

Research on the Change Process of Curved Roof of Chinese Ancient

Architecture by System Dynamics

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1 , Review and set forth the problem; Discuss on what the systems thinking can do; search for the law of thought of the conclusion

Chinese ancient architecture is unique in the world architecture systems and the roof form, which pictures a curve full of aesthetic sense, ends with sprockets, and dances with graceful melody are the most eye-catching one among all constitution parts. (Fig1.1, Tang Dynasty-Palace of FoGuang Temple in Wutai Mountain ; Fig1.2, Qing Dynasty-Imperial Ancestral Temple in Beijing).



Fig1.1

In general, the roof of wood structure is larger and “ There’re many chalets in wood structure in Europe villages,though the roofs seem to be larger than those in China, the roof and the eaves are not curved.” How is this roof form developing? Some agree that it’s convenient for daylight and drainage and others suggest it is only for aesthetic. The above explains sound to be reasonable, but “ A formation of an

architecture which is a formed style should have a long time practice and contains many factors such as material, structural form, construction technology, function require, aesthetic sense and so on. So does the large roof of ancient architecture.” If only the explain on one or two specific angle is given, the conclusion will be relative powerless and absent of cogency.



Fig1.2

It can be found that the law of thought in which the prior people discuss on this problem places emphasis on feature of one time and one place of the buildings and is static, linear, single and facial, so this law of thought can’t reflect the change process and inward kinetic of architecture and we can’t do more closely research on economics, sociology, aesthetics background and value which are included behind this form process. This will be a pity.

So we should concentrate on the problem that how these factors, which force the curved roof of Chinese ancient architecture, percolate and translate mutually. From the angle of logic, this way belongs to the research field of system dynamic discipline.

The view of system dynamics transfers the heart of this problem to the research on inner power of change process and checks the develop status of one building by figure: the arise of some architecture system could be a random trial of a architect completely and is accidental and not directional, but it can be very popular and with strong vitality because this building style has many fitness such as solidness, practical, economic, graceful and so on. The above view can be compared with “vitality” in biology by analogy, just as several deer that arrive at one place accidentally may become a great number and stable population on the basis of natural and

anthropic factors. (This analogy will be shown in the following word again.) Study on this fitness could give us some cognition on the general law of human behavior.

Though the roof form is fixed for every building, it is changing time after time for an architecture system. Let's put this change into the History River and uptake its whole process with a "quick shot".

2 ,Establish frame and model of system dynamics; Survey on the variable factors

The official buildings are the main study objects for in order to make more definite discuss center. Because the hierarchy of Chinese ancient buildings is very perfect, the official and civil buildings were developing each through two different ways, which both tightly link and distinguish mutually. The depth of civil buildings could not be more than seven frames and use Chinese hip-and-gable roof and Chinese hipped roof, so the development space of curved roof is not enough. On the contrary, the official buildings could be with no limits and display the curved roof fully. By the way, the discuss time in this paper is limited from East Han dynasty (about 1st century) to Song dynasty (about 12th century) which is the period of "appear to mature" for curved roof.

Here the center of the problem is "the development degree of curved roof". There're two meanings for the word "degree", one is to show how the "crook" form be more obvious

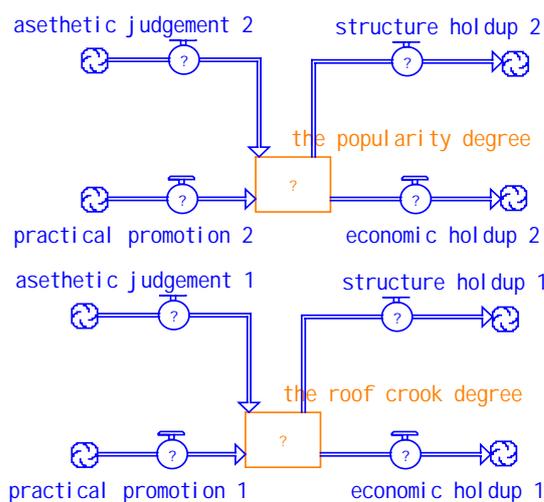


Fig2.1

(longitudinal); the other is to show the universalize degree of this form (transversal). So I will build two stacks to show them in the form of figure. Four parameters around the stack are two input flows-"aesthetic judgment promotion" and "practical promotion" and two output flows-"structure holdup" and "economic holdup".

These four values summarize the default factors, which affect building form comprehensively. The model is shown in Fig2.1.

Structure means the safety and solid requires of buildings (maximal moment and shear in beam mainly) and the limit of material character.

Practical means whether the roof form could

bring convenience to daylight and drainage.

Aesthetic judgment means the visual impact and mind identify, in the other word, the spiritual needs and following creation desire.

Economic means construction cost and material choose of the building due to structure change.

When the compositive effect of four flows on stacks is considered, there must be one "container" to contain these different flows to ensure that these four flows be connected tightly. So this container, two new central stack, means building scale and experience accumulation of construction.

Roof, not an air castle, is developing both relatively independent and of very close linkage with the whole building, particularly with the building scale. "Scale" is the most direct effect in

the develop process of architecture system and offers develop space for change of roof form. While the experience accumulation, which is relative perpetual, shows the potentiality in architecture field with both innovate and fogyism and shows the general society progress. Experience accumulation is the source of architecture development, and structure, practical, aesthetic and economic are all the extrinsic factors of it.

A further explain is that “experience” is the direct input value of “scale” to show the global effect of “experience” which is shown in the right graph (Fig2.2).

The computation formula during discussion is: **Holdup (promotion) flow= Holdup (promotion) factor central stack value**

This formula can be compared with the one used for population breed in biology by analogy: input flow=birth rate deer number. For example, when we talk about the effect of promotion flow in the stack of “popularity degree”, the procedure of “promotion” is: at first there are 100 houses using the curved roof. Then there will be 100

20% (20% is the promotion factor) = 20 more houses using the style because they are encouraged by the promotion flow. Next time, there should be (100+100 20%) 20% more houses using the curved style...cycling like this.

Holdup (promotion) factor is a coefficient, a description for every factor’s change in abstract mean, to note importance of one factor and set up some comparability among different fields.

The “popularity degree” and “the roof crook degree” both have some inner relationship with each other. If the roof becomes more curved, it may be more attractive and this will make more people to follow the style; but if it’s too curved, the public may consider it spoilt and reject it. This will be shown in the “aesthetic judgment flow” of the “popularity degree” stack.

