outward, there are 4 connected gardens.

The basic modular is composed of a 3-bays living unit and two gardens. The dimension derives from the article –China's old dwelling. It records that " *the width of each jian(a bay) in north China generally ranges between 3.6 and 3.9 meters*" and " *the depth of bays is usually also deeper in southern china, reaching as much as 6.6 meters, those in the north rarely exceed 4.8 meters . The width of jian in the south is usually a little smaller than those in the north*" [43]. As estimated from those records, traditionally the common grid in the southern area China can be around 3.9m x 6.6m and 4.2m x 6.6m. In this design, each bay is chosen to be 4.2m x 6.3m

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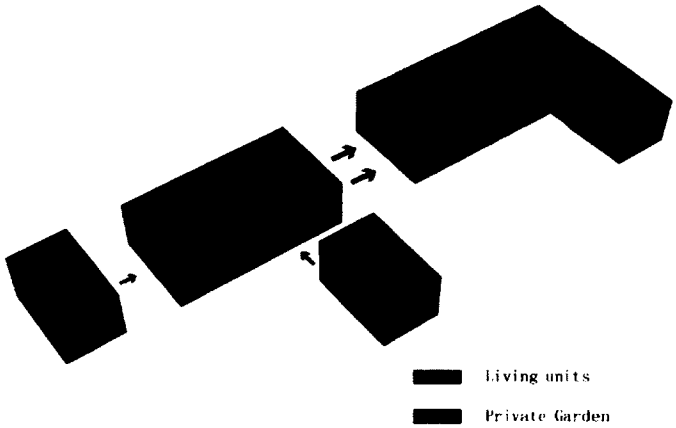
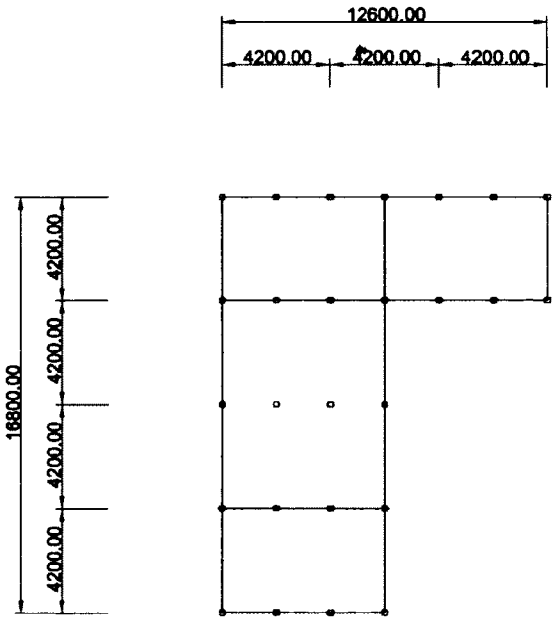




The basic modular dimension

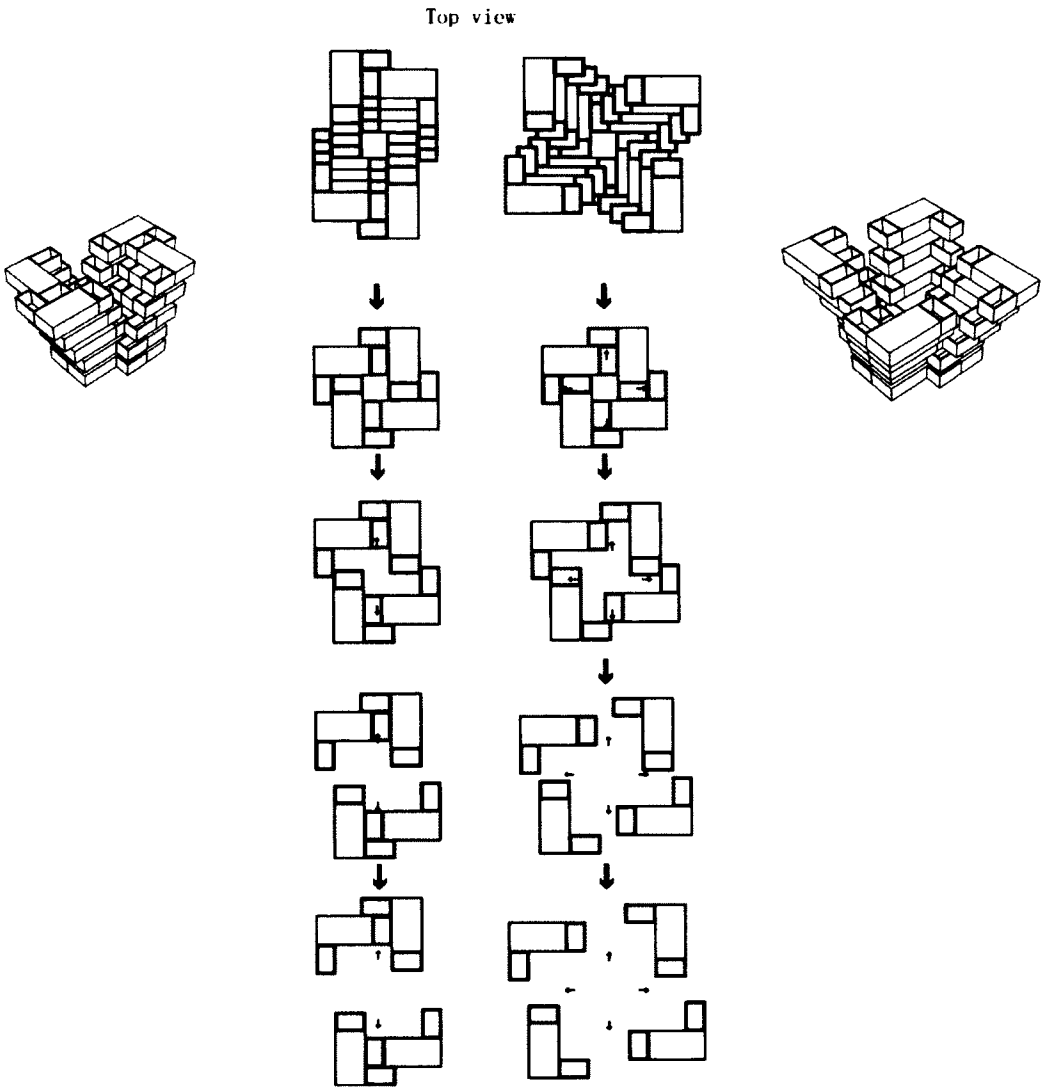
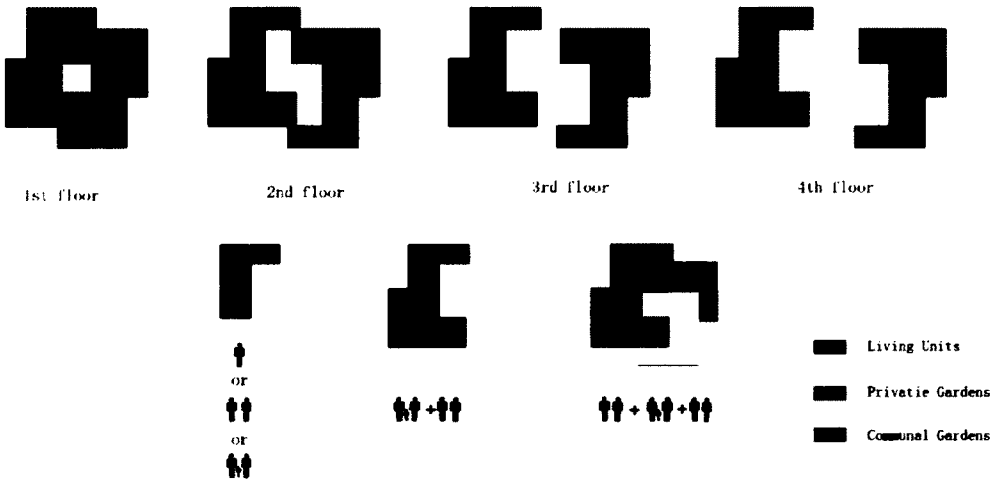


FIG 57 Two combinations formed by L-shape modular units

Contemporary family structure consideration

Contemporary family structure has dramatically changed since Ming and Qing dynasties. According to the research from the 1980's, most children , including sons, move out from parental home where as only the daughters moved out in the past, not only the daughters as in the past. The research also indicates that usually parents will live with the eldest child [44]. However, as the one child policy is affective, the family structure has become smaller. It wouldn't be wrong to assume that one couple will have to take care of parents on both sides in the future. As a result, the design will have to be flexible for future situations, such as a new type of mult-generatianl dwelling, a young couple living with parents from both sides. The design approach is to create a connection, which is a communal garden, between each single unit. The connection makes the units flexible to be assembled for different needs .{IMG 58}

Comparing to the past, the contemporary dwellings breaks the restrictions of multi-generational dwellings. As a result, the courtyard should have a further meaning: a connection of neighbourhood. A vertical communal courtyard for the neighbourhood is formed for the purpose.

