

# Automatic Parameters Modeling of Wood-Frame Construction of Chinese Yingzao Fashi in Song Dynasty by Spatial Semantic Rules

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**Abstract**— This study will refer to the SONG Yingzao Fashi, wood-frame construction (WFC), as an example to explore and construct spatial semantic rules (SSR) applied to building information modeling (BIM) parameters of automated modeling methods and their effectiveness. The theoretical framework of the automatic modeling of BIM parameters for SSR is deduced, the establishment of Yingzao Fashi WFC component relevant literature databases, analytic geometry and structural properties related to Yingzao Fashi WFC component, construction of WFC component basis BIM object database conversion build a 3D model of the spatial simulation display, analyze and deduce Yingzao Fashi WFC component factor and its bonding mode program to construct prototype GDL dynamic simulation platform. Using this simulation program developed by the correlation matrix of semantic rules. It could provide the future of China's architectural research tools, teaching, design reference to use.

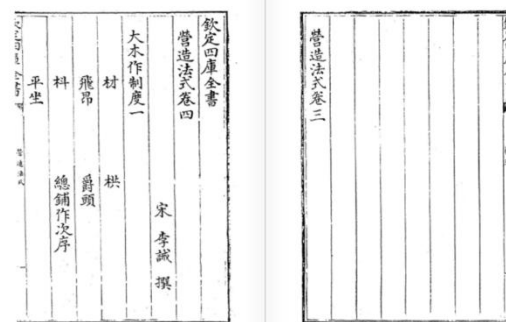
**Index Terms**—building information modeling (BIM), parametric modeling, spatial semantic rules (SSR), wood-frame construction (WFC), Yingzao Fashi.

## I. INTRODUCTION

Spatial semantic rules (SSR) are attributes, geometries, and their three-dimensional spatial relations that define objects. It analyzes the rules by the properties and combinations of component units and organizes the geometric properties of objects. Parametric modeling of Building Information Modeling (BIM) is one of the most effective design automation modeling methods available today. It can be automated in a parametric way to produce a rich variety of composite components. It enables faster, more accurate way to build a database, summarize information and analyze it for evaluation. The SONG Yingzao Fashi is China's earliest building construction project legal rules. It can be constructed in the most efficient way. The database that it establishes has described in detail the legal norms of building design, proportion, structure, construction, materials and so on. In particular, the Wood-Frame Construction (WFC) in the roof system, full of rich description of the components. However, its complex structure, even with a unified simple Dou Gong stacked. Even simple system of object vocabulary can be used to describe the overall complexity of the manifestations. Which in turn can reflect the different dimensions of the use of its unified look. Really amazing and curious.[1-3]

## II. YINGZAO FASHI & WOOD-FRAME CONSTRUCTION

The Yingzao Fashi is the first official book in China that deals with architectural engineering practices in detail. For the study of ancient architecture, the development of the Tang and Song dynasties, the examination of the architectural form of Song and later buildings, the practice of project decoration, and the organization and management of the construction at that time were invaluable. This book was compiled in the three years (1100) of Yuanfu in the Northern Song Dynasty and was issued in the second year (1103) of Chongning. It will be made by the supervisor and Li Jian. The book regulates a variety of architectural practices and specifies the requirements for various architectural construction designs, materials, structures, and proportions. It is the collection and summarization of architectural design and construction experience at that time, and has a profound impact on future generations [4, 5]. A total of 34 volumes of the book is divided into 5 sections: name definitions, various production systems, work limits, material examples, and drawings. These describe how to select materials according to the grade of the building to determine the proportions, positions, and relationships among various components. The Wood-Frame Construction (WFC) and Wood Decoration together account for 8 volumes. Among them, WFC first regulated the use of Chai. The proportion and size of WFC use Chai as the basic module [6-8].



1a.

所用材之分以為制度焉... 造拱之制有五... 一曰華拱... 二曰泥道拱... 三曰瓜子拱... 四曰合拱... 五曰斗拱...

第七等廣五寸二分五釐厚三寸五分... 第八等廣四寸五分厚三寸... 右殿內梁... 梁廣六分厚四分... 各以其材之廣為十五分以十分為其厚...

出四跳謂之七鋪作... 出五跳謂之八鋪作... 自四鋪作至八鋪作皆於上跳之上橫架... 凡於額須坐椽科安鋪作者謂之補間鋪作... 其鋪作布令遠近勻...

總鋪作次序... 總鋪作次序之制凡鋪作自柱頭上椽科內出一拱... 出一跳謂之四鋪作... 出兩跳謂之五鋪作... 出三跳謂之六鋪作...

1b.

1f.

Fig. 1: The content of Yingzao Fashi.[5]

二曰泥道拱其長六十二分... 三曰瓜子拱... 四曰合拱... 五曰斗拱... 每頭以四瓣... 每頭以四瓣... 每頭以四瓣...

交安椽柱口內若椽鋪作數多... 每跳之寬心不過三十分... 鋪作之數斜出跳一... 長分之... 三十二分出仰其五分...