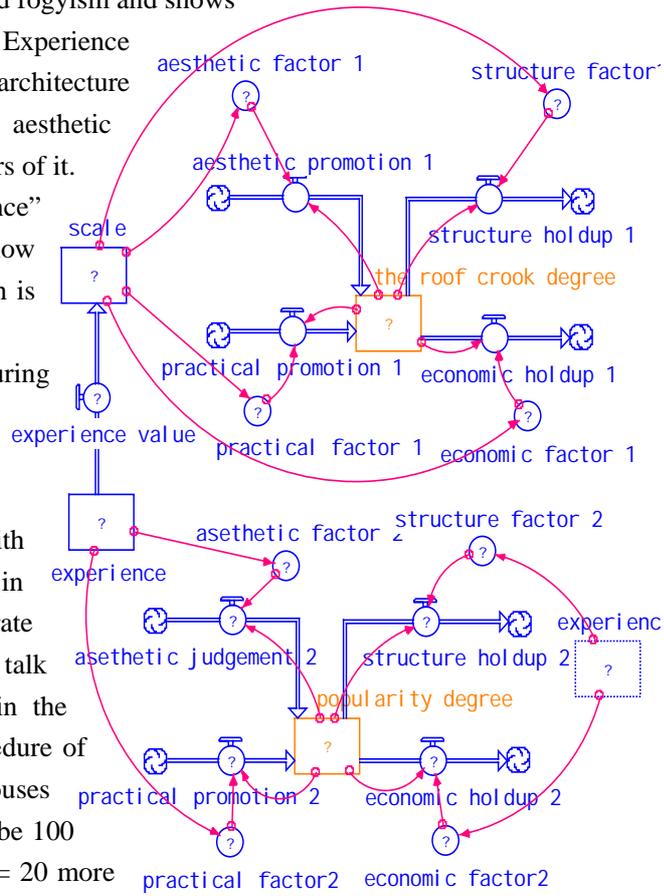


Fig2.2

3 , Discuss all factors from every side; Relation among all factors.

3.1 Experience

It is the basis for all the discussion.

For Chinese ancient architecture system, “Experience ” , which develops not in form of invariable linearity just as time and information explode in index grade, forms a specific character of “growth in S style” with both active innovation and negative

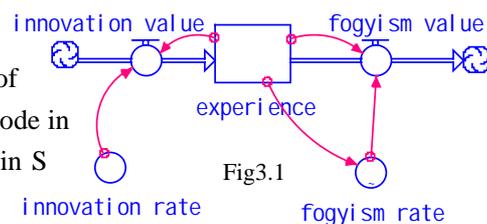


Fig3.1

fogyism. Active innovation means comprehension of material use, ability of construction and pursue desire of graceful building form that are deposited slowly during the long history. Negative

fogyism could fix one building form, but it also limits the creation so that the building system turns to be aging irretrievably. The traditional culture and thought law in china are “respecting ancient and attaching importance to tradition”, “ not going back on ancient law”. So the more accumulated, the more resistance will be faced during creation.

In model (Fig3.1), Experience is central stack, “Creation” is input flow, “conservation and forget” is output flow. The formula is:

$$\text{innovation (fogyism) flow} = \text{innovation (fogyism) rate} \times \text{central stack.}$$

The base number of experience value is 100. The value of innovation rate is a constant number-0.2, and the fogyism rate is the exponential type function of experience value. The input of related data shows in Fig3.2.

Then we can draw the potential trend of experience accumulation. (Fig3.3)

If this figure is in comparison with the practical experience which accumulated in Chinese ancient buildings, the “experience value” of each dynasty can be given which will be involved in discussion of “Scale” : before East Han dynasty (before 1st century):100; East Han dynasty to “Three Countries Period” (1st century to late 3rd century):160—280; Jin dynasty to “south and north dynasty period”(4th century to late 6th century):100—160; Sui dynasty and Tang dynasty (7th century to 10th dynasty):280—400; Song dynasty (late 10th century to 13th century): staying at about 400 steadily.

