
Chapter 4 Building the digital model for the Foguang Temple

Computer simulation and representation make up the central part of the study. This chapter introduces the modelling process and the academic issues that relate to the computational modelling process. A detailed record of the modelling operation of the Foguang Temple is provided. It explains the whole implementation process in terms of information collection and management, analysis of the structural form and connections, computer modelling, and dealing with the unknown structural parts. It is important to point out that the two important issues of “ideal model” and “minimal adaptation” which have been described earlier in this thesis are discussed in this chapter.

4.1 Information management prior to modeling

The reliability of the computational model depends mostly on the reliability of the sources of information gathered. Basically, there are two main ways for the data collection in the research: on-site investigation and documentation review - graphical and textual. This section focuses on the graphic information, which includes the photos from previous studies, the pictures from the on-site investigation, and most importantly, the manual structural drawings by Liang in his book “Pictorial history of Chinese architecture: a study of the development of its structural system and the evolution of its types”.

4.1.1 Graphic information collection

In order to ensure the validity and reliability of the research, a lot of preliminary data is required. For this purpose, a field trip was made to the historic site. The on-site investigation was planned to look at the information about:

- The natural environment
- The artificial environment (including partitions & columns)
- The components and elements (joints and connection)
- The architrave girders, corbel brackets and tie beams
- The ceiling and roof

As mentioned earlier, the most valuable architectural wisdom of ancient Chinese architecture is its unique timber structural style. Therefore, the major concern of the on-site investigation was to try to identify and record in as much detail as possible the structural features of the building. The trip resulted in approximately 100 detailed photographs of the temple.

Other graphic resources are the drawings based on the measurement by previous studies, most of which are drawn by Liang. The drawings include a site plan, east elevation, and two sections. Unlike the photographs, the drawings offer an integrated view of the whole building. Liang states that the sectional drawings seem to be more important than the elevations for the understanding of this ancient Chinese architecture.

The drawings and photographs are the entire graphic resources for the modelling. A digital model, which needs to be valid and reliable, was to be constructed based on the limited on-site information and Liang's drawings, and supported by other relevant textual documentations.

4.1.2 Graphic information validation

The information resources of the temple available at this stage for computer modelling, then, were:

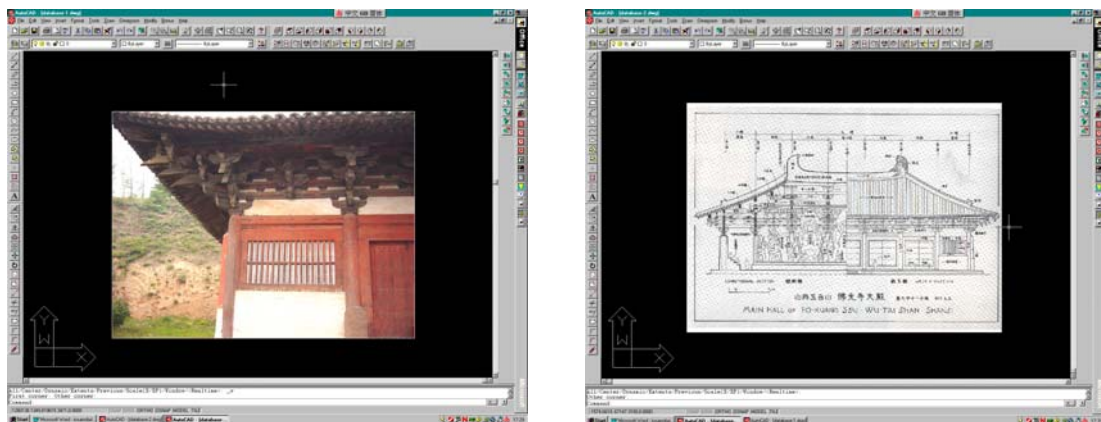
- Photographs of the site
- Drawings by previous researches

To achieve the best result, the modelling must be based on the combination of these information sources. Standing on their own, each does not provide enough for a clear basis for modelling. The accurate digitisation of the plan, elevation and some important sections of the building depend on both types of data mentioned above.

These 2D digital vector drawings act as a platform for the creation of the 3D model.