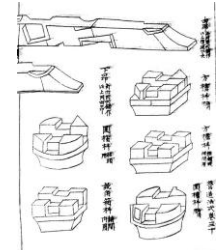
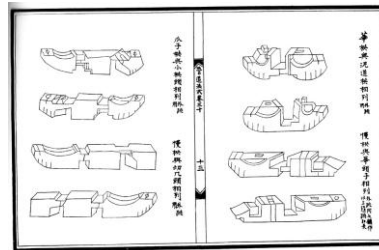


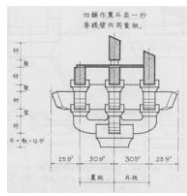
Fig. 2: The drawing of Dougong WFC in the Yingzao Fashi.[5]

1c.

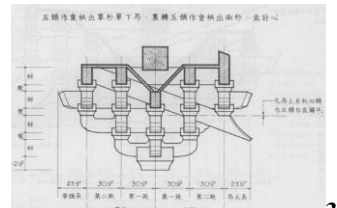
The drawing of WFC representation in the Yingzao Fashi in 1984 like (Fig. 3), (3a.)-(3e.) is the 4-8 Puzuo, (3f.)-(3h.) is the Dou and Gong.

若累鋪作數多... 外令樑出數之如上... 故過樑身有不出... 心版卯只用... 造料之制有四... 一曰椽科... 於椽柱上者方二十六分...

凡駢科樑用其下跳... 造樑頭之制用足材... 樑下六分自頭上量五分... 留心各樑五分... 大樑上兩面開龍牙...

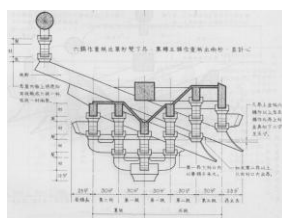


3a.

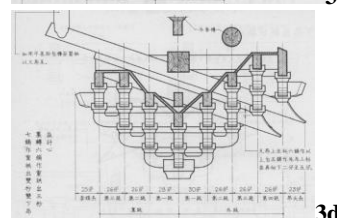


3b.

1d.



3c.

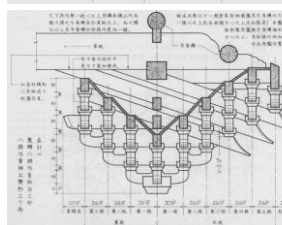


3d.

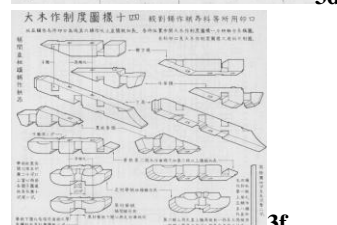
1e.

凡四耳科... 造樑之制有五... 一曰樑科... 二曰散樑... 三曰斗拱... 四曰散樑... 五曰斗拱...

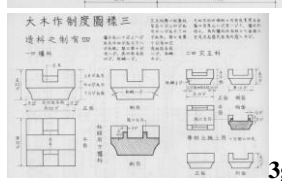
高二十分上八分... 樑之開口廣十分... 樑底四面各殺四分... 二曰交料... 三曰齊心... 凡四耳科... 造樑之制有五...



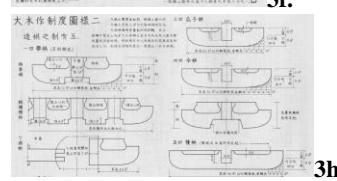
3e.



3f.



3g.



3h.

Fig. 3: The drawing of Wood Frame Construction (WFC) in the Yingzao Fashi.[9]

There are some images of Yingzao Fashi (Fig. 1), (1a) is this is content, (1b), (1c) is the Gong descript, (1d), (1e) is the Dou descript and (1f) is Puzuo descript. The drawing of Dou and Gong like (Fig. 2).

III. METHODS

In this study, the theoretical method of spatial semantic rules is deduced first, and the grammatical rules are compiled to establish the object parameter data. After analyzing and integrating the system of Yingzao Fashi WFC, the article attributes are generated through the constructed semantic rules. Then use their attribute grammar to establish mutual relationship between the parameters [10, 11]. The BIM builds a parametric repository of component models. Combine different component models with automated modeling [12]. And then take these Yingzao Fashi WFC's elements to combine components [13]. The complete objects of WFC's components, there are included plan, elevation, section, detail, three-dimensional view, perspective, material tables and other information. And import BIM quantity estimation function for analysis and evaluation. And then programmed, converted to GDL (Geometric Description Language) parameterized object modeling [14, 15]. Then use BIM's ArchiCAD software as a simulation platform to parameterize the model database and construct various parameterized views as feedback [16, 17]. Finally, the benefits of traditional modeling and automation parameter modeling are evaluated, to verify the effectiveness of its dynamic simulation. Then further explores the integral relationship between the geometric dimension of the component and the relation and its attribute in the Yingzao Fashi WFC. Including component name, size, shape, location, level, bonding and so on, for architectural design diversification of design attributes and geometric model to do verification. Then construct the core theory of the automatic benefit evaluation of the initial dynamic simulation and parameter modeling [18].