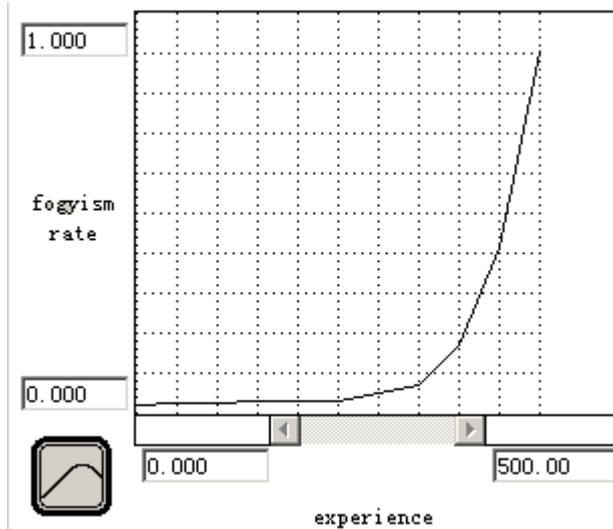


Fig3.2

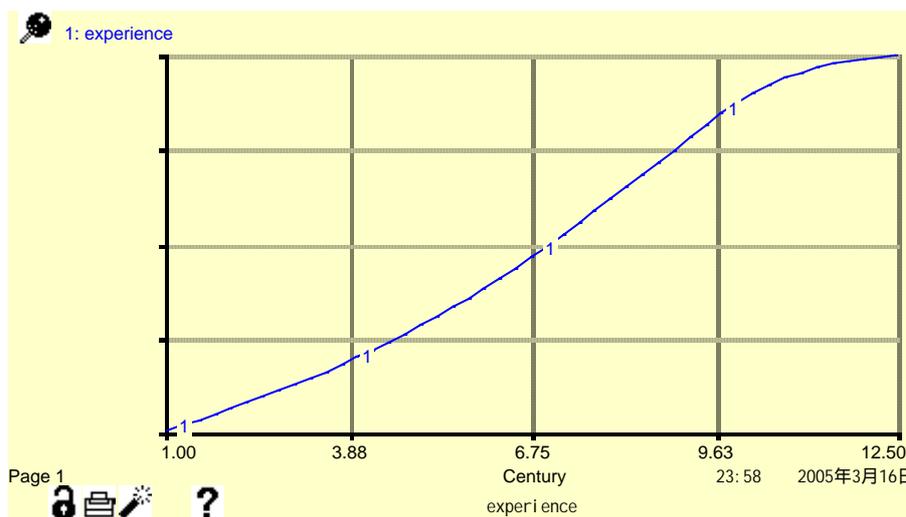


Fig3.3

3.2 Scale

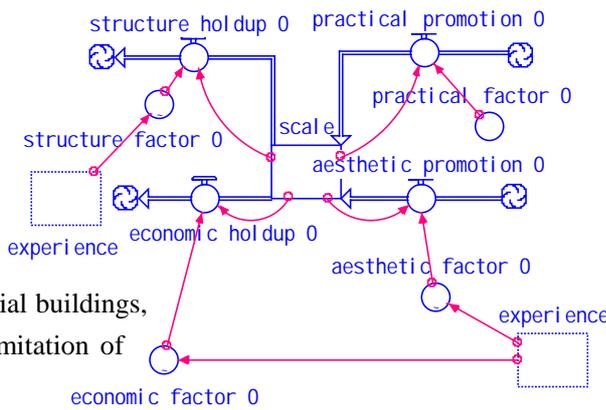
As a carrier, scale itself develops unceasingly on the basis of experience guide. The action of experience guide is more complicated, that is to say, there’s not a direct ratio relationship between experience accumulation and building scale. Because the four factors which are

controlled by experience—practical, economical, structural and aesthetic judgment functionate. The system graph is shown in Fig3.4. (There's subscript 0 added to each factor to distinguish with the other factors in the below paper):

The computation formula is also :

$$\text{Holdup}(\text{promotion})\text{flow} = \frac{\text{Holdup}(\text{promotion})\text{factor}}{\text{central stack value}}$$

“Factor practical 0” here is a constant, because for human the scale need is also the space need, so for official buildings, this demand is endless and have no limitation of experience.

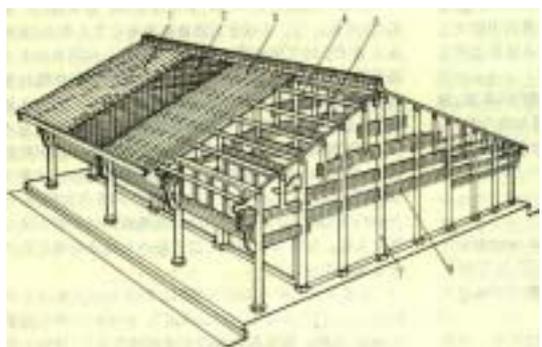


As to the structure, our ancestor invented “Hangtu” technology during the period of the Xia, the Shang and the Zhou dynasty (the 21st century BC to 2nd century BC). They could build huge terraces and high walls. This technology is quite simple and easy to practice. The materials come from the very process of the construction. The above two facts render the construction of large building possible. Two important features, wooden framework and “Dou gong” also began to appear in this period. In the Han dynasty, with the three basic types of Chinese traditional wooden framework coming into form, people could build independent, large, multi-storey wooden mansion. The two types are

Fig3.4



Tailiang style



Chuandou style

Fig3.5

“Tailiang” and “Chuandou” (Fig3,5). The technology of wooden framework became mature and steady in the Wei, the Jin, and the South and North Dynasty. It reached a new height and became comparatively perfect in the Tang and the Song Dynasties. The size of materials and the design have been unified according to certain standards. The last but not least important, art and technology combined in the archeology. The value of “structure-factor 0” gradually decreased. This falling process was slowed down when the great terraces eventually faded out from the history in the Han and Wei period, and multi-storey wooden mansion became the main form of great building. It is a big challenge.

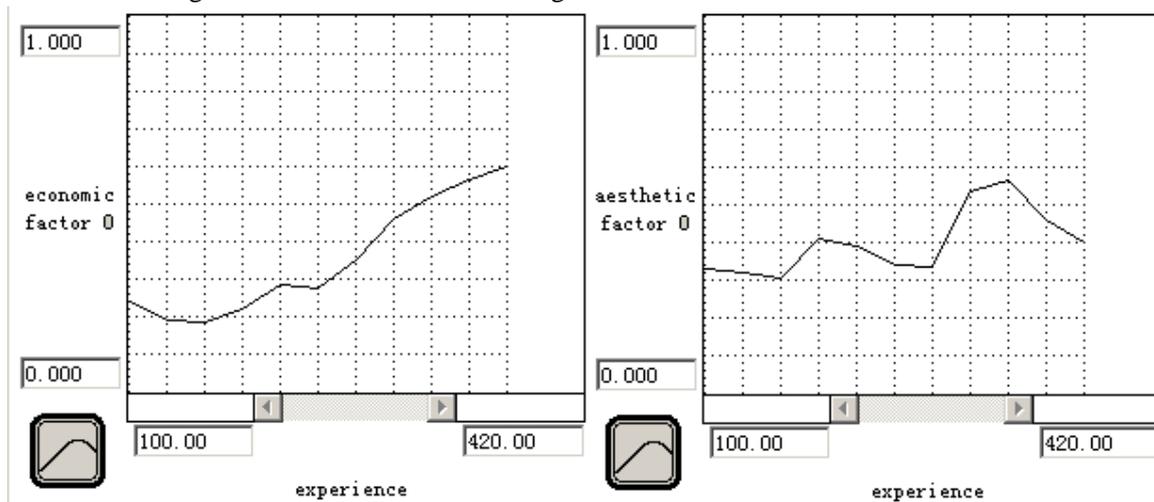
As to the economy, ancient governmental buildings seemed to have no serious financial problems, not to mention the imperial buildings. Royal people never care about how much it costs. Thus the “structure-factor 0” started on a very low level and went down constantly. However there is another serious contradiction, that is, large amount of wood is cut down and many forests are destroyed (as the poetry says: “Shushan Mountain becomes bald when Epang Palace is built.”). Huangtu plateau, the traditional ruling center, is originally abundant of wood resources, but such

resources have been used up and its forests were completely destroyed till the Sui and the Tang Dynasties. Thus, when Emperor Wu Zetian in Tang Dynasty wished to start a large constructional project, people had to transport wood from “Jiangling”. The wood for beams and pillars could only be taken from south China. In their own place (north), they can only find inferior wood of mulberry and willow and so on. The lack of wood resources is bound to greatly restrict the scale of building. Thus “economic factor 0” will greatly rise up.