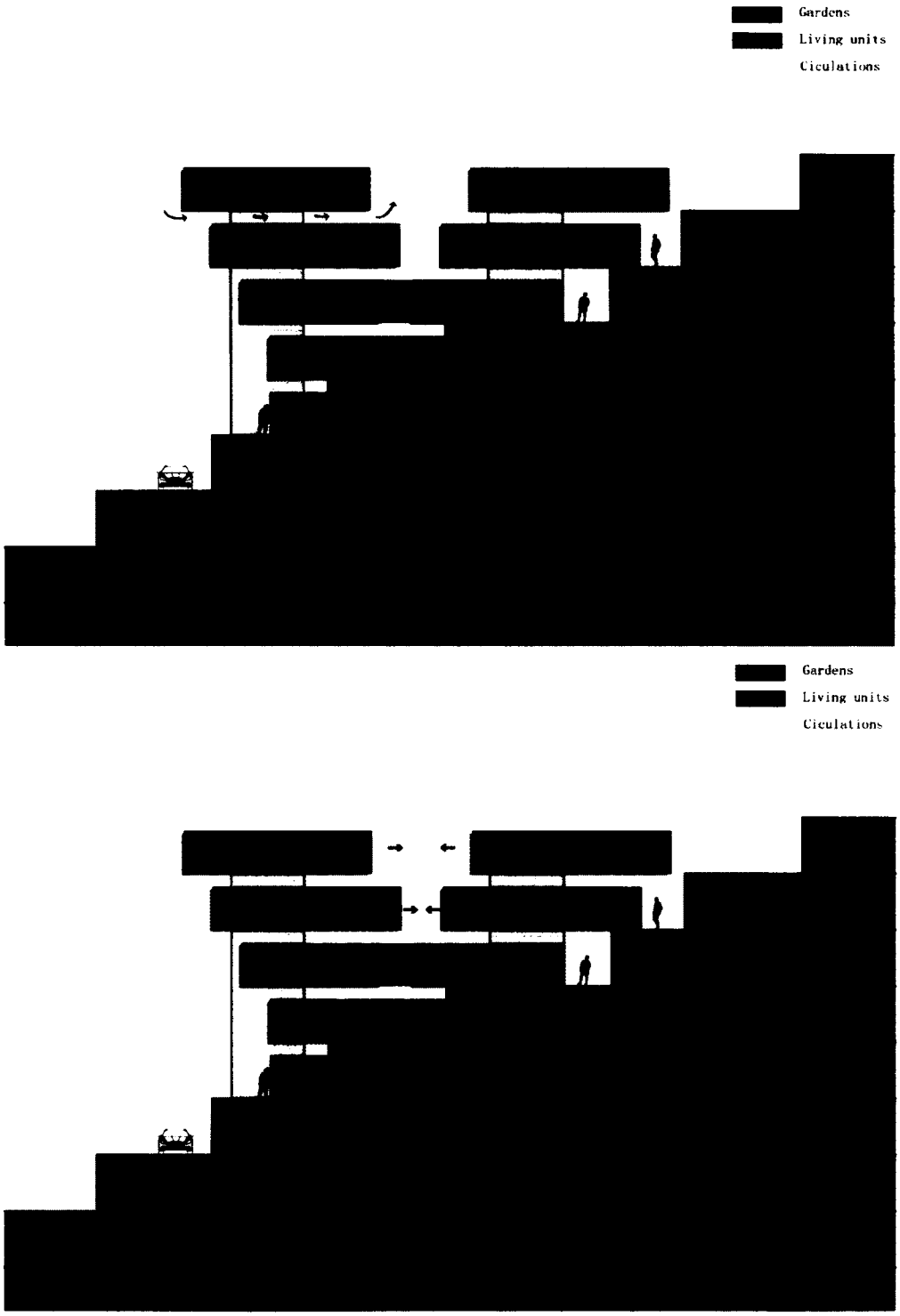


{IMG 58} Combinations for different needs

The geography and climate characters consideration

Chongqing is a hilly area. The traditional vernacular dwellings used the 'leg' to adopt to the terrain and the space create by the 'leg' promoted natural ventilation in the humid climate. The layout of the dwelling follows the landscape and the traffic Instead of using 'legs',. The new design matches this characters with its cantilever, a feature of tou-kung. The cantilever uses the vertical space more efficiently and also adopts the slope without unnecessary excavations. In addition, the cantilever makes the building itself a canopy to shade the surrounding area. At last, the space between layers gives a good opportunity for ventilation and light penetration. It is a new way to interpret the 'leg' and the tou-kung .[IMG 59&60]

[IMG 59] **Shading**



[IMG 60] **Vertical communal gardens and ventilation.**

Garden design

Chinese garden, as the thesis mentioned, is 'an imitation of nature and the owner's imagination, a microcosm in the defined space and the owner's personal world.' While designing a Chinese traditional garden, there are compositions to follow and garden elements to be considered.

The composition of a garden intends to avoid giving a complete idea of the garden in a single view. The journey through the garden is expected to be surprising and the garden is expected to be discovered and enjoyed by stages.

The elements in Chinese garden include natural elements such as mountains and streams, trees and flowers, and architectural elements

1.The mountains and streams:

The mountains are usually imitated by rocks. The streams are usually imitated by ponds. It also emphasizes the mysterious head stream of the pond to indicate the endlessness of the mini-world [45]

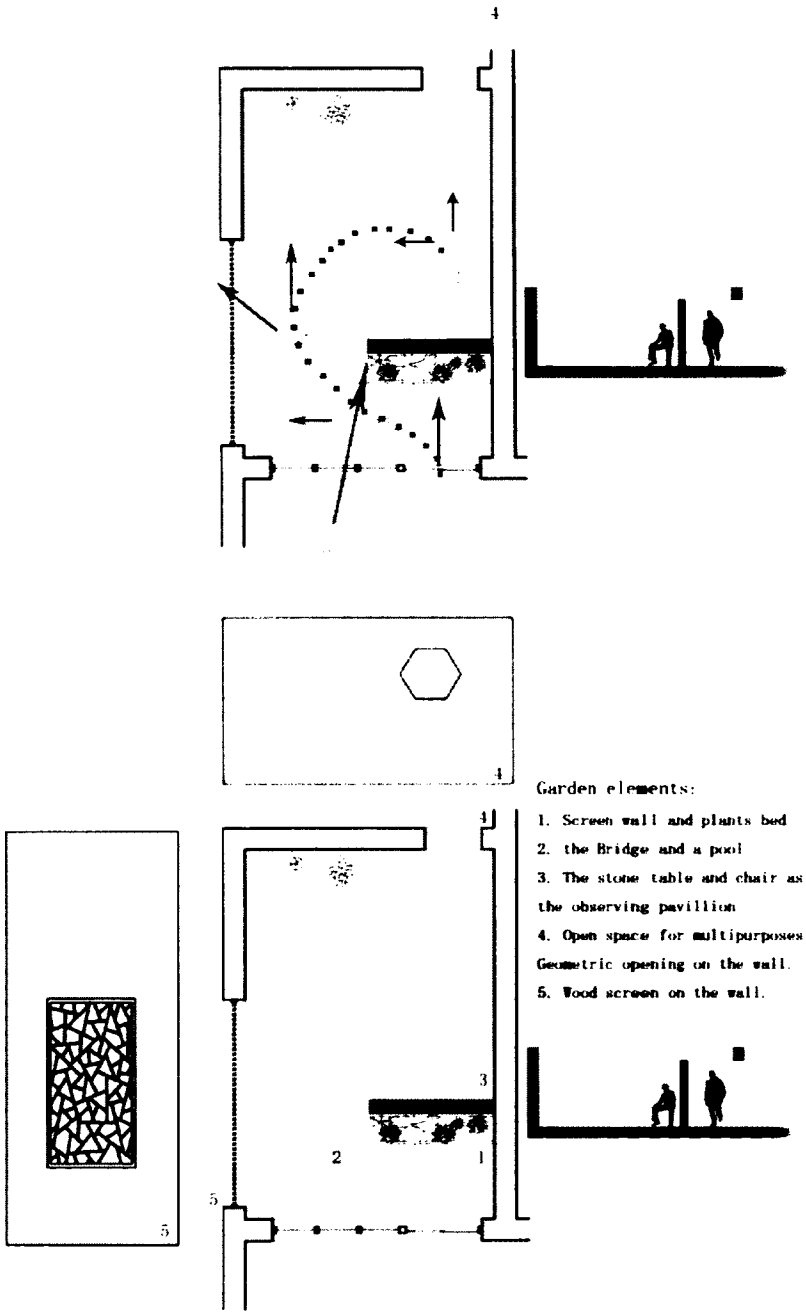
2. The trees and plants:

The most favoured trees are the plum tree for its white flowers in spring; the bamboo, which symbolizes the morals;and the pine, which symbolizes the longevity. The flowers vary with the seasons, and it is expected to have flowers blooming in all seasons. [46]

3. The architectural elements:

It includes a number of motifs: the open gallery, the wall, the bridge and the pavilion. The walls are especially important. They are painted pure white as a background to emphasize the shadow of plants and the geometry of the window on the wall. They are also used to frame the viewing point with ornamental opening or to orient visitors' path. [47]

The new design of the garden arranges the visitor's viewpoints by setting up the visiting path. The screen wall prevents the visitor from viewing the whole garden in one glance ; the pool and the bridge suggests a path; the stone table and chairs are functioning as the pavilion , which allows the visitors to rest and view the garden.