A. Dou

There are three method for Dou elements included in this study: the geometry parameters of Dou elements (Table 1), the semantic model of Dou (Fig. 4) and the dimension rules of Dou (Table 2).

Table 1: Parameters of DOU Elements

variable	name	LD	LDc	LDr	LDrc	CHDh	CHDt	CHDe	CHDf	CCD	CCDp	PPD	SD
dou_height	DH	20	20	20	20	10	10	10	12.5	10	10	6	10
dou_width	DW	32	36	32	36	16	16	16	18	16	16	16	14
dou_length	DL	32	36	32	36	18	18	18	24	16	16	16	16
top_ear_height	TH	8	8	8	8	4	4	4	6.5	4	4	0	4
middle_flat_height	MH	4	4	4	4	2	2	2	2	2	2	2	2
bottom_chi_height	BH	8	8	8	8	4	4	4	4	4	4	4	4
bottom_chi_length	CL	4	4	4	4	2	2	2	2	2	2	2	2
bottom_chi_curve	CR	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
latch_width	LW	10	10	10	10	10	10	10	0	10	10	0	10
latch_length	LL	10	10	10	10	10	0	10	18	0	10	0	0
latch_depth	LD	8	8	8	8	4	4	4	6.5	4	4	0	4
latch_wall_height	LWH	4	4	4	4	2	0	2	0	0	2	0	0
latch_wall_thick	LWT	3	3	3	3	1.5	0	1.5	0	0	1.5	0	0
ride_latch_length	RLL	0	0	0	0	0	0	14	0	0	0	0	0
ride_latch_width	RLW	0	0	0	0	0	0	6	0	0	0	0	0
ride_latch_height	RLH	0	0	0	0	0	0	5	0	0	0	0	0
corner_gong_cut_depth	CGCD	0	0.5	0	0.5	0	0	0	0	0	0	0	0

elevation dimension

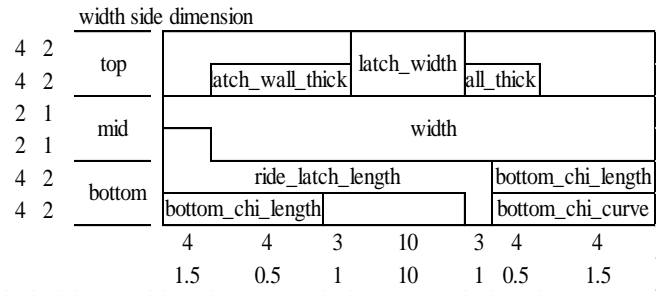
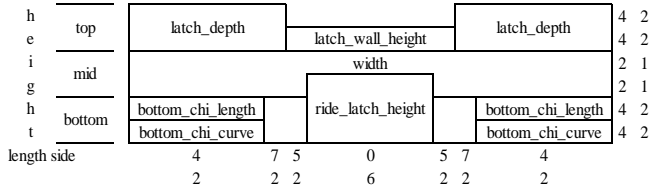


Fig. 4: Semantic Model of DOU Elements (up is length dimension, down is width dimension)

Table 2: Rules of DOU Elements

object	length	width	height	location
Ear	(DL-LL)/2	(DW-LW)/2	TH	
Lear	LL	LWT	LWH	only LL direction
Flat	DL	DW	MH	
Chi-up	DL	DW	BH	
Chi-dn	DL-CL*2	DW-CL*2	curve(CL, BH, CR)	
RideL	DW-CL	triangle(RLW)	RLH	only CHDe
Ear-cut1	(DL-LL)/2/2	(DW-LW)/2/2	triangle(TH)	only LDc
Ear-cut2	square(((DL-LL)/2/2)^2+((DW-LW)/2/2)^2)	CD	triangle(TH)	only LDc

The LDr for example:

object	radius	angle	height	location
Ear	(L-LL)/2	90	TH	
Lear	LL	LWT	LWH	only LL direction
Flat	DL/2	360	MH	
Chi-up	DL/2	360	BH	
Chi-dn	DL-CL*2	360	curve(CL, BH, CR)	
Ear-cut1	curve length (square(((L-LL)/2/2)^2+((W-LW)/2/2)^2))	curve	TH	only LDrc
Ear-cut1	curve length (square(((L-LL)/2/2)^2+((W-LW)/2/2)^2))	CGCD	TH	only LDrc

B. Gong

Also, there are three method for Gong elements included in this study. Like the geometry parameters of Gong elements (Table 3), the semantic model of Gong (Fig. 5), the rules of Dou on Gong (Table 4) and the rules of Gong under Gong (Table 5).