In terms of aesthetics, great building, with its magnificent outlook, conveys an unparalleled and overwhelmingly impressive air. For the governmental building, its scale is usually the symbol of power and rank, the emblem of order of cosmic, the embodiment of dignity of rites and the psychological premise of their reign. With the accumulation of experience, their residence is the larger; the better---especially after the centralized government is established. According to history, Xiao He, a senior official in Han Dynasty, once took charge of the construction of Weiyang Hall. It is recorded that “when the emperor saw how magnificent the hall is, he thought it’s too luxurious and became very angry...but Xiao said to him: ‘Your majesty, since you are the ruler of the whole nation, without such a magnificent palace, neither your greatness and grandeur nor our reverence to you can be demonstrated, and no evidence will be left to your offspring to sing high praise of you.’ Hearing these words, the emperor was pleased.” Isn’t such psychological motivation one of the great impetuses for the ever-increasing scale of buildings? Aesthetic impetus keeps on increasing and lastly stabilizes at a quite high level. In the Tang Dynasty, art and technology finally blend with each other perfectly. However, in the following Song dynasty, the system of wooden framework highly maturates. Simultaneously, because the empire itself isn’t strong and is frequently invaded at its border. The aesthetic psychology tends to be more introversive and rational. Thus the curve of aesthetic impetus goes down.

Here the value of each factor is given, the trend of each value is on the basis of dynasty that is represented by experience and very agrees with actual history. (Fig3.7) The transverse comparison among each factor can be shown here: Aesthetic judgment is equal to structure in the Tang dynasty and economic is equal to structure also in the Tang dynasty which is poor of woods, and finally, the two most unessential actors- aesthetic judgment and economic turn into the most vital factors, Maybe it’s the inevitable law of history .

The change of four factors is shown in Fig3.6:



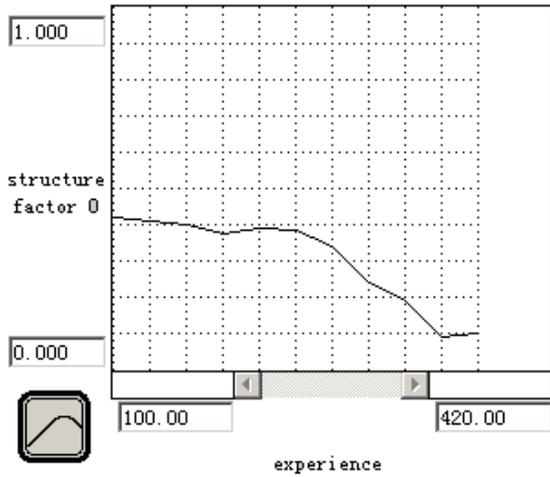


Fig3.6

The drawing of scale value is Fig.3.8. It can be seen from the figure that the developing of building scale is full of zigzag with the accumulation of experience. There're some history examples, for instance, in this drawing the first peak and consequent low valley stands for the blooming and decline of the large scale buildings. (The wood palace in "Three Countries Period" dynasty was smaller than the "Gaotai" (large scale) buildings which was blooming, such as the mega-setback building with 80m each edge in the center of Wang Mang temple.)

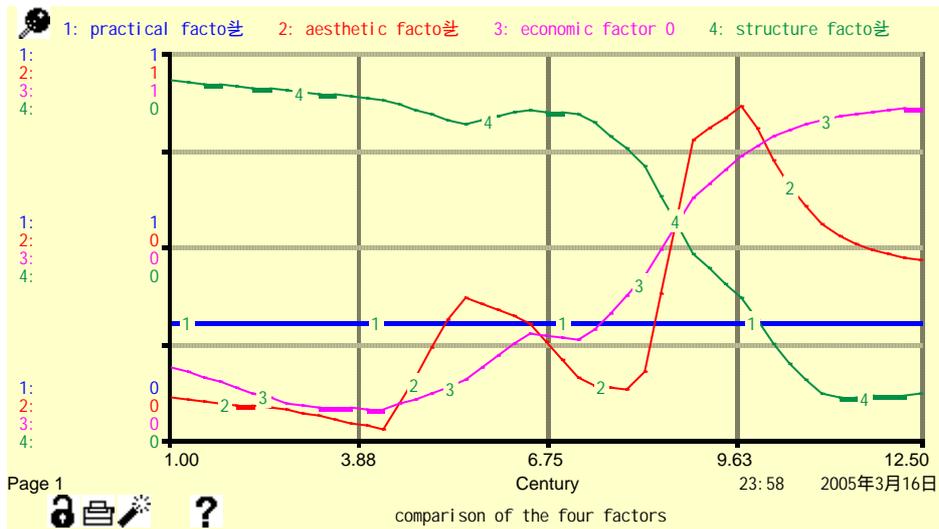


Fig3.7

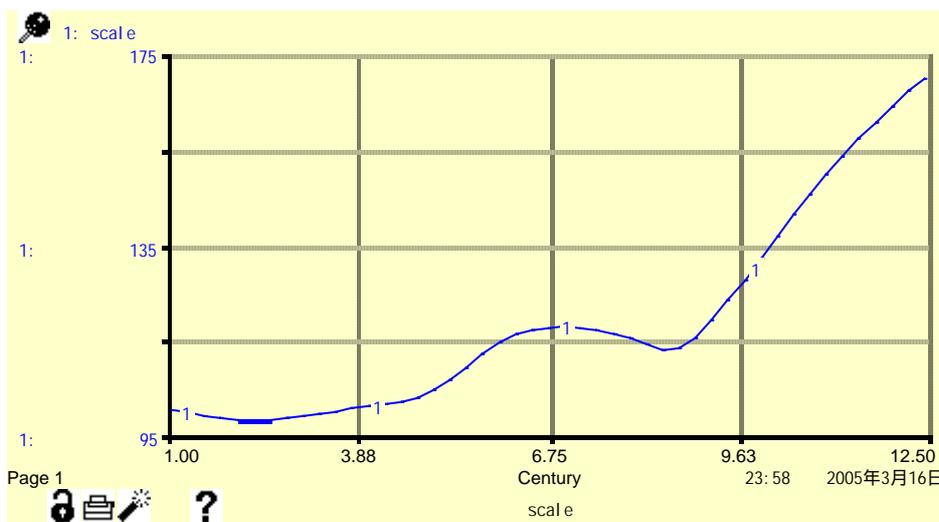
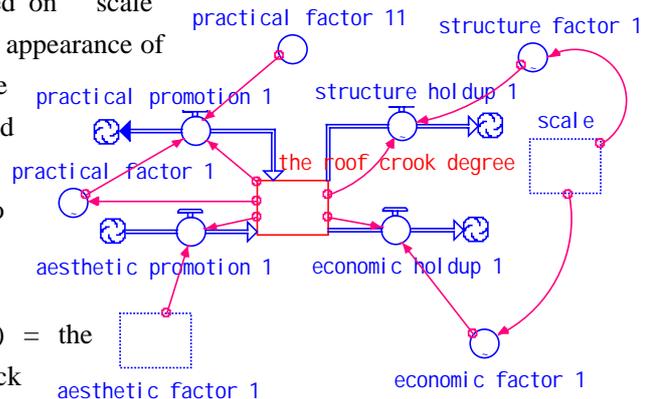