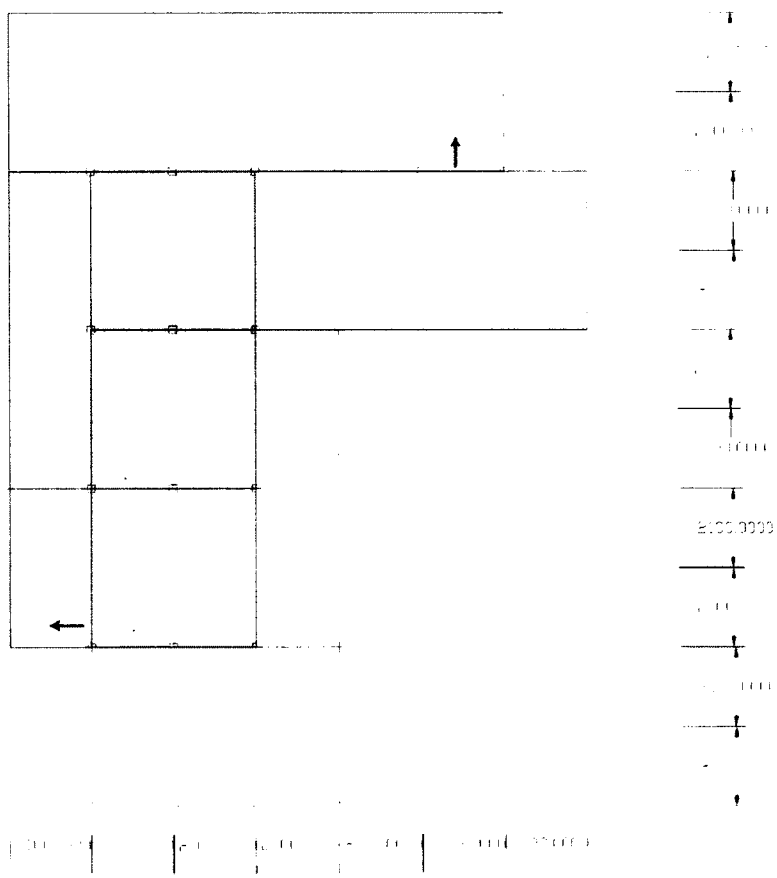


[IMG 61] The visiting path and the garden elements.

The Structure study

The structural system needs to match the height of the surrounding existing buildings (3-6 stories high) and give the cantilivering gesture derived from the toukung's feature. As a result, the project requires a structural system for a mid-rise wooden structure apartment.

The grid system is applied to organize the cantilever. The grid is determined as 2100mm x 2100mm. Each shift is the multiple of the grid.



IMG 62 The grid study diagram.

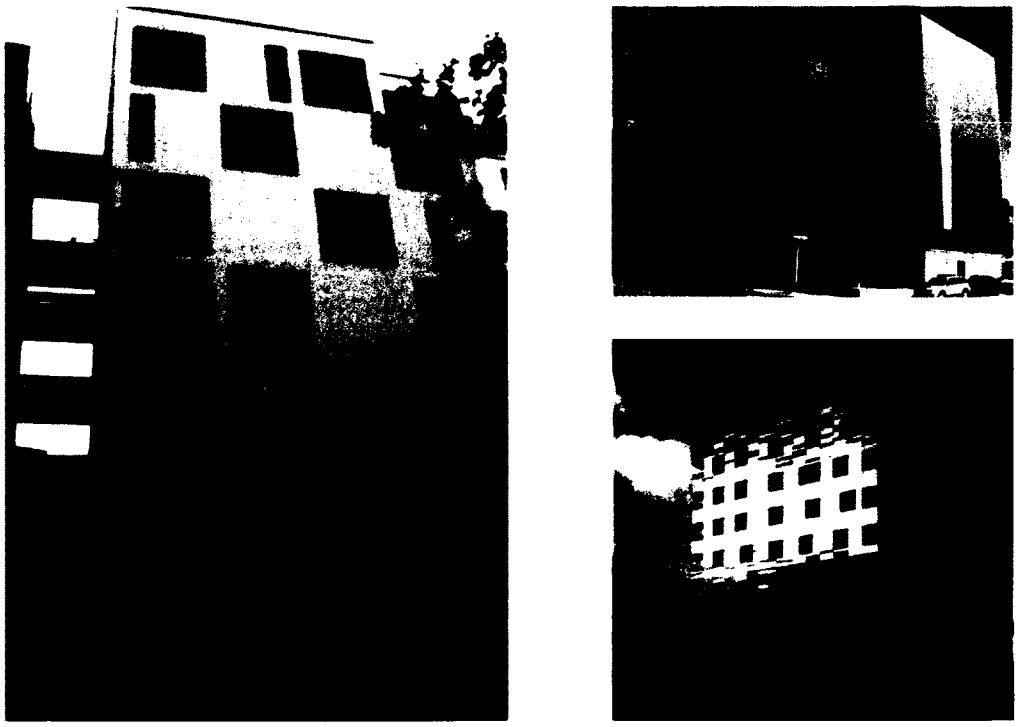
The multi- storey wooden structure building has been developed since 1990's. During the early phase, multi- storey buildings were constructed with light timber frame construction system. Today, many multi- storey wooden structure buildings have been successfully constructed using various construction system, such as the seven-storey building in Germany in 2000, the six -storey hybrid wood and concrete building in Quebec ,Canada in 2009, and even a nine -storey cross-laminated timber building, the Stadthaus apartment building in Murray Grove in east central London in 2010[49]. Four major systems have been identified:

Platform frame wood construction (up to 6 storeys)

Heavy Timber Frame Construction (up to 10 storeys)

Cross Laminated Timber (up to 10 storeys)

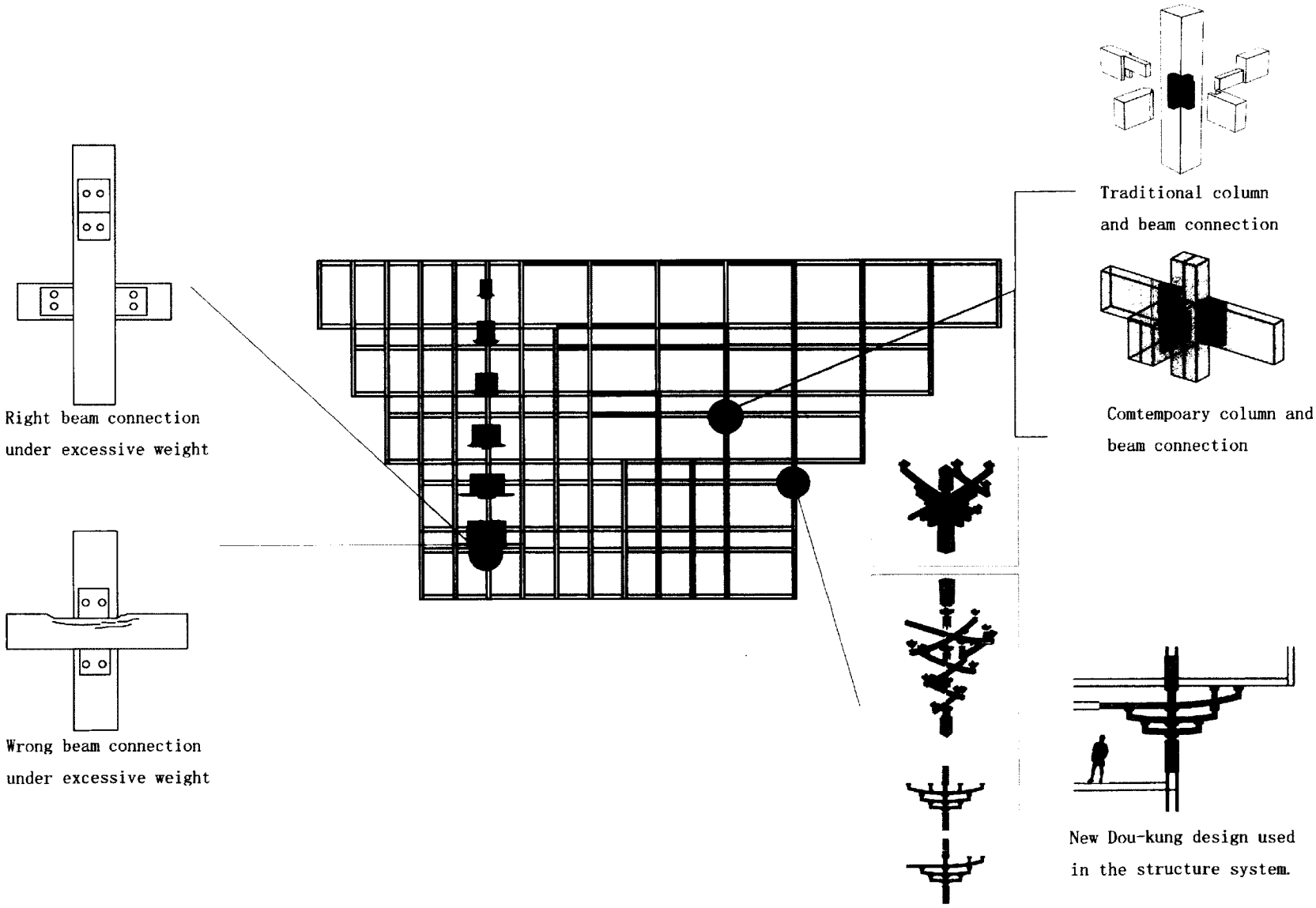
Hybrid Construction [50]