Table 3: Parameters of Gong Elements

variable	name	HG	NDG	GZG	LG	LGcf	MG	MGcf	HGn	HGt	Stu	Std	EN	EN2
jump_number	JN	2	2	2	2	2	2	2	3	1	3	3	3	3
jump_length	JL	30	30	30	30	30	30	30	30	30	30	30	30	30
gong_height	GH	21	15	15	15	21	15	21	21	21	21	21	21	21
gong_width	GW	10	10	10	10	10	10	10	10	10	10	10	10	10
gong_length	GL	72	62	62	72	72	92	92	72	72	72	72	72	72
chee_height	CH	6	0	0	0	6	0	6	6	6	6	6	6	6
gong_height_up	GHU	6	6	6	6	6	6	6	6	6	6	6	6	6
gong_height_dn	GHD	9	9	9	9	9	9	9	9	9	9	9	9	9
GS_cut_number	GSN	4	4	4	4	4	4	4	4	4	4	4	4	4
GS_cut_length	GSL	4	3.5	4	4	4	3	3	4	4	4	4	4	4
dou_seat_length	DSL	12	12	12	12	12	12	12	12	12	12	12	12	12
eye_height_up	EHU	6	0	0	0	6	0	6	6	6	6	6	6	6
eye_height_dn	EHD	3	3	3	3	3	3	3	3	3	3	3	3	3
eye_length_up	ELU	14	0	0	0	15	0	25	18	18	18	18	18	18
eye_length_mid	ELM	18	14	14	19	19	29	29	18	18	18	18	18	18
eye_length_dn	ELD	12	8	8	13	13	23	23	12	12	12	12	12	12
eye_concave	EC	1	1	1	1	1	1	1	1	1	1	1	1	1
center_length	CCL	10	8	8	8	8	8	10	10	10	10	10	10	10
center_concave	CCC	1	5	5	5	1	5	5	1	1	1	1	1	1
center_width	CCW	8	0	0	0	8	0	8	8	8	8	8	8	8
center_height_up	CHU	21	15	15	15	21	15	21	21	21	21	21	21	21
center_height_dn	CHD	5	5	5	5	5	5	5	5	5	5	5	5	5
seat_length_up	SLU	10	0	0	0	20	0	20	10	10	10	10	10	10
seat_height_up	SHU	5	0	0	0	5	0	5	5	5	5	5	5	5
seat_length_dn	SLD	16	0	0	0	0	0	0	13	13	13	13	13	13
seat_height_dn	SHD	4	0	0	0	0	0	0	2	2	2	2	2	2
eye_side_length	ESL	1	1	1	1	1	1	1	1	1	1	1	1	1

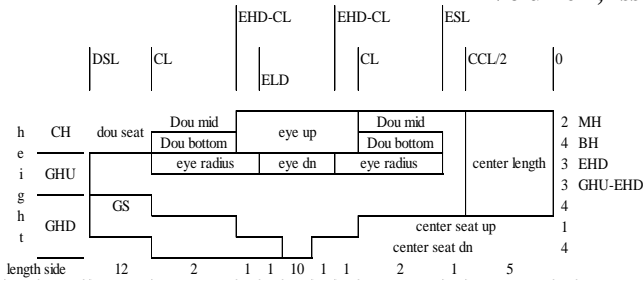


Fig. 5: Semantic Model Gong Elements

Table 4: Rules of Dou \* Gong

	HG	HGn	HGt	STin	EN1	EN2	STout	NDG	MG	GZG	LG	LGcf	MGcf
CHDh	1x1	2lx											
CHDt													
CHDe					x2	x3							
CHDf													
CCD	x	x										x	
CCDp				x			x						
PPD													
SD								1x1	1x1	1x1	1x1	1x1	1x1

Table 5: Rules of Gong \* Gong

	HG	HGn	STd	EN1	EN2	STu	CFT	NDG	MG	GZG	LG	ZTF	LHF	PQF	LYF	YCF
HG		u						x								
HGn			3u	u				x	1x1							
STd				(2u)				1x		2x						
EN1				u				1x			x	1x	2x			
EN2					u3	(1u)			x2		x	1x				
STu						u2		1x		x2						
CFT													x2		x3	x

C. Puzuo

The Puzuo is the combination of Dou and Gong, there are three sequences that define: which Dou must connect upon the regulated Gong, the layer is which Gong must connect across the regulated Gong and which layer must connect upon the regulated layer. The Semantic Model of Puzuo Relationship (Fig. 6), Rules of Puzuo relationship cross layer (Table 6) and Rules of Puzuo parameters (Table 7).