Fig3.8

3.3 The roof crook degree

We should also discuss the four factors of "practical, economy, structure, appreciate beauty", these discussions are all established on "scale" (Because they are mostly concerning with the appearance of the house), and at the same time these discussions are relatively opposite and independent. The mode diagram is in Fig3.9 (There's subscript 1 added to each factor to distinguish with the other factors):



The formula of computation:

The value of obstruction(promotion) = the obstruction(promotion) factor × central stack

The function of "practical promotion" here is already no longer needed as the pure space which has been discussed in the section of 3.2. Theoretically saying, for the house which hold

certain scale, the roof change from "flat surface" to "curved surface" can with easy to adopt the light and drain: the roof jacks up, will not make the eaves that stretch outside hold up the person's view, and house inside also can accept the more sunlight; The rain water is flow by the ridge, can rush out at the eaves that jack up farther, eased the degree that the house body which had be poured and avoided leaking. But "practical factor 1" is weak when compared to the factor going with the space need which discussed in the last section. The curved roof reduce the indoor space, and the ray that accept is after all limited, Professor Lou Qingxi even thinks: "The whole roof has been wet by rain at the same timethe phenomenon of the rain to rush out from the roof almost can not be seen." By the way, "practical factor 11" is a function of the roof crook degree, so in fact, the "practical promotion" is a biflow, that's to say, if the roof crook degree is too large, the factor will be below zero, being a block to the increase of the degree.

The influence on the structure mainly as follow: One, when the roof has been changed to the curved face that can influence the stability of the wood frame. Because of the curve, the weight of tiles and the rafter should be increased and on the other hand the weight of the pillar should be decreased, so actually the increase of whole weight is not very distinct. In the beginning, in the structure of lift beam wood frame, the beam had been designed to subject the moment, because of the large span (can amount to more than six meter), which also should bear more moment and shearing force, with the appearance of the structure of through-jointed form, the beam use only to connect different parts of structure, the influence of the increase of the roof weight is extremely minute. Two , the roof is also under the influence of itself, someone thinks when the roof changes to the flat surface, the timber can easily distorted by the rain and the sunlight, but with the construction of buildings, they detected that the warp of the curve face roof is also very distinct ; For the flush of the rainwater, it means to increase the vertical load of cornice but to decrease the load of ridge of the house, so the total influence is also not very patent. Three, it is about the construction difficulty; to make the roof flat surface is relatively easy. Colligate the above discussions, the "structure factor 1" is also weaker, but when the scale has been enlarged, the structure factor should also be enlarged.

Taking the economic aspect into account, to make curve face can save the timber of the pillar but increase the timber of the rafter, two aspects counteract each other, the whole affect is not very

obviously (but totally saying that still increased the timber). The key is that the dosage of the glazed tiles increased, because of the officer buildings usually use the glazed tiles; the cost certainly will be higher. This condition had not changed until Song dynasty, because the yield of glazed tiles increased very much and the breed of the decoration tiles became much more abundant, so the price problem was not outstanding. This is a resistance function, which decreases gradually; certainly the scale increment can enlarge this influence.

The most complicated is the function of appreciate beauty. The roof plays as a higher part in the whole building system, its appearance mainly influenced by the complexity of people's mentality on appreciates beauty. Because of this, delineate this kind of mental trend directly is very difficult, might as well "appreciate beauty" to be seen as a central stack, its value and each factor of front meaning homology.

This stack value is affected by both promotion and holdup factor. The computation formula is :

$$\text{Holdup(promotion) flow} = \text{Holdup(promotion)factor} \times \text{central stack value}$$

The drawing of model is shown in Fig3.10.

The accelerative factors include: 1.

Vaunting mentality of rich and powerful people.

Since city became flourishing after the Song Dynasty,

plenty of tall buildings were built by magnates strive

to be the first and roof driven up showed display

while glass tile looked magnificent and jewelry by

added roof slope. 2. Beautiful consideration of

relaxation and lifelikeness in architecture field. Huge

volumes of roofs bring lines rigidified formally and make ponderous and depressive but curved

surface roofs show lighter and blander. 3. Desire of creation. The ancient architecture workmen

were suppressed firmly; so they abreacted their innovation only by such alter. 4. Mental catering

for the Chinese ancient traditional philosophy. Curved surfaces symbolize harmonious, intelligent

and grandiose while lines hardly express. In the above four factors, 1 and 2 can regard as functions

of scale values, while 3 and 4 are stable relatively.

The impeditive factors include: 1. Conservative concepts, as discussed in the chapter 3.12. Sense. Things will develop in the opposite direction when they become extreme. That is, when roofs curve to certain extent, the above accelerative factors will bring the

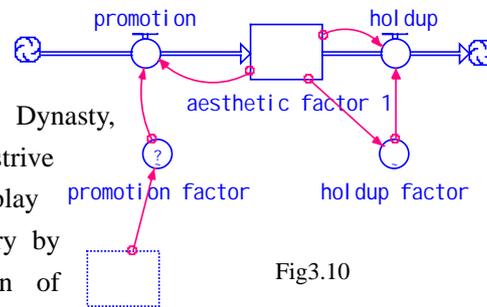


Fig3.10

Aesthetic factor 1	Holdup factor
0.100	0.050
0.150	0.055
0.200	0.060
0.250	0.064
0.300	0.068
0.350	0.070
0.400	0.075
0.450	0.080
0.500	0.090
0.550	0.100
0.600	0.150
0.655	0.190
0.700	0.200