The digital west elevation of the temple is mainly based on the previous manual drawing. The photos help to understand the relationship between the lines. Based on the structure and construction principles that are shown from previous documentations, the length and distance of lines are refined. Diagrammatically, the main procedures are as follows:

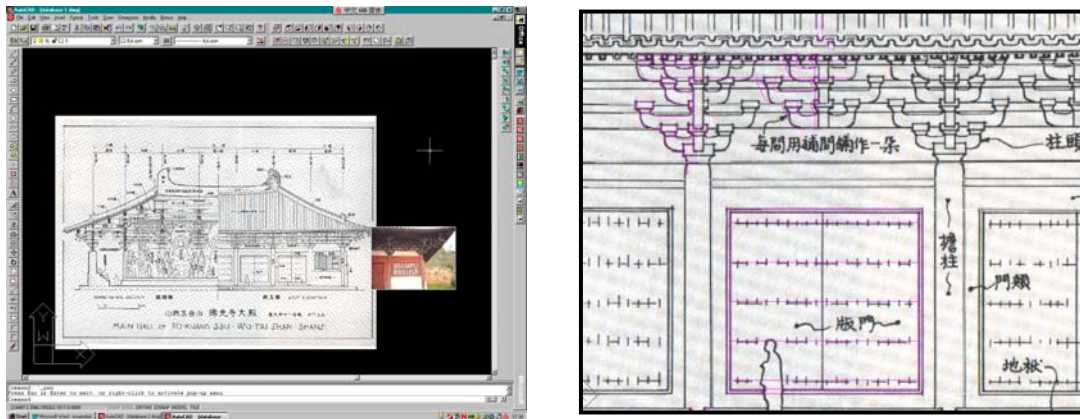
- Previous manual draft input computer (Figure 4-1)
- Photos of physical reality input computer (Figure 4-2)



(Figure 4-1: previous manual drawing input computer)

(Figure 4-2: photos of physical reality input computer)

- Set the link between manual draft and photos (Figure 4-3)
- Draw a computer drawing based on the manual drawing (Figure 4-4)
- Refer to photos to adjust the drawing



(Figure 4-3: the link between manual drawing - photos)

(Figure 4-4: a digital drawing based on the manual drawing)

4.2 A basic study of the construction rules

A digital model of the temple should follow the construction rules of the structure.

This demands that the rules need to be taken into consideration during the modelling process. This section of the thesis discusses the construction rules.

4.2.1 The “Grammar book” as modelling reference

To understand the structure of the temple, we refer to the construction features of Chinese traditional architecture. For this purpose, there are two important books about ancient building activities: Yingzao fashi (Building standard) of the Song dynasty (960-1279), and the Kungcheng tsofa tseli (Structural Regulations) of the Qing dynasty (1644-1912). Liang assessed that these books are “of great importance for the

study of the technological aspects of Chinese architecture.”

For this work, however, the former manual seems to be more valuable and relevant.

Since the development of Chinese traditional architecture has experienced a continued evolution pattern, every change of the construction rules and regulations of the

structural system refers back to the original format. The Foguang Temple was constructed in 857AD of the Tang dynasty, which was several hundred years prior to the Song dynasty. The structural systems of these two eras are closely related.

Consisting of 34 chapters and preceded by preliminary work and calculation, the Yingzao fashi was an official building standard for that era. The first two chapters list 49 terms for construction members. The rest of the work can be divided into four parts:

- Rule: deals with construction methods for different structural members
- Labor: discusses work units, the amount of work for each different category that a skilled artisan is expected to carry out in one day.
- Material: lists the amount of material needed for each type of work and the ratio of ingredients for mortar, plaster, pigments and glaze.
- Drawings: illustrates details of construction

Since timber is the major material used in Chinese architecture, the chapters on “major carpentry” make up the core elements of the book for understanding the structural system. The essence of these construction rules are explained visually and may be summed up as follows:

- Modules: standards of the timber units.

All rules for building construction have measurable units as their basis; for example, the depth of the eaves, the size of each construction member, straight or curved, and the curvature of the roof, are measured in “fen” (section of the unit).

The unit of a building is the same as the cross-section of its bracket-arms. “The actual size of a unit varies, but as soon as the category of a building and the number of span across its front was known, the artisans knew the actual size of the building’s unit and could then proceed with construction” (Steinhardt, 1984).

“The distance between two superimposed bracket-arms is six sections. The bracket-arms that carry the heaviest load are reinforced by stiffeners. Six sections deep, and placed on top of the bracket arms. This is the way the ‘full unit’ dimensions came about. The depths of the largest beams are given in full units” (Steinhardt, 1984).