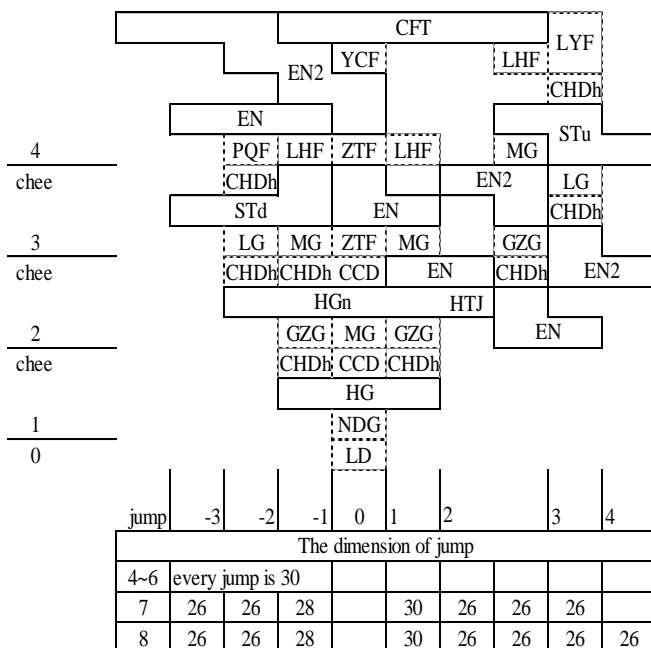


Fig. 6: Semantic Model of Puzuo Relationship

Table 6: Rules of Puzuo relationship cross layer

chai	base_obj (put_obj_1 in_or_out_jump, put_obj_2 in_or_out_jump, ..., put_obj_n in_or_out_jump)
0	LD ((NDG 0) (HG 0))
1	HG ((GZG -1, MG 0, GZG 1) (HGn -2 1 0))
2	HGn (LG -2, MG -1, ZTF 0) (STd -2, EN 1 2)
3	STd ((PQF -2, LHF -1) (EN -2 0))
3	EN (ZTF 0, MG, 1, GZG 2) (EN2 2))
3	EN2 ((LG 3, MG 2, LHF 1, ZTF 0) (Stu 3))
4	Stu ((LYF 4, LHF 3, YCF 0) (CFT -1 3))

Table 7: Rules of Puzuo parameters

PUZUO	GONG	JUMP	EN	I N S I D E	PUZUO	GONG	JUMP	EN	CEN.
6	2	1	2		5	2	2	0	1
5	2	1	1	5	2	2	0	1	
7	2	2	2	6	2	3	0	1	
8	2	2	3	6	2	3	0	1	
5	2						1	1	
6	2						1	0	
7	2						2	0	
8	2						2	0	

D. GDL Coding

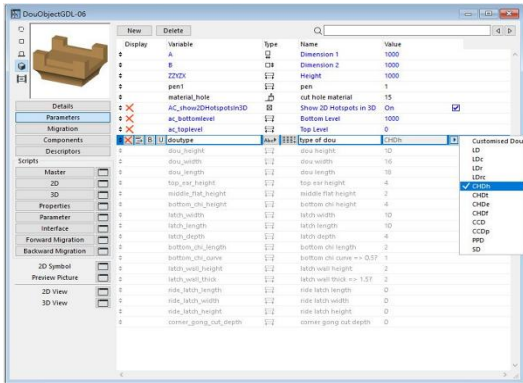
The GDL coding there are Object Element and Combine Sequence. The Object Element coding is create the object elements by the geometry parameters and sematic rules from the Dou and Gong into unit models. There are Dou Object function model, Gong Object function model and Other Object depended on Puzuo number. The Combine Sequence coding there are DouGong, Layer and Puzuo included. (Table 8)

Table 8: the function of GDL coding

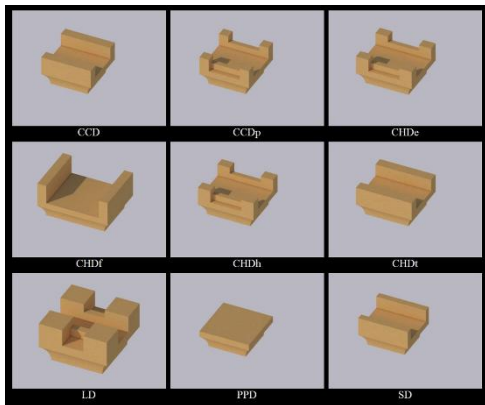
sequence	function	elements
OBJECT ELEMENT	Dou	LD, LDc, LDr, LDrc, CHDh, CHDt, CHDe, CHDf, CCD, CCDp, PPD, SD
	Gong	HG, NDG, GZG, LG, LGcf, MG, MGcf
	Others	HGn- (HGnHG, HGnHTZ), ShuaTou (STin, STout), EN (EN 1 2 3), ChenFangTou (CFT)
COMBINE SEQUENY	DouGong	Dou * Gong
	Layer	Gong * Gong
	Puzuo	Layer * Layer

IV. RESULTS

The results of this study with GDL display every element object of Dou (Fig. 7), Gong (Fig. 8) and Others (Fig. 9, 10, 11) defined in Yingzao Fashi. And the some combination sequence of Dou upon Gong (Fig. 12), Layer of Gong across Gong (Fig. 13) and Puzou of Layer upon Layer (Fig. 14, 15). There are display the GDL parameters interface and show some result of every stage output.