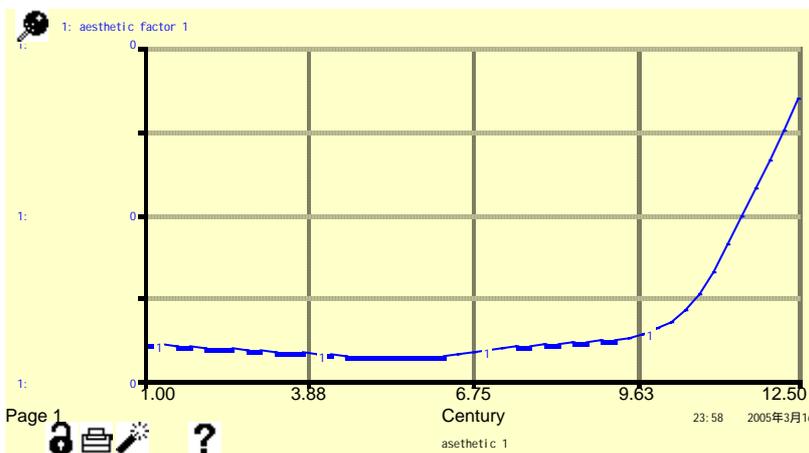


Fig3.13

Fig3.11

inverse.

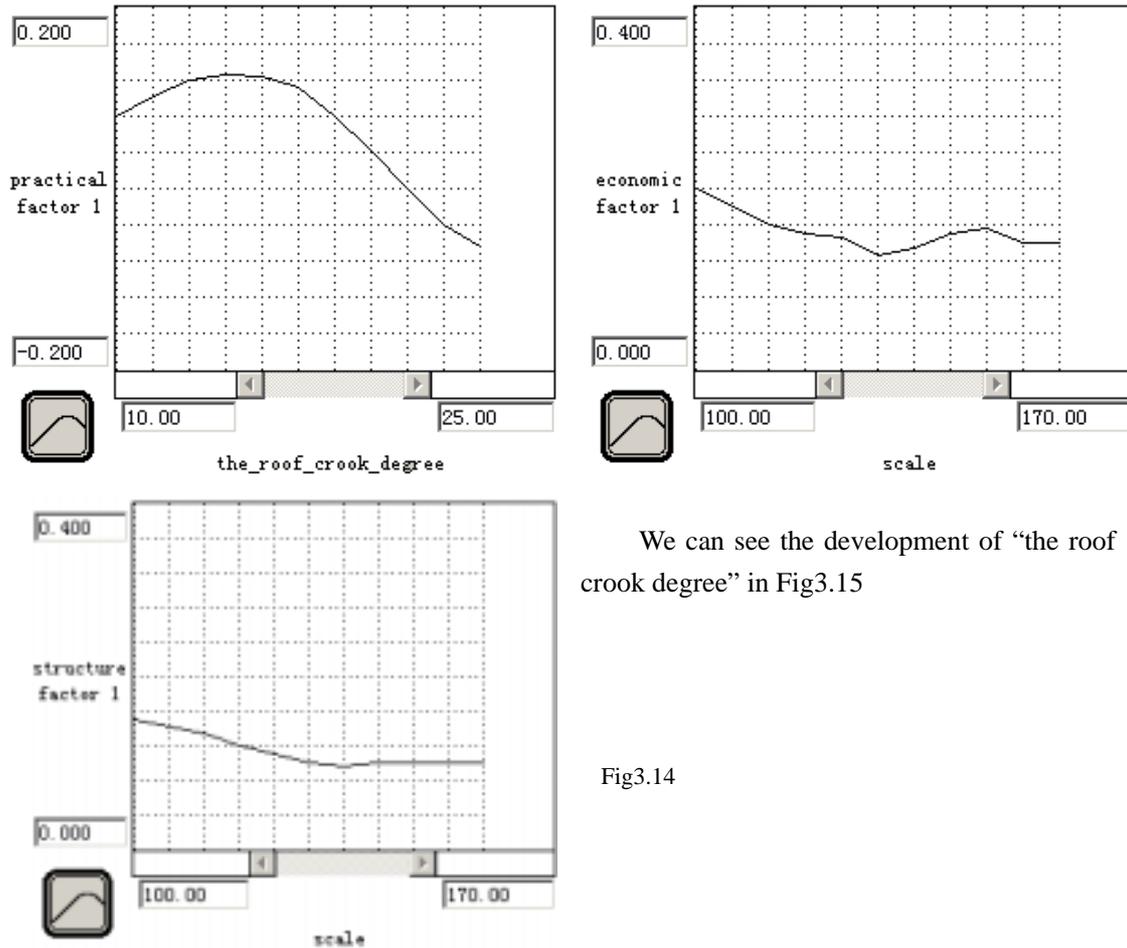
The data is shown in Fig3.11, 3.12:

I think the simulative figures are reasonable because there is two history facts can state them. The first fact is that the first ascend pinnacle represents the rise of aesthetic concept (that is

Scale value	Factor 1	Factor 2	Factor 3	Factor 4	Promotion factor
100	0.001	0.02	0.015	0.02	0.056
105	0.002	0.022	0.015	0.02	0.059
110	0.003	0.024	0.015	0.02	0.062
115	0.003	0.027	0.015	0.02	0.065
120	0.006	0.033	0.015	0.02	0.074
125	0.013	0.035	0.015	0.02	0.083
130	0.019	0.037	0.015	0.02	0.091
135	0.03	0.04	0.015	0.02	0.105
140	0.05	0.05	0.015	0.02	0.135
145	0.07	0.06	0.015	0.02	0.165
150	0.08	0.07	0.015	0.02	0.185