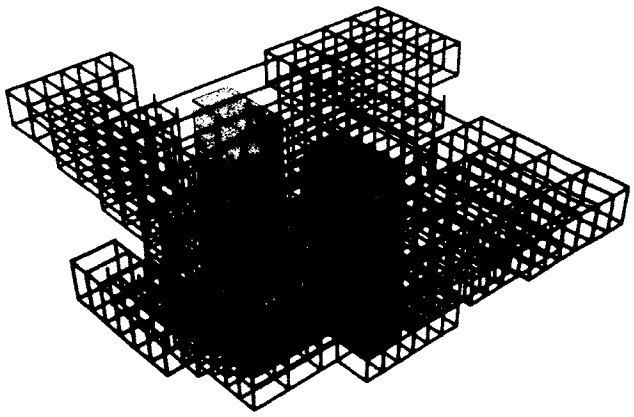
[IMG 63] **Wood or hybrid construction architectures**

Seven-storey building in Germany in 2000, six -storey hybrid wood and concrete building in Quebec, Canada in 2009, and nine -storey cross-laminated timber building, the Stadthaus apartment building in Murray Grove in east central London in 2010

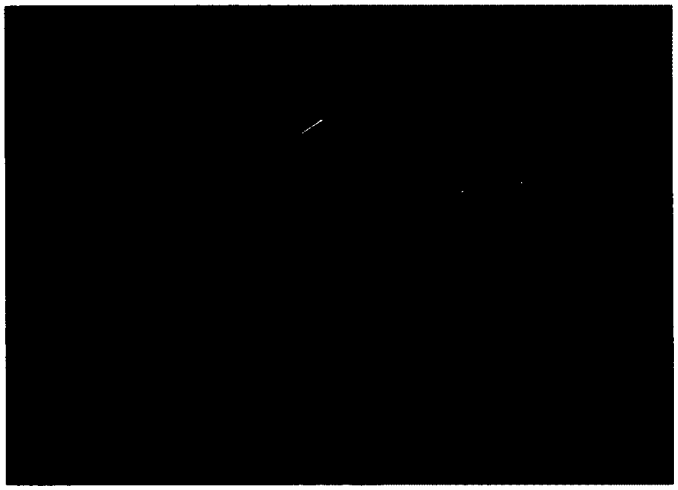
Innovations and improvements have also been made. The hybrid wood and concrete structure system uses the combination of glued laminated timber beam and heavy post with reinforced concrete shear-walls and cores to act as seismic force resisting system (SFRS) [51}. Additionally, the excessive deformation has to be considered. The joints are designed to avoid placing beams on top of the columns so that the excessive weight won't damage the beams [52].

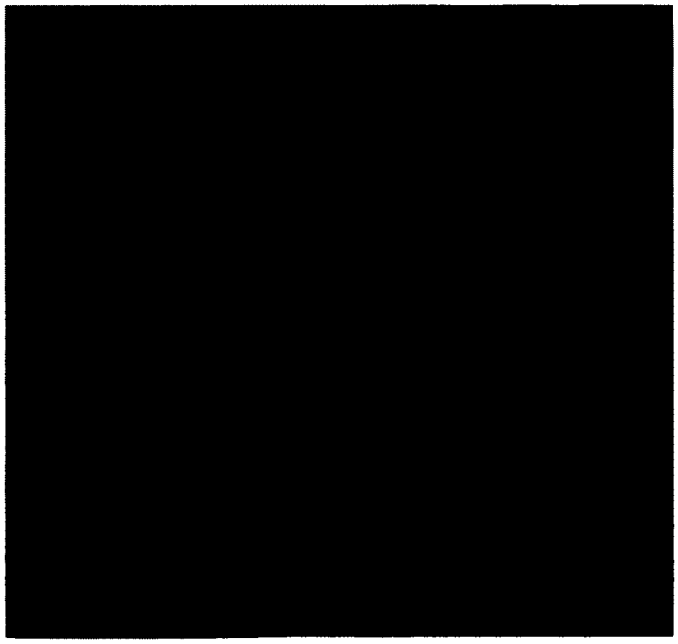


[IMG 64] **The structure system analysis.**



[IMG 65] **The hybrid structure system of laminated timber frame and concrete core.**





[IMG 66] **The structure system model.**

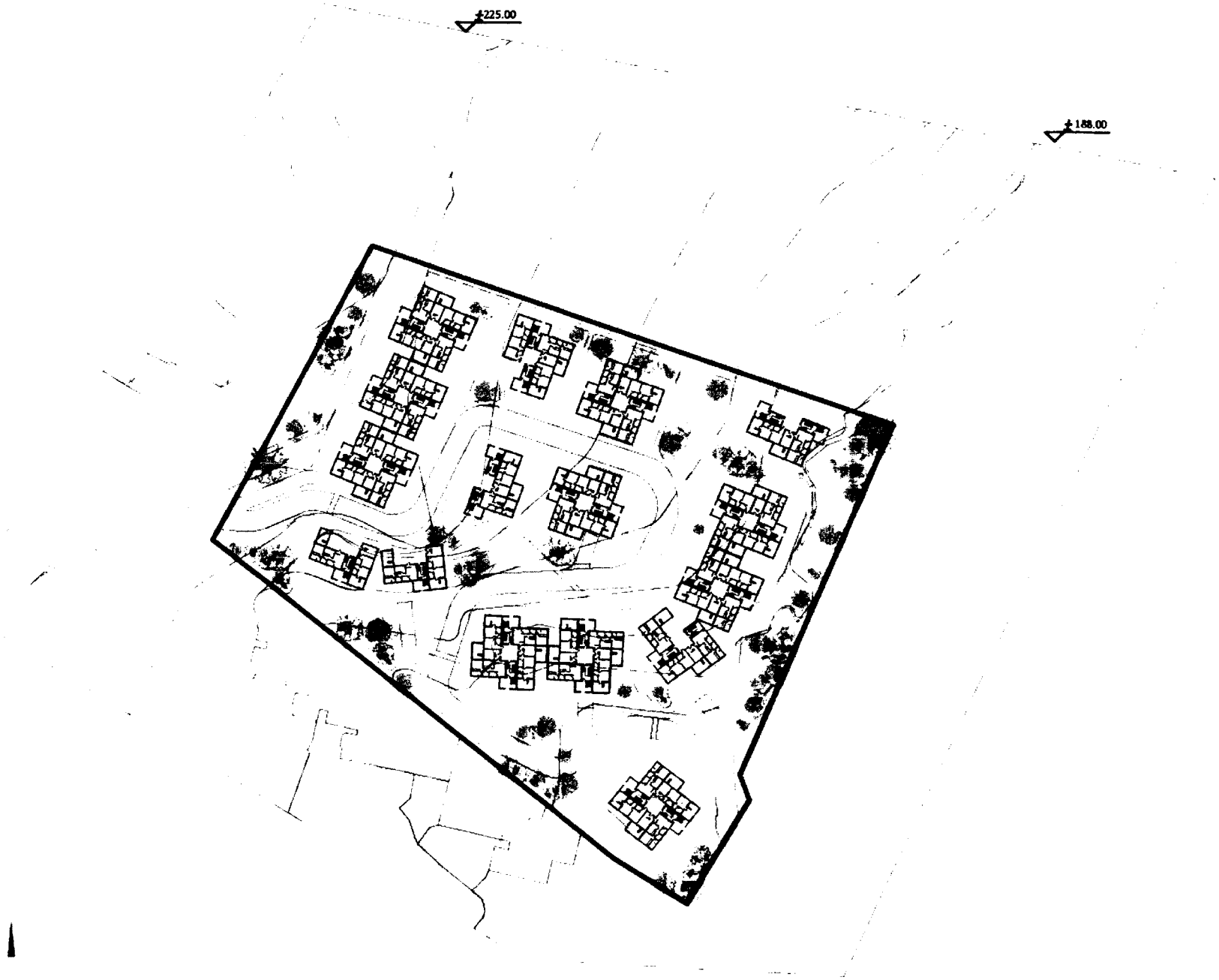
The Final Design Project

The designed residential plaza includes a totally of 265 single units. 123 of these single units can be combined into 41 combinations, which are designed to hold a young family with parents of both sides. The whole plaza is able to accommodate approximately 719 -795 person. Since the site is 0.01989 square kilometres, the population density is 36,312 person/square kilometres--40,150 person/square kilometres, which is higher than the average population density of 27,391 person/ square kilometres.

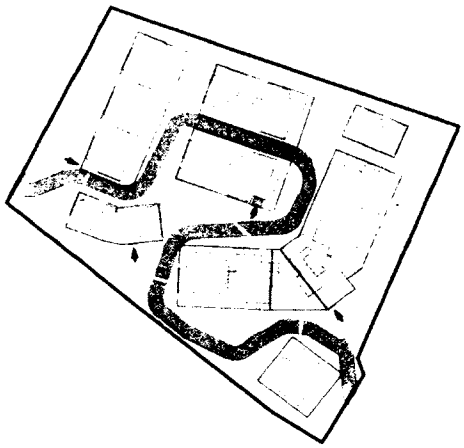
Conclusion

The research on the woodcraft and traditional vernacular dwellings both leads to the study of the social relationship of their periods. The evolvement of the toukung for the Song Dynasty to the Qing Dynasty is related to the cultural differences of the Han and Mongolian and multi-generational dwelling tradition is a result of the family structure. Therefore, in order to connect to the past, the contemporary social relationship has to be studied and understood first.