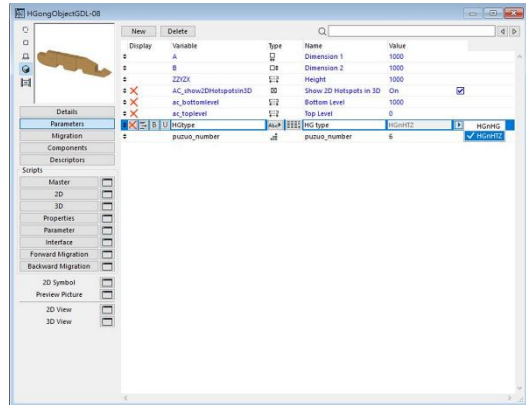


7a.

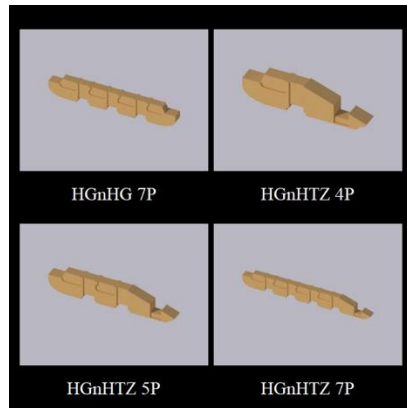


7b.

Fig. 7: Element Object of Dou (The Dou's GDL parameters interface (7a.) and the results partially (7b.))

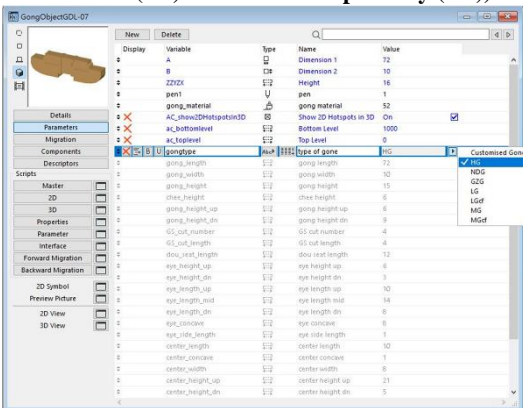


9a.

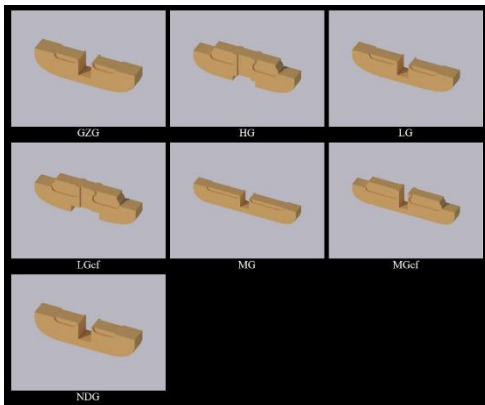


9b.

Fig. 9: Element Object of other – HGn. (The extent HGn's GDL parameters interface (9a.) and the results partially (9b.))

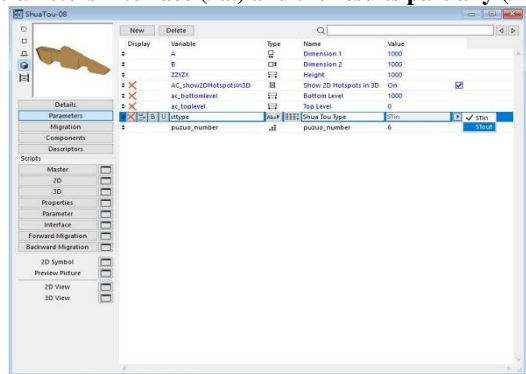


8a.

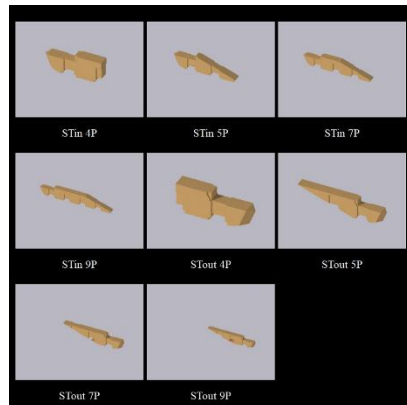


8b.

Fig. 8: Element Object of Gong. (The Gong's GDL parameters interface (8a.) and the results partially (8b.))

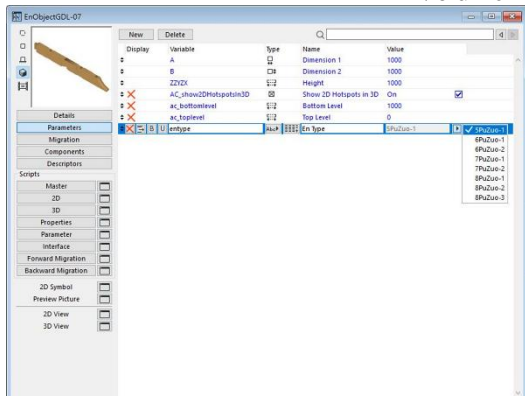


10a.