- Bracket sets & Beams

The beams-in-tiers method forms its major framing system. With this method, columns support beams, which in turn support other tiers of beams on top. Purlins are supported at the ends of these beams. The superstructure consisted of an integral and rigid framework, and included bracket sets which supported projecting eave components. Brackets and the overall timber framework were integrated as mutually strengthening components of one integral whole (Chinese Academy of Architecture, 1982).

- Columns

The column grid can be varied, allowing omission or shifting of column supports in planning. The width and length of the bays are also variable to satisfy different functional demands (Chinese Academy of Architecture, 1982).

4.2.2 Possible construction rules

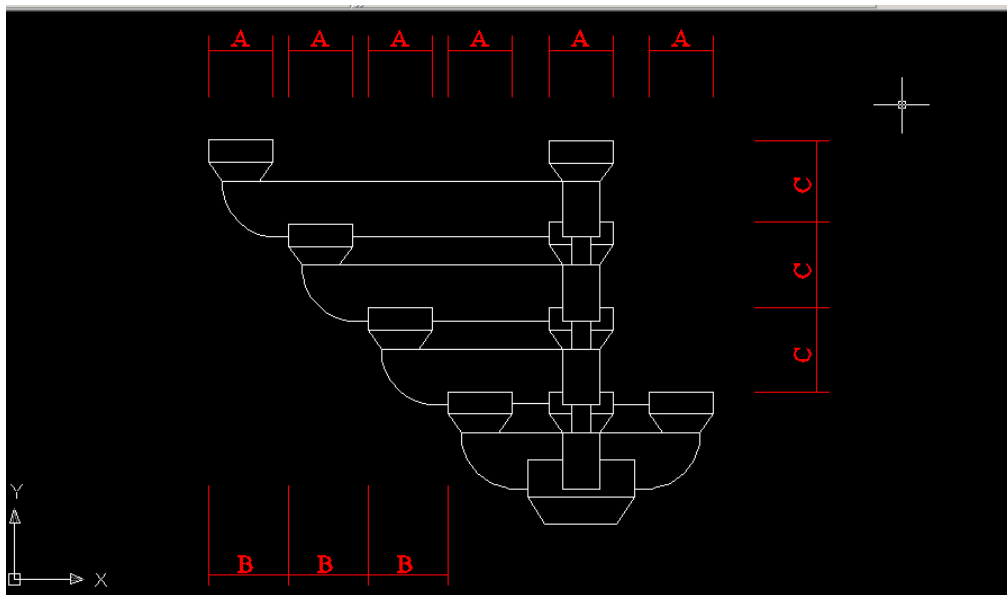
The Foguang Temple can be dated to 857AD. Although the Yingzao Fashi was written 200 years later, it has proven to be valuable in understanding the temple. Therefore, the component and construction rules of the structure of The Foguang temple are studied from the aspects described in the document.

It needs to be emphasized here that the dimensions and shapes from the “building standard” may not exactly fit the Foguang Temple. However, they are related. The book can be a reference to identify the construction rules of the building.

In addition, the previous studies on this building by others are taken as the second reference. They may also later function as assessment tools for a proposed construction rule.

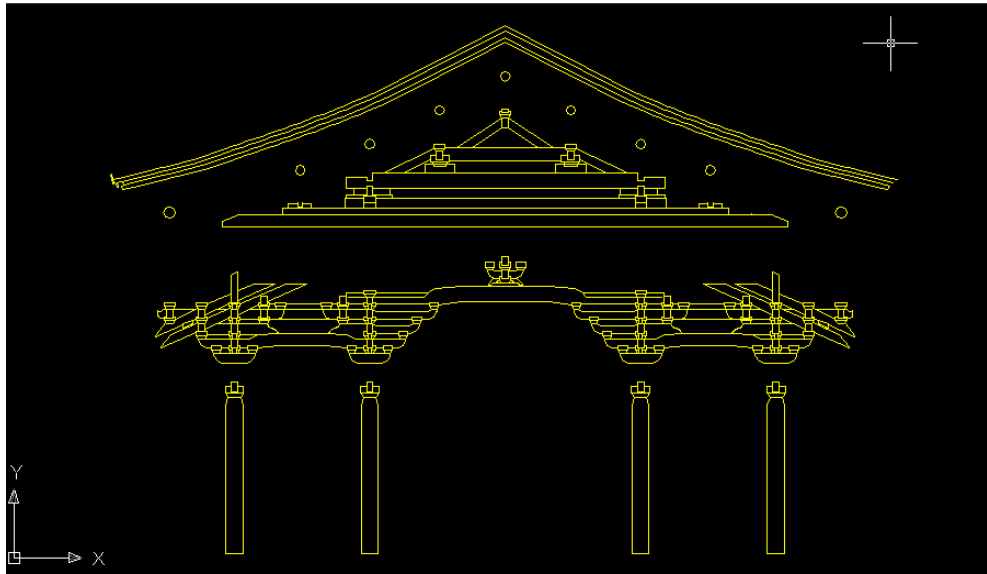
From these references, a series of component and assembly rules are derived for this particular temple:

- Standard of module unit (figure 4-5): the dimension and size of structure elements, and the distance between each element are based on measurable module unit.