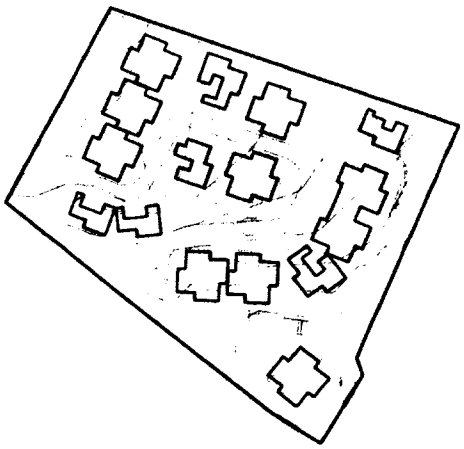
After a thorough analysis of the contemporary family structure and the city conditions of Chongqing, the residential project is designed to suit the high population density , and to retains the historical urban fabric footprints and improves it with vehicular accessibility. The design preserves the courtyard dwellings and brings it into a new level—the vertical communal courtyard which adapts to the high density neighbourhood; it returns the Chinese woodcraft into people's daily life. Most importantly , the design responds to the new family structure and provides a new multi-generational dwelling system with gardens. All these features are to build the connection of the contemporary social relationship to the past with the respect of Chinese culture.



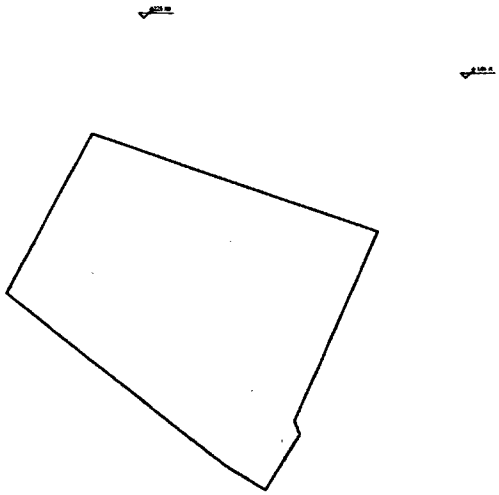
[IMG 67] The master plan.



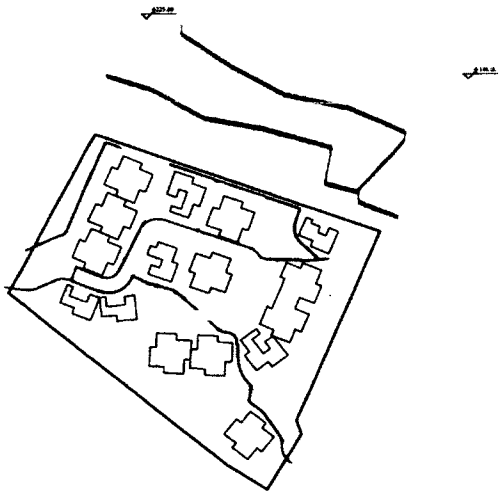
[IMG 68] The underground parking.



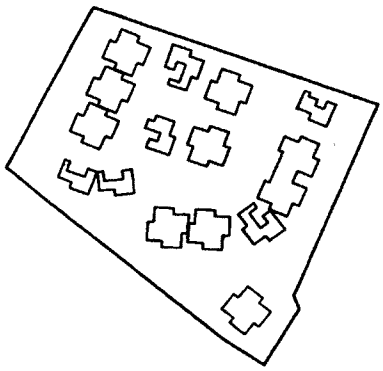
[IMG 69] The shade of buildings related to the streets



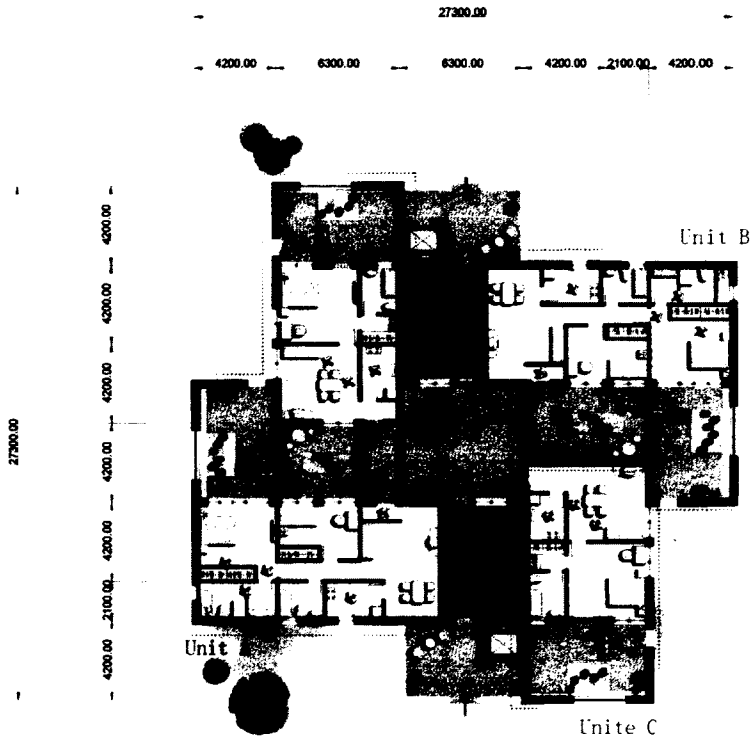
IMG 70 The vehicular and pedestrian accessibility



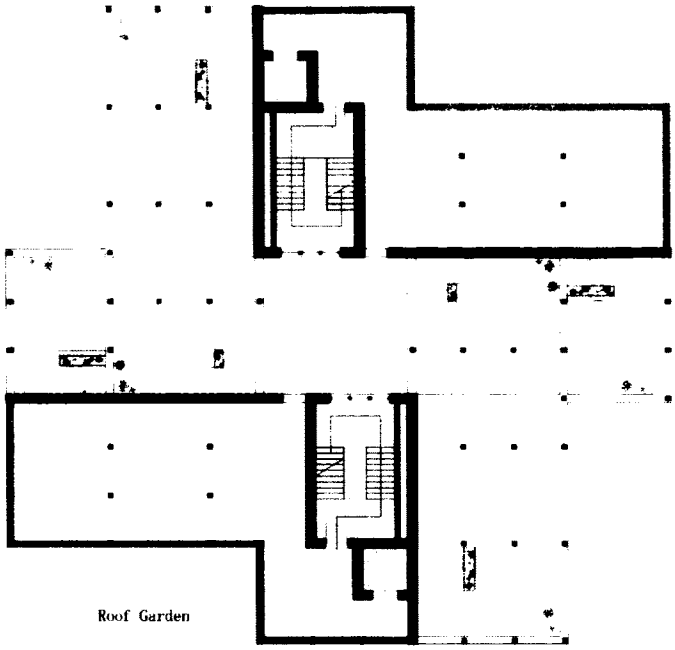
IMG 71 Footprints of old pedestrian paths.



IMG 72 The building footprints related to the old fabric.