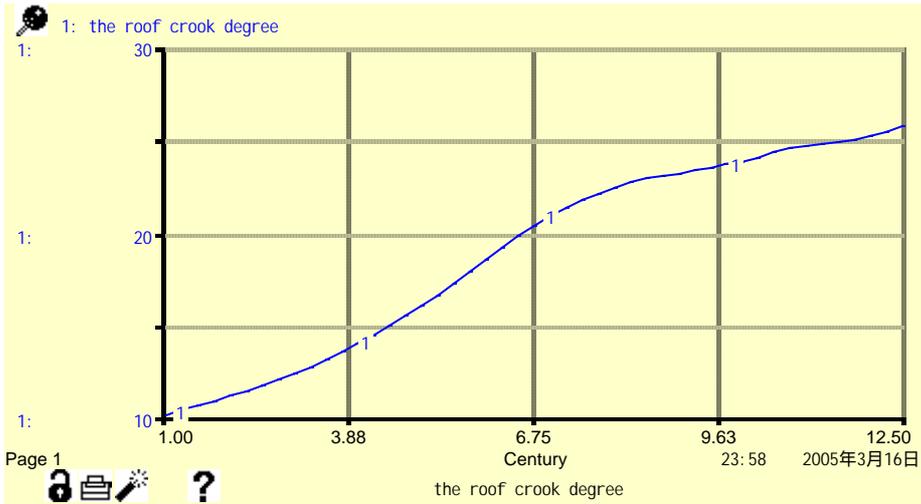
metaphysics and Buddhism philosophy) in the Wei and Jin Dynasties. The concept breaks through the fetter of the Han Dynasty's scripture and ceremony so that the art style alters consequently. The second fact is that the final ascend trench represent the mentality of rich and powerful people affect architecture form due to the rise of magnates in the Song Dynasty.

On the basis of above discussion, the value of other factors can be given in Fig3.14:



We can see the development of “the roof crook degree” in Fig3.15

Fig3.14



It can be seen from the trend graph that the crook degree of roof is strengthening and becomes a consequential trend after a long time. This degree can be

quantized by a series of given values.

Fig3.15

10—15, the curved roof is not obvious; the technology is not mature; no rule for the crook degree.

15—20, the curved roof is fairly obvious; the technology develops a lot; no rule for the crook degree.

20—25, the curved roof is very obvious; the technology is almost perfect; many people consider it a necessity to give a rule for the crook degree.

Above 25, the curved roof is perfectly obvious; the technology is perfect; a strict rule for the crook degree.

(Fig3.16: The crook form of all kinds of roof)

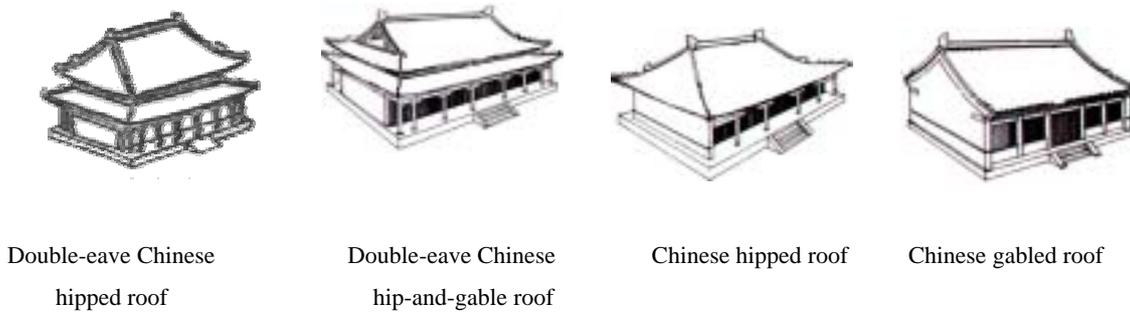


Fig3.16

3.4 The popularity degree

We have already explained the development of the curved roof from the angle of “the curved crook degree”. It’s about the shape. Now let’s turn to the discussion of the popularity of the curved roof, which has something to do with the psychology.

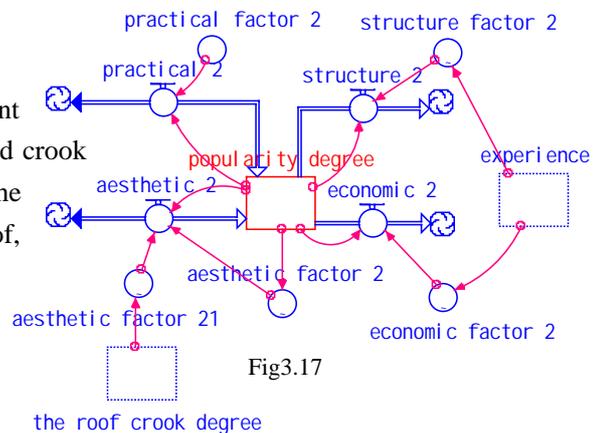


Fig3.17

It's a complicated procedure that the social members accept a style of architecture. Some factors can be the promotion flows while some others are the holdup flows. Quite similar with the discussion in 3.3, we use a stack named "popularity degree". But how the four factors have influence on the "degree" is a little different. As "popularity" is more concerning with psychology, we make "economic factor 2", "structure factor2" functions of the value of "experience". It's shown in Fig.3.17.

As to "practical", we can find that the demand of "practical" is a steady value according to the discussion in 3.3.

"Structure factor 2" is a function of "experience value". As experience accumulates, the holdup effect gradually decreases, and the falling process at first is more and more quickly. But when prior people tried to unify the design according to certain standards, roof, which is an important part during the trial, needed to be explored hard. So the falling process of "structure factor 2" will slow down.

As to "economic", the change process of "economic factor 2" is quite similar to that of