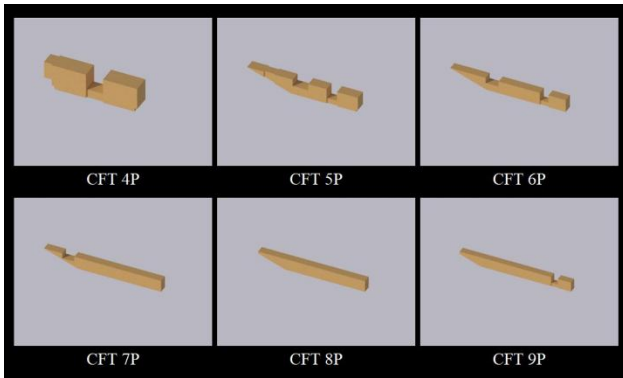


10b.

Fig. 10: Element Object of other – ShuaTou. (The ShuaTou's GDL parameters interface (10a.) and the results partially (10b.))



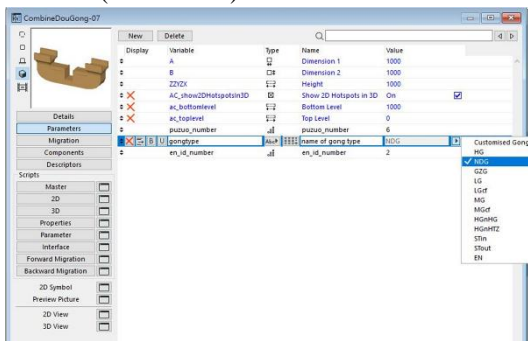
11a.



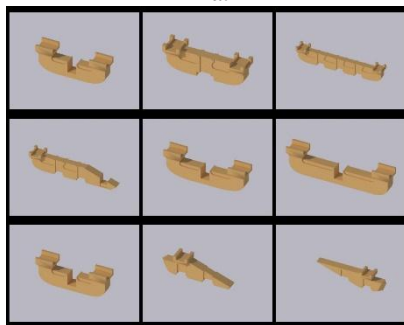
11b.

Fig. 11: Element Object of other – EN. (The En’s GDL parameter interface (11a.) and the results partially (11b.))

The Combination of Dou\*Gong (see Fig. 12) is the first stage of combine sequence into Puzuo. The special Gong must combine the special Dou defined in the Dou\*Gong’s sematic rules (see Table 4).



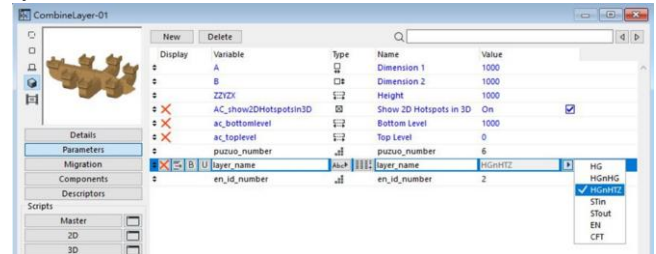
12a.



12b.

Fig. 12: Combine Sequence of Dou \* Gong. (The Combination Dou\*Gong’s GDL parameters interface (12a.) and the results partially (12b.))

The Combination of Gong\*Gong (see Fig. 13) is the second stage of combine sequence into Puzuo. The special Gong must cross combine the special Gong defined in the Gong\*Gong’s sematic rules (see Table 5). It is also call one Layer combination. For example the (Fig. 13b) is HG across by NDG.



13a.