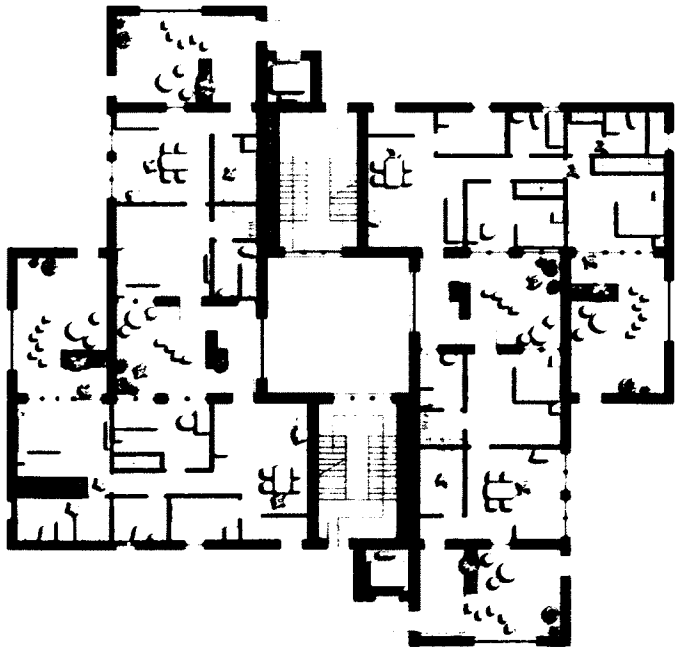


IMG 73. **Ground floor plan.**

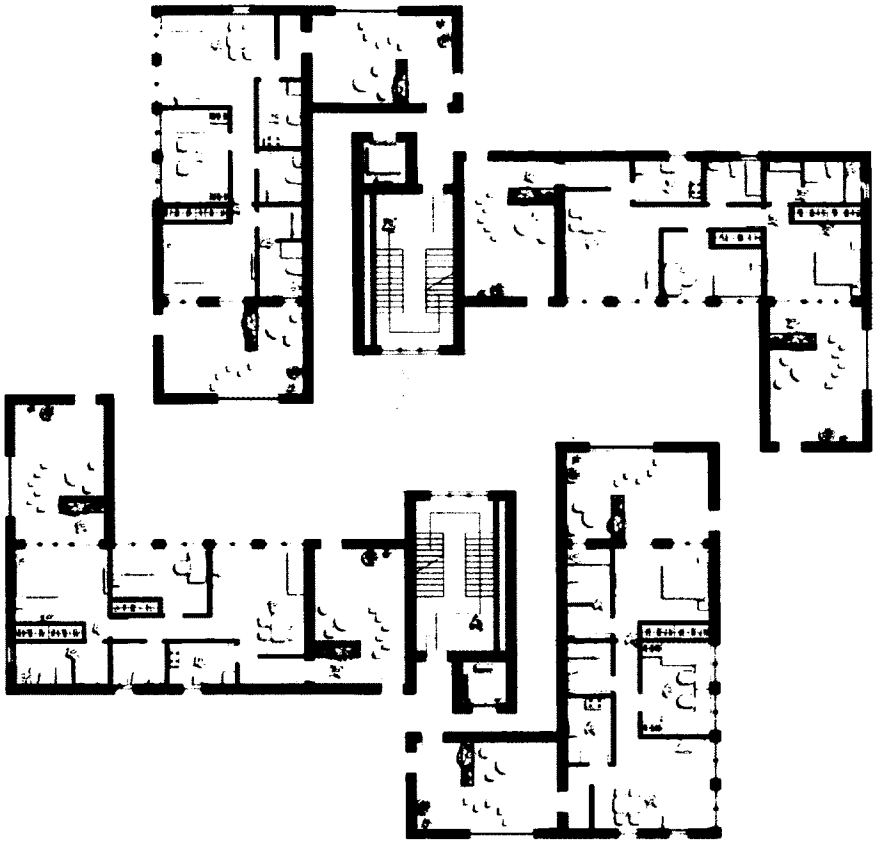


[IMG 74] **The Second floor plan.**

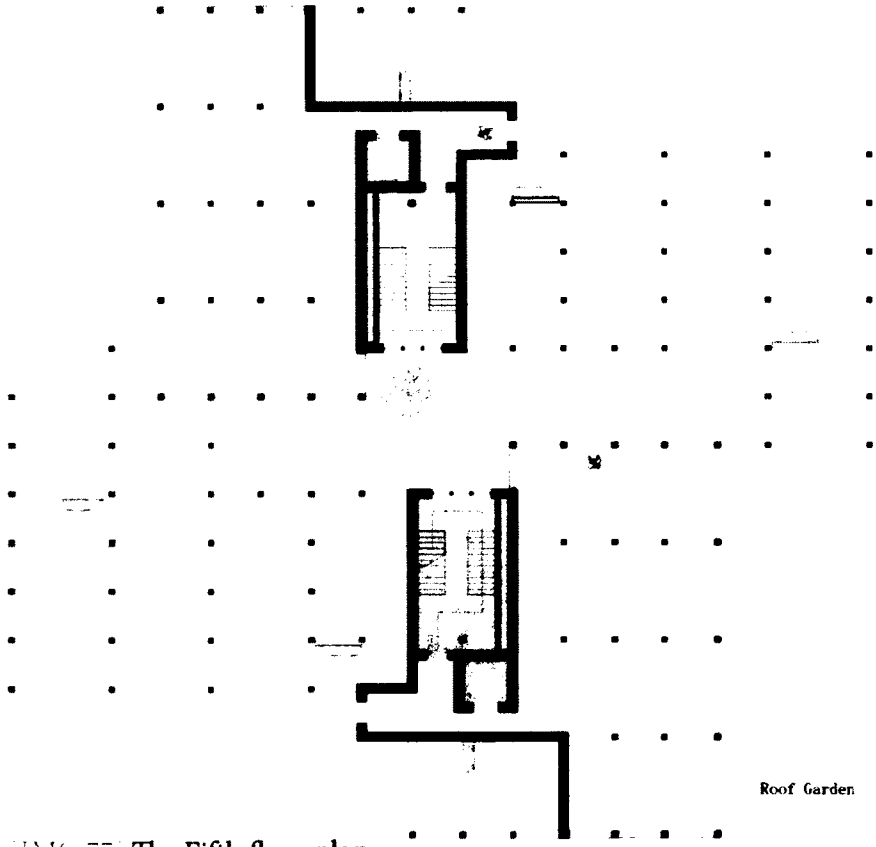
[illegible]



[IMG 75] **The Third floor plan.**

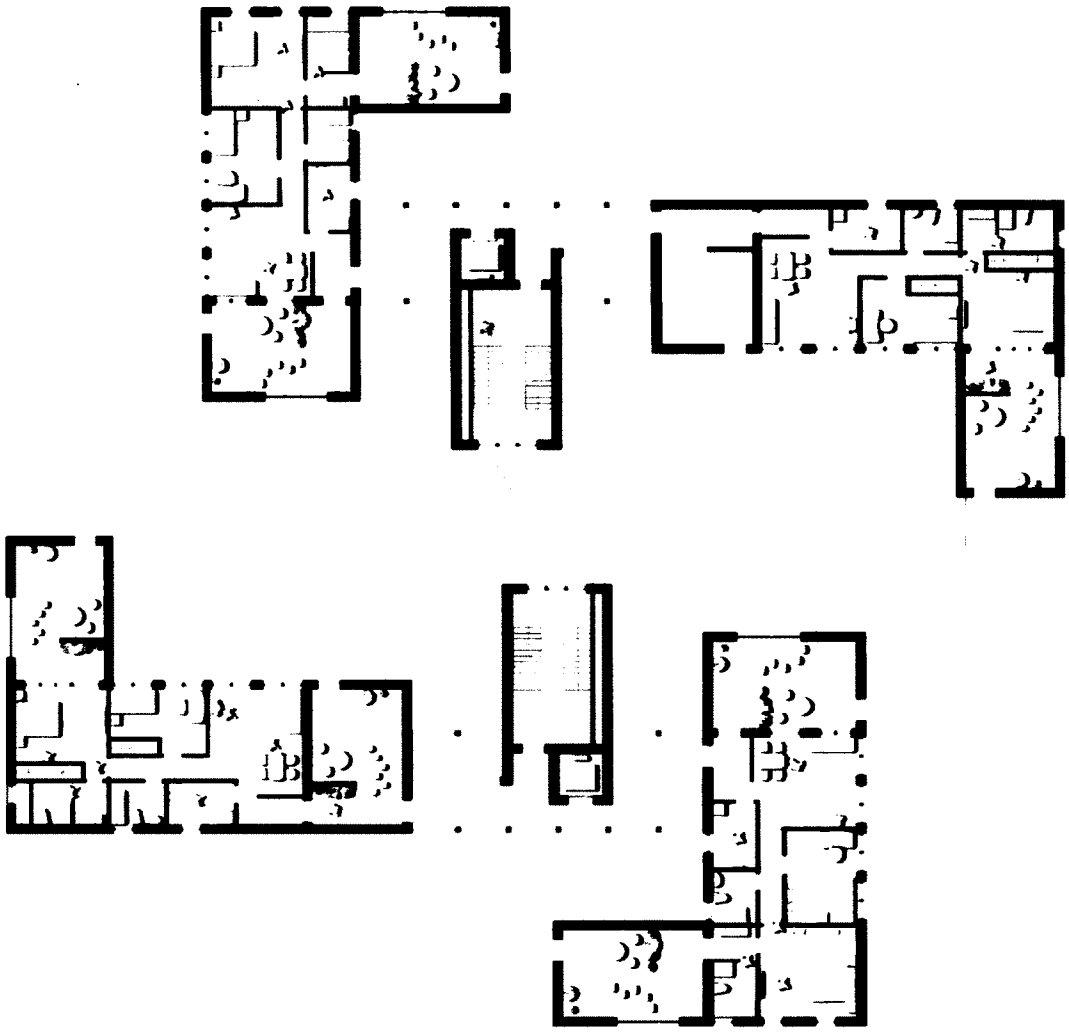


[IMG 76] The Forth floor plan.



[IMG 77] The Fifth floor plan.

Xiaoning Zhang, *[illegible]*



[FIG. 78] The Sixth floor plan.