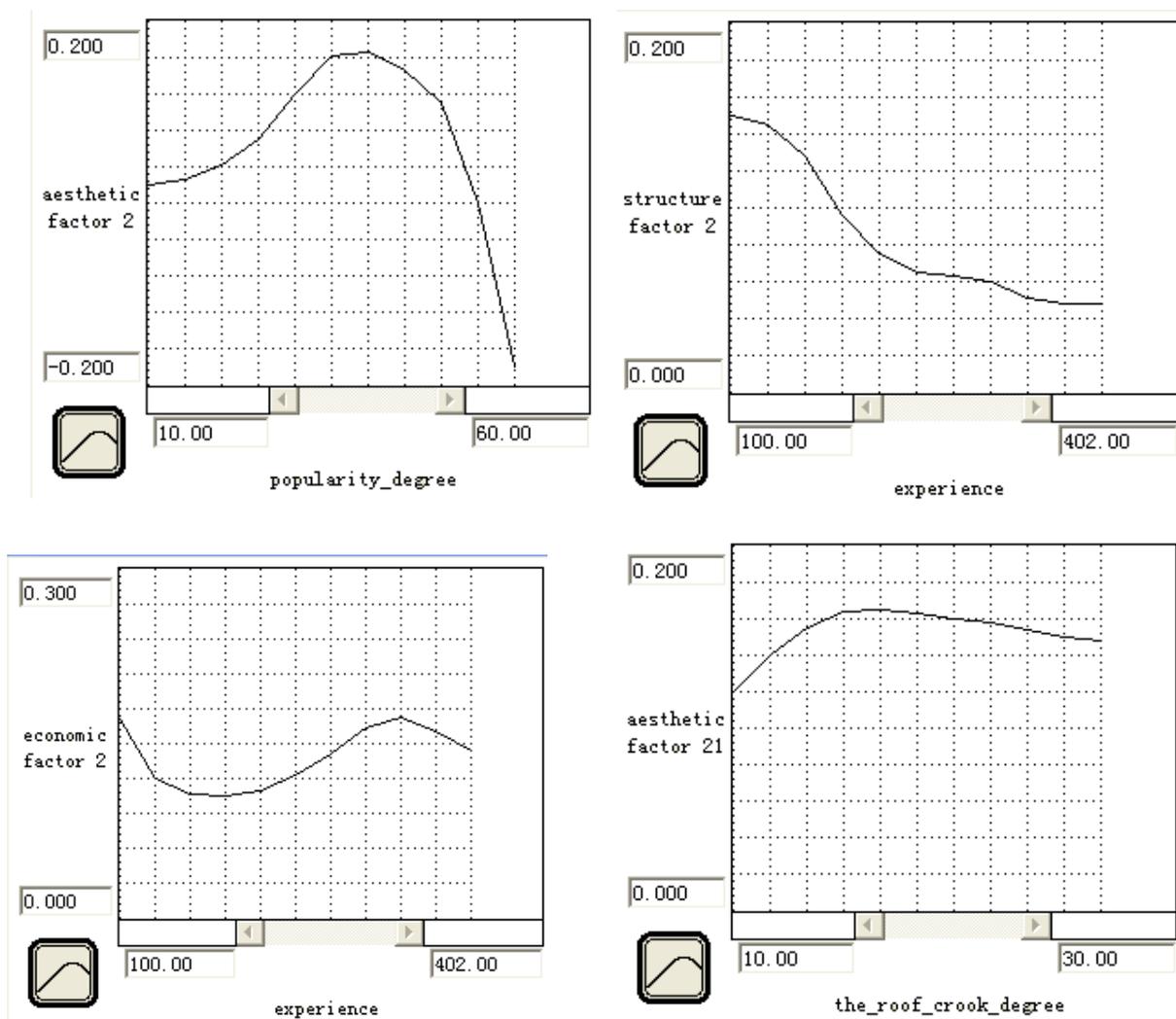


Fig3.18

"economic factor 1", being influenced by the yield of glazed tiles and the wood supply.

The effect of "aesthetic judgment" is also very complicated. We have already analyzed why

the curved roof looks beautiful in 3 · 3. So here I divided the “aesthetic factor 2” into two parts. One is affected by the roof crook degree straightly: as the shape of the roof becomes more and more mature, the popularity will be larger. So “aesthetic factor 21” is higher at first. But if the shape is completely mature, the “vitality” of “aesthetic judgment” won’t so “fresh” as before. There will be more rations. Then “aesthetic factor 21” will fall down. Another (aesthetic factor22) is that the popularity can adjust itself. When most people accept it, some others prefer the new style. They want to change. This kind of creativity belongs to everyone. Then the “aesthetic factor 2” will be below 0. However, this “creativity” didn’t defy the former of the curved roof completely. This also proves that only a simple factor cannot decide the appearing of a phenomenon.

According to the discussions above, we can offer the data. (Fig3.18)

The change process of “popularity degree” will be shown in Fig3.19.

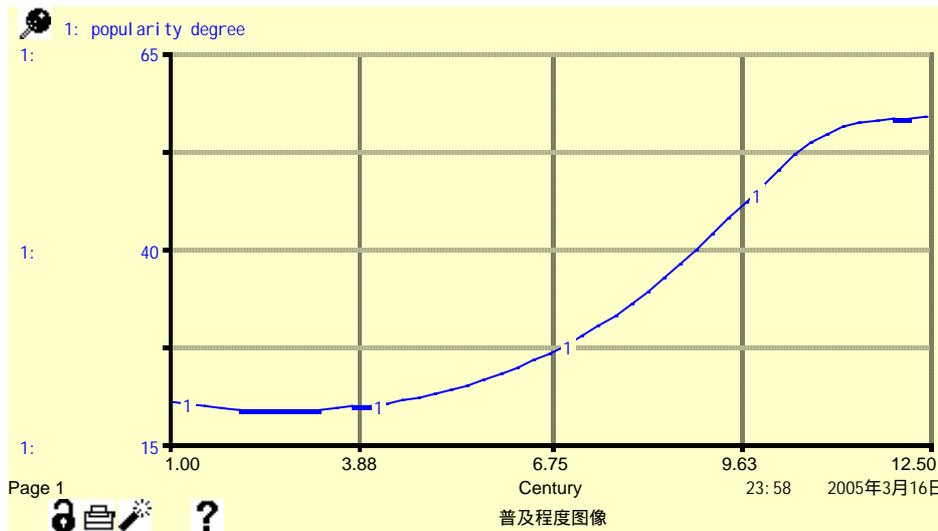


Fig3.19

This has told us that the trend of “popularity” is, before Han dynasty, the curved roof was rare; at about “south and north dynasty” period, it was fairly popular in some certain area; after Tang, Song dynasty, the curve style was very popular in official building (Fig1.1, Tang Dynasty-Palace of FoGuang Temple in Wutai Mountain is a good example). The popularity then reached a balance.

4 , Some other words

Using the Stella software, we have a try on explaining the former of the curved roof of Chinese ancient architecture by system dynamics view: the factors we call “structure”, “practical”, “aesthetic judgment”, “economy” affect each other. The trend of the using of the curved roof was increased a lot at first, and then reached a balance eventually. As I’m a high school student who really enjoy the world of architecture, the explanation itself has caused and satisfied my interest of a kind of research. But something more important is that I have cemented an opinion here: in our world, physical and mental (we call it a system), so many social phenomena exist under the control of different basic factors. It’s more complicated than we expect most of the time. Luckily the system dynamics view makes us face the complicating world in a deeper, wider sight, and retrace the procedure of its former and change. Then we can make sense of world better. So this kind of try has encouraged me a lot.