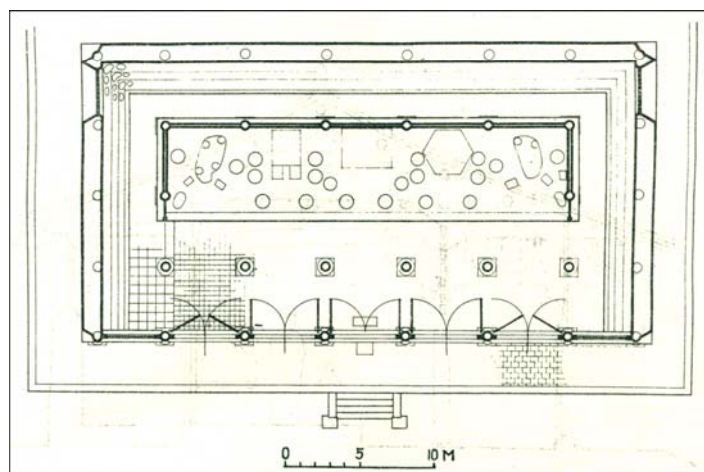
(Figure 4-5: the standard module of elements)

- Structural relations (figure 4-6): the timber structure is of a typical rectangular column network with a “WuDian” (hipped roof) roof style. The structural relations are from columns to bracket system, to roof frame, then to the roof.

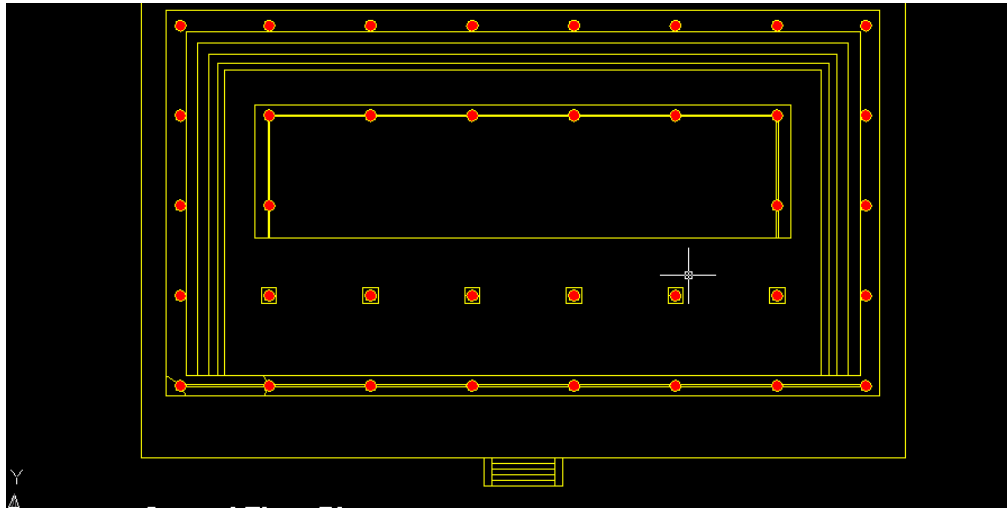


(Figure 4-6: structural relations)

- Column (figure 4-7, 4-8): the network of columns of the Foguang temple is in the format of “rectangular cao”. According to Guo’s research (Guo,1999), “Rectangular cao is the combination of a double cao and two transverse cao. At a distance of two rafters inside the perimeter cao ring, there is a smaller frame ring. These concentric rectangular or regular polygon frames divide the whole structure into two parts, the inner part and the outer. In addition to this, at each corner of this structure, a diagonal bracing beam is usually placed between the inner and outer cao, which adds rigidity to the structure.”