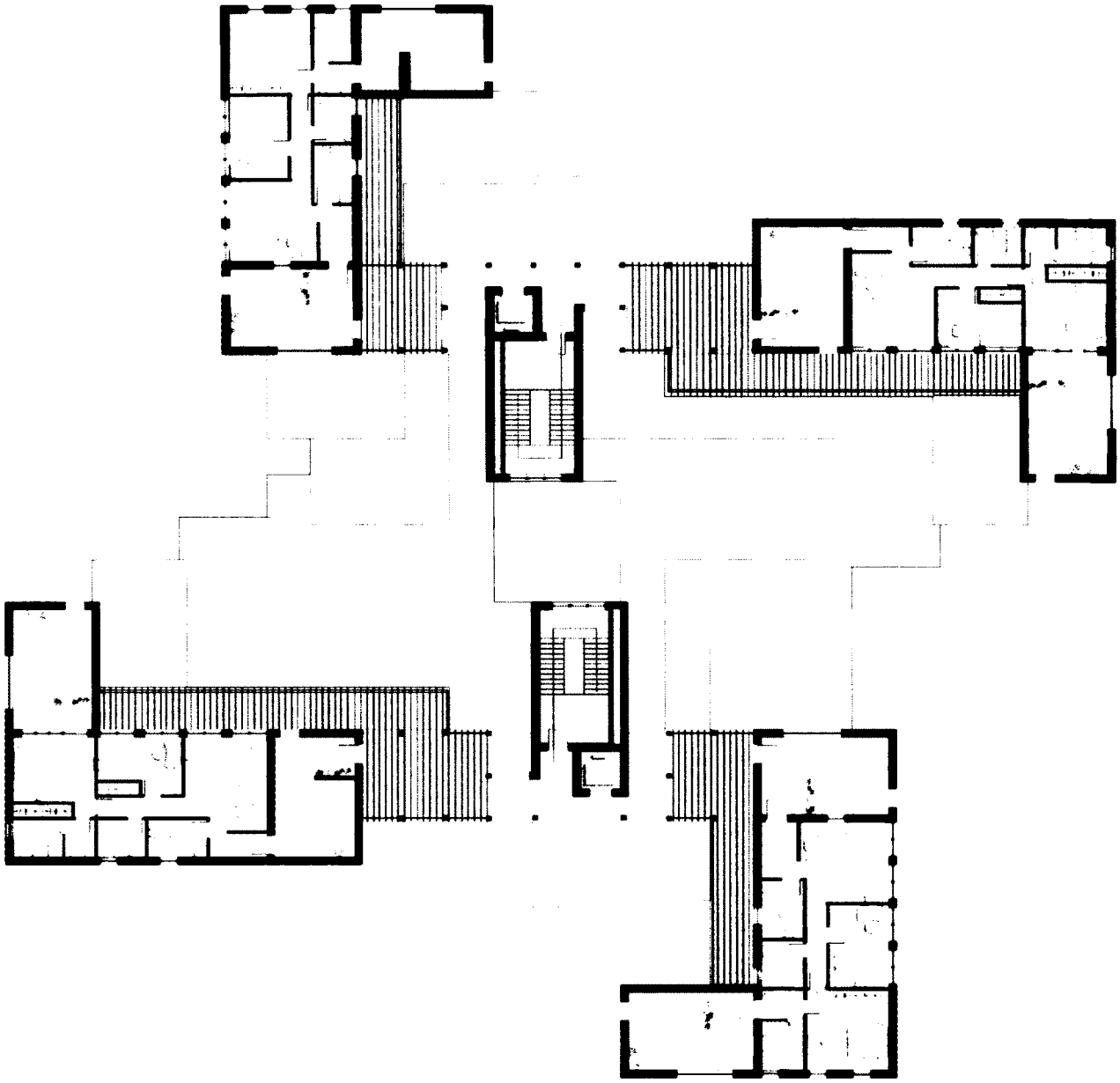
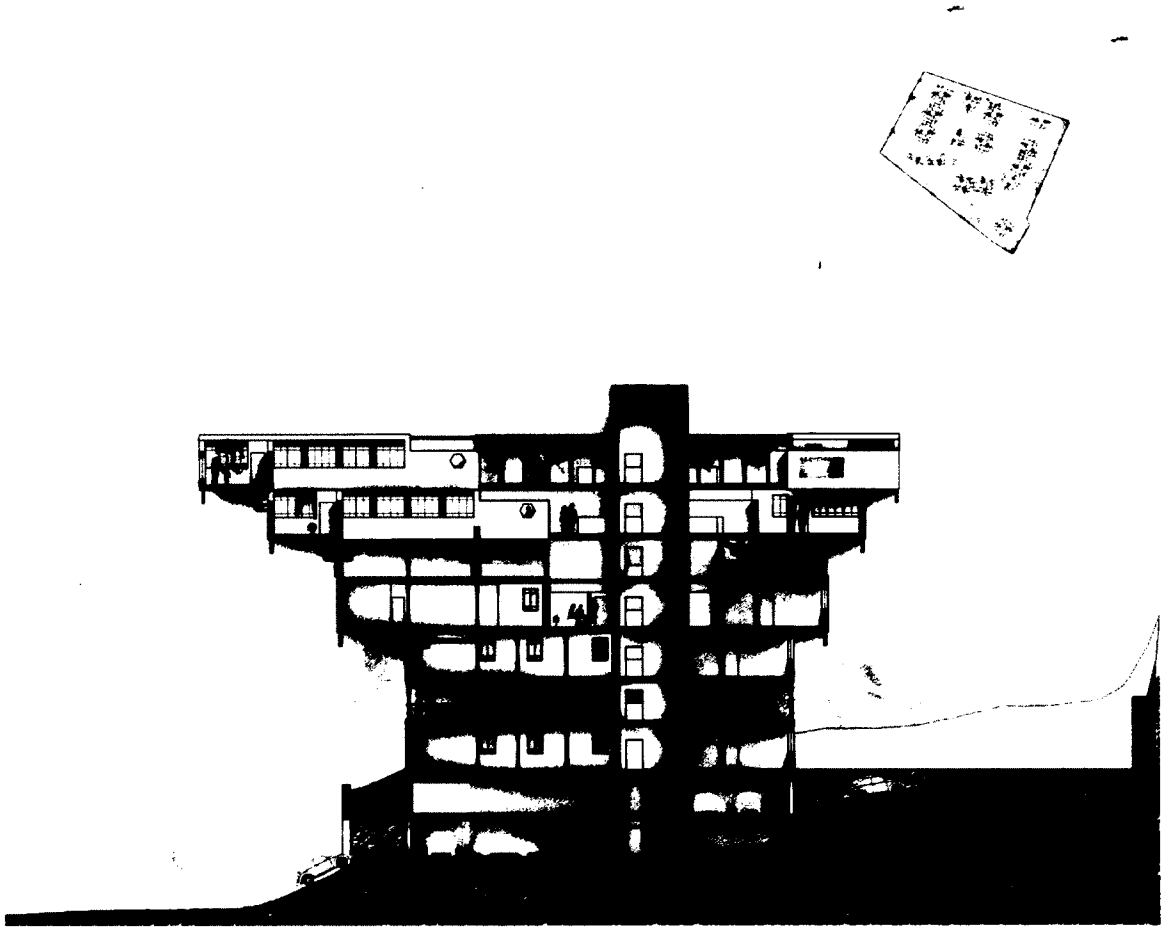
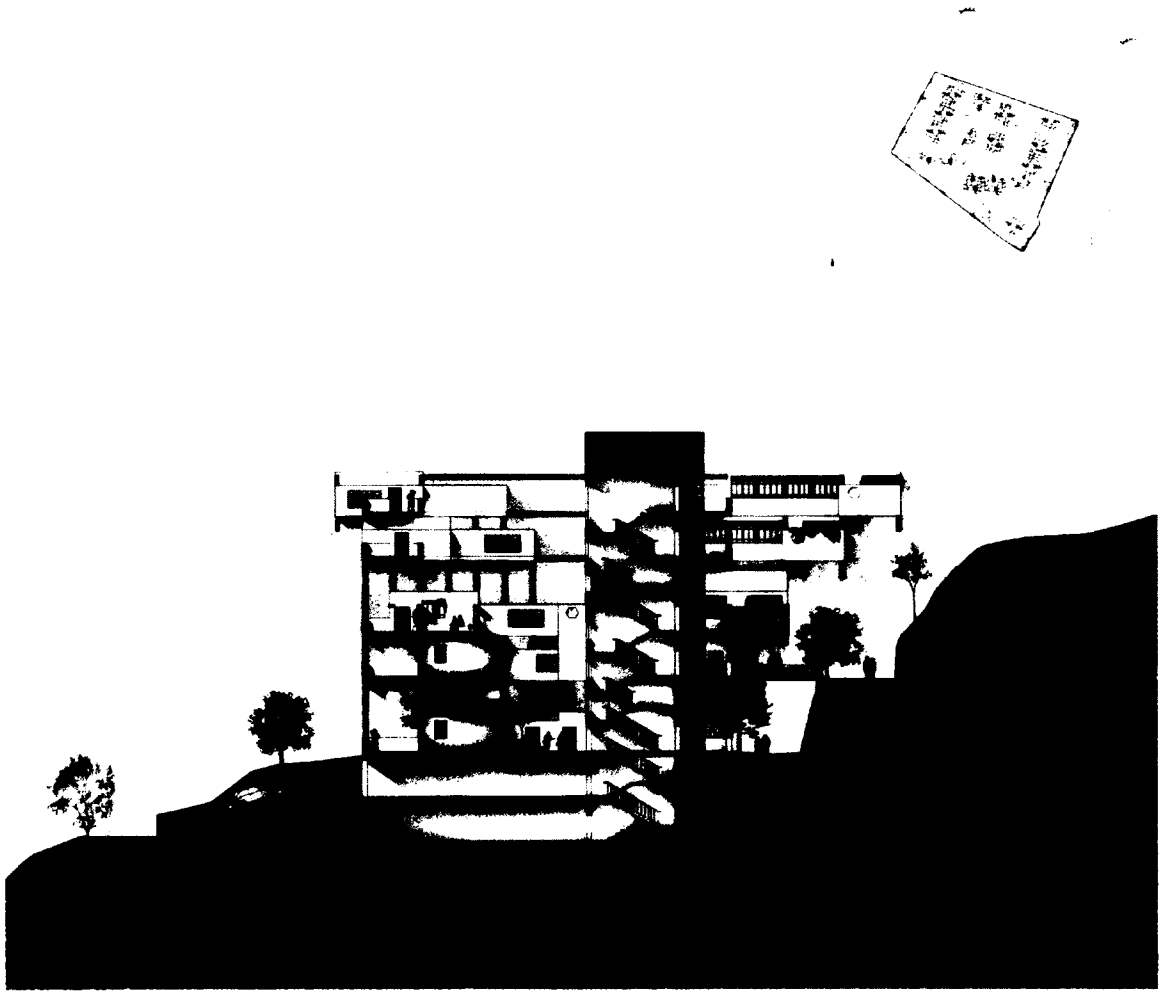


FIG. 79 The Seventh floor plan.