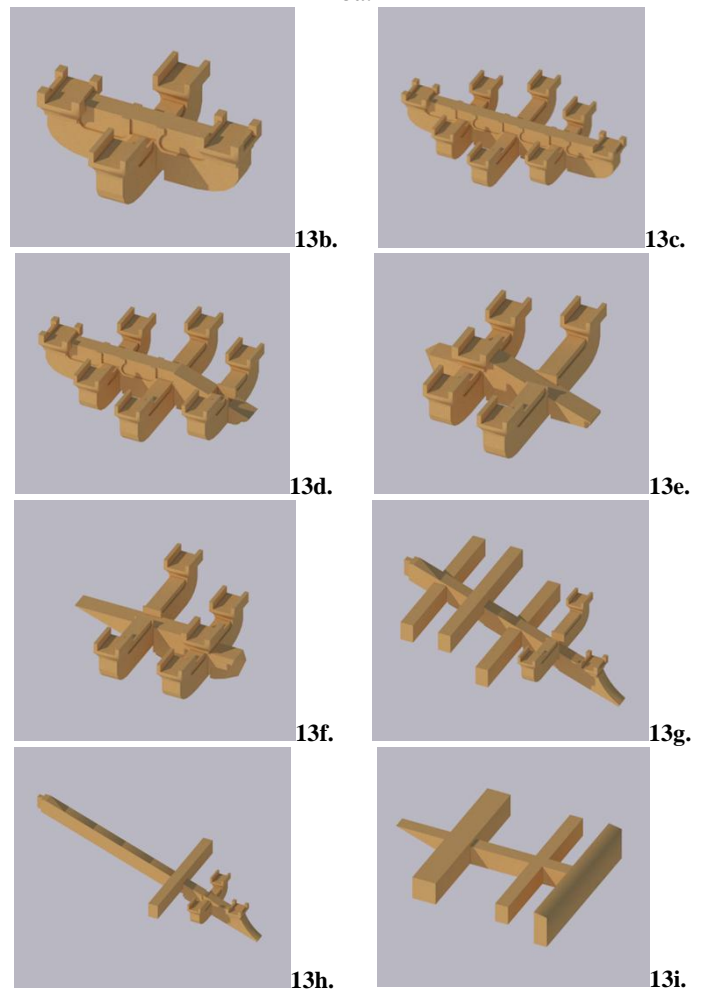


Fig. 13: Combine Sequence of Layer of Gong \* Gong. (The Combination Gong\*Gong’s GDL parameters interface (13a.) and the results partially (13b.- 13i.))

The Combination of Layer\*Layer (see Fig. 14, 15) is the third stage of combine sequence into Puzuo. The special Layer must upon combine the special Layer defined in the Rules of Puzuo relationship cross Layer’s sematic rules (see Table 6). The different puzuo is by different relationship cross Layer’s rules. For example the 6 PuZuo (see Fig. 14. right). It is “outside 6 puzuo double Gongs jumping once and double down Ens, then inside turn 5 puzuo double Gongs jumping

twice and counting jumping center” (see Table 7). There are some types of Puzuo, like 4 PuZuo (Fig. 15a), 5 PuZuo (Fig. 15b), 7 PuZuo (Fig. 15c), 8 PuZuo (Fig. 15d), can be easily modeling and simulation by GDL combination sequence of Puzuo function in this study.

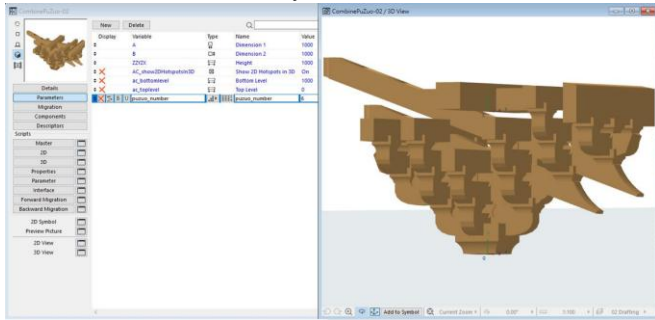
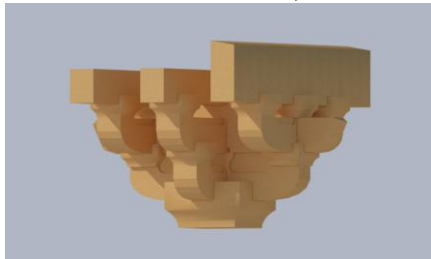
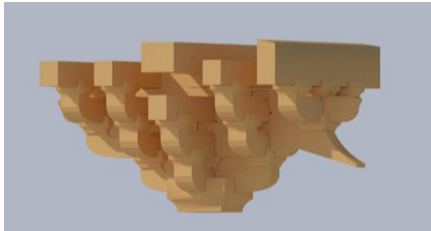


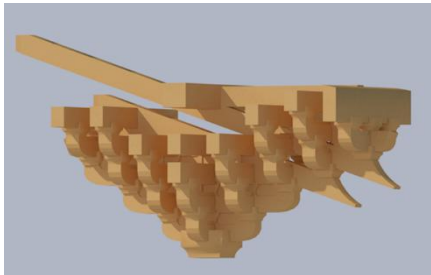
Fig. 14: Combine Sequence of Layer of 6 PuZuo. (The Combination Layer's GDL parameters interface and the result of 6 PuZuo)



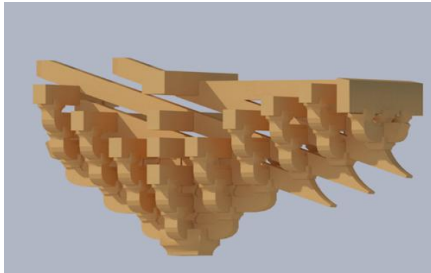
15a.



15b.



15c.



15d.

Fig. 15: Combination Sequence of PuZuo from Layer. (4 PuZuo (15a.), 5 PuZuo (15b.), 7 PuZuo (15c.) and 8 PuZuo (15d).)

## V. CONCLUSION

In this study, Automatic modeling of BIM parameters for SSR is deduced, the establishment of Yingzao Fashi WFC component relevant literature databases, analytic geometry and structural properties related to Yingzao Fashi WFC component, Simulation programming GDL developed by the correlation matrix of semantic rules. There are construction of WFC component basis BIM object database conversion build a 3D model of the spatial simulation, analyze and deduce Yingzao Fashi WFC component factor and to construct prototype GDL dynamic simulation platform. It could provide the future of China's architectural research tools, teaching, designing reference. In this study just focuses on the Dou, Gong and Puzuo, there are still more partial construction of WFC not include, like the plan, column, beam and roof structure, etc. It will be study in the future time.

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