[IMG 80] **Section one.**



[IMG 81] **Section two.**

[IMG 82] **Rendered image of front facade in the site (1)**

[IMG 83] **Rendered image of front facade in the site (2)**

[IMG 84] **Rendered image of the bolcony in sunset scense.**

[IMG 85] **Rendered image of a private garden.**

Part 4 Post Scripts

It is found out that the new contemporary tou-kung is reluctant to be integrated into the new designed wood structure residential typology. It is because that at the early stage of the design process, they were not intended to be used together. Their design processes are from different strain.

The design approach of new contemporary tou-kung was from the new materials and the new manufacture technology. The curved form was derived from them. The glued laminated timber, a new material used, is stronger than saw timber and make kung or the beam thinner and create longer projection. However, in order to counter the deflection, the defect of the glued laminated timber, a technique called 'camber' is used. It is the reason that the new tou-kung has curvature on its kung. In addition, the new designed wood joints are relied on the CNC machine. CNC machine is better in making curves. This was not a designed structural detail for a specific architecture but only the technical propose.

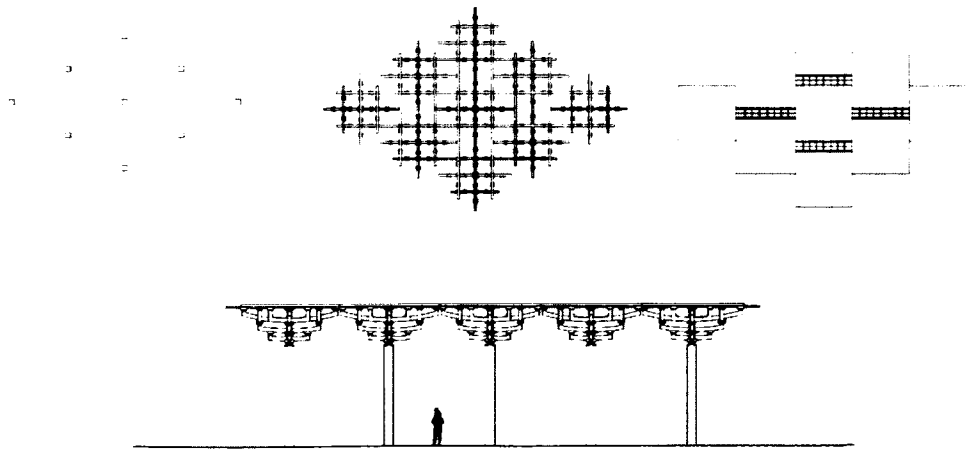
The design of the new residential typology was developed from the characters of the traditional tou-kung, the cantilever projection and the separation between layers. The entire building as a result was interpreted into a 'tou-kung': the modular unit projects outward and make cantilever to shade the street and the separation between each level becomes the balcony and ventilation tunnels. It is a tou-kung in macro point of view rather than a construction details in micro point of view. In addition, the structure system of the residence is capable of functioning on its own. The structure system uses glued laminated timber frame construction. It is made of 8"x 8" standard glued laminated timber column and 6"x8" standard glued laminated timber beam. The span between columns is 2100mm or 4200mm. The glued laminated beam can span this distance without additional support. The new designed tou-kung can be used to support the cantilever modular unit. However, to complete the form of cantilever, the wood truss system seems to be more convincing than the new tou-kung. Probably the 'camber' can be used in the structure system for the beams, but the new designed tou-kung is obvious an addition to the new residential typology.

The meaning of new tou-kung to contemporary architecture

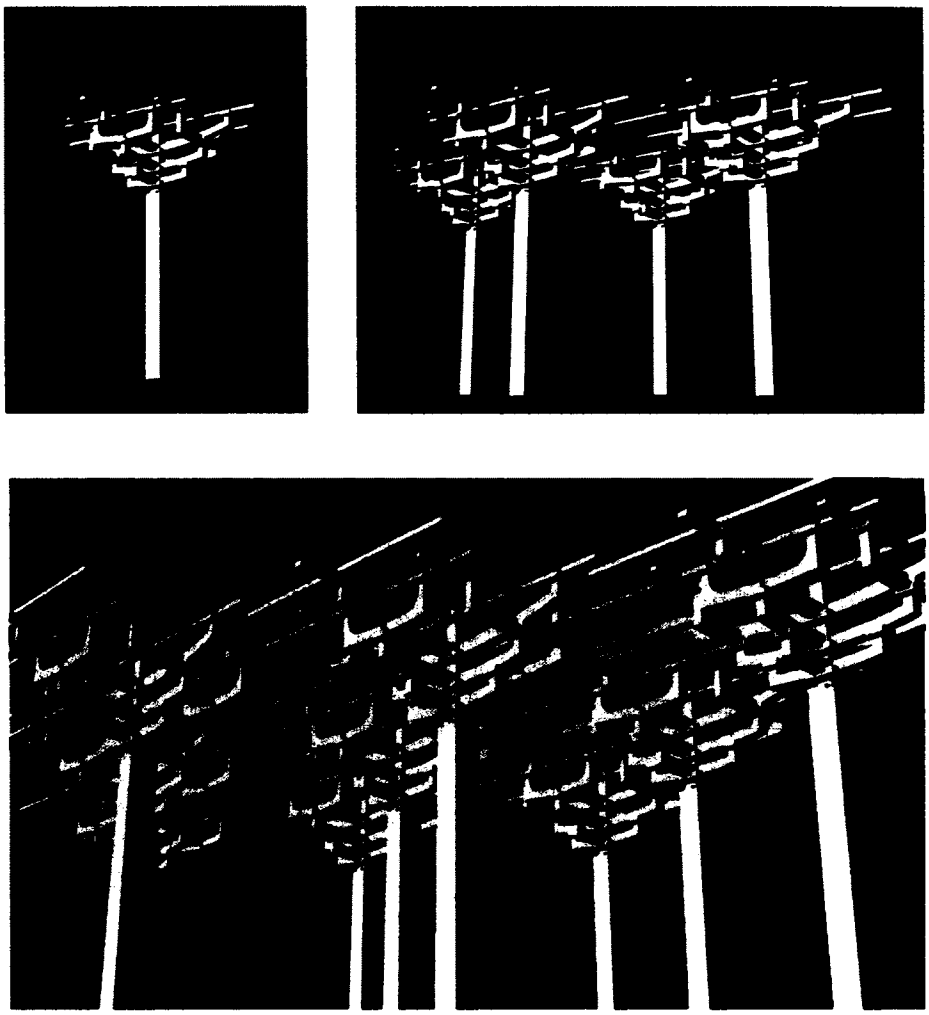
The structural function becomes less important to the residential typology. However, from the perspective of the meaning of tou-kung to the temporary architecture, the new tou-kung develops its own meaning. It is a cultural symbol of Chinese architecture. As the thesis indicates that the tou-kung in the Song Dynasty is a structural detail providing the cantilever support. In the Qing Dynasty the function decreased from structural to ornamental. The tou-kung has continued this flow and becomes symbolic. The structural function of the tou-kung is interpreted as a macro representation: the separation between layers is articulated into the balconies of public activities and ventilation tunnel of the vertical courtyard; the cantilever function is presented not by structural details but the building structural system. The building itself is a gigantic 'tou-kung'. Even though the new designed tou-kung was placed in the cantilever position; however the structural support they provide was not convincing. In addition, the tou-kung placed in the balcony is more as ornament than structural support because the beam in the structural system can span the distance without additional support. There is no structural function of the new designed tou-kung in the balcony area. As a result, the tou-kung used in the balcony is only desired to create a ceiling of strong cultural impression. This result connects the conclusion of the studies of tou-kung in the Song Dynasty and Qing Dynasty: the function of the tou-kung in these two periods is a shift from structural to ornamental. To the new residential typology the contemporary tou-kung is a continuity of the ornamental function: the new residential typology has a symbolic architectural concept and the ornamental details are considered as the cultural identification. It is also a protest to this period of globalization that each culture should be distinct from others.

The use of the new tou-kung in public buildings

If the new designed tou-kung does not function well in the residential typology, it can be used in the public buildings. Historically, the traditional tou-kung was used in temples, towers, and palaces but rarely in the residences. It is not a coincidence that the new designed tou-kung is better used in the public building because of the cantilevering supporting function. It is a necessary function to create large open space. With the contemporary materials and technologies, this function is enhanced. The cantilever supporting has the potential to create grand open space. For example, following the modular principle, each single tou-kung can be developed as a canopy which can be used in the gardens as a pavilion; dozens of them assembled can form a market or gathering place with less columns but wider open space with ceiling of strong cultural impression. Each single canopy is connected to others with the beams that the tou-kungs support. [IMG 84]There are other expectations of the use of the tou-kung for public building. In a grand scale, they can be considered as the structural support for other commercial or civic architectures, such as theatres or stadiums. The potential of the bracket system is expected to be explored.



[IMG 86] The plans and the section of the 'gathering' space



[IMG 87] **Rendered image of the composition of the canopies**

There is a skylight among each group of four canopies.

In conclusion, the tou-kung is a wood technique which is more practical for public buildings rather than residential buildings. As the technology improves, the new tou-kung will be used in the contemporary architecture as a more important role. It becomes the most important structure member in the structural system than the Ming Dynasty and the Qing Dynasty. The scale of the new tou-kung becomes the largest than any period and it is the major structure support. In addition, it carries the Chinese architectural cultural identities. The new tou-kung will carry forward and flourish the Chinese architecture

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