(Figure 4-7, previous drawing of the plan of the column network)

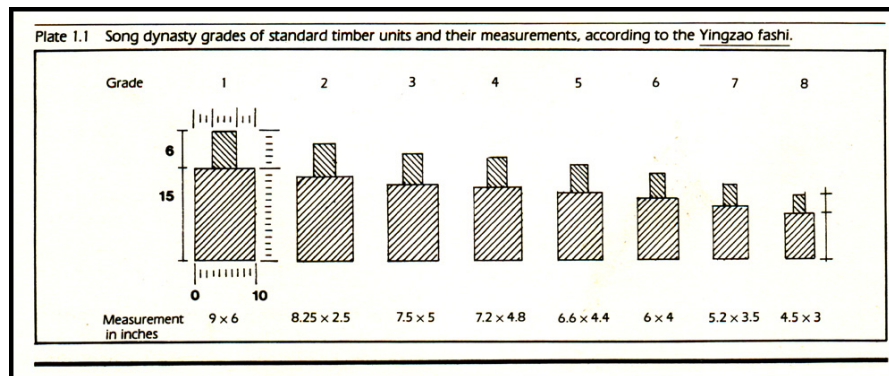


(Figure 4-8, computer drafting of the network of the columns of the structure)

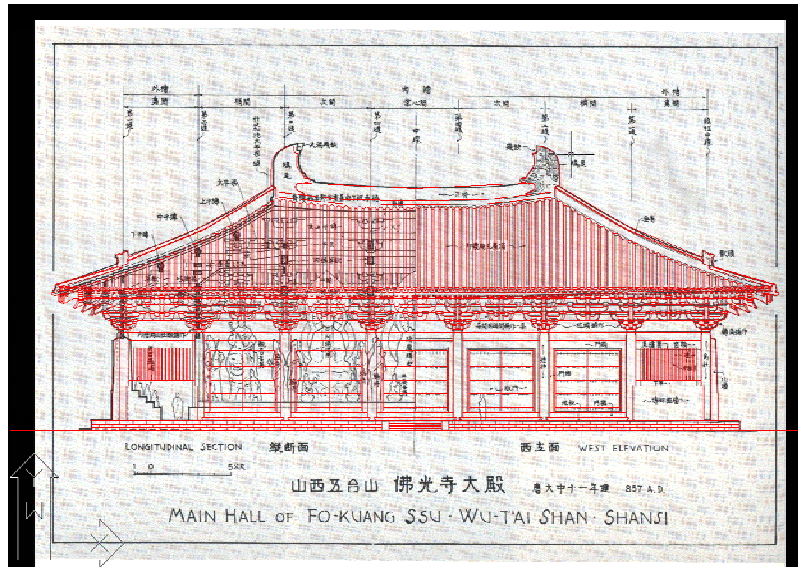
4.2.3 Adoption of rules and grammars in Computer drawing of the temple

The computer drawing from the last phase can be refined further:

- Details are amended according to the structure and construction principles of ancient Chinese timber structure



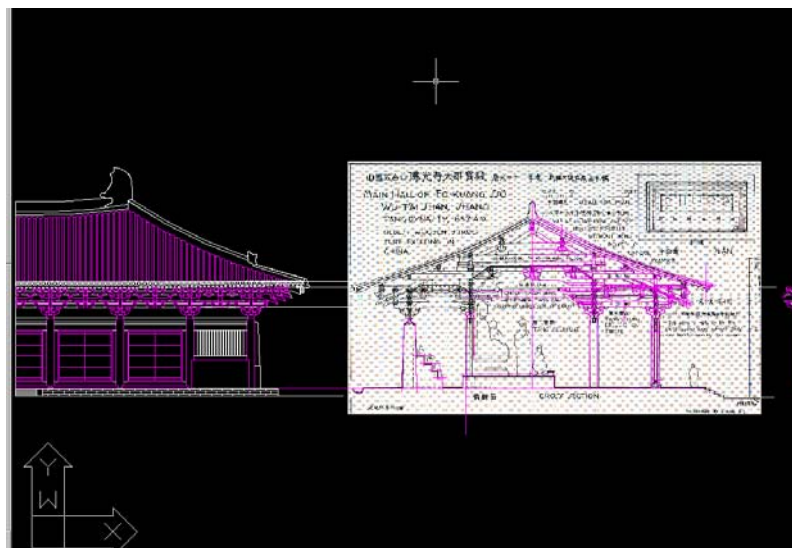
(Figure 4-9: Samples of standard timber units, Steinhardt, 1984)



(Figure 4-10: Manual and digitalised drawings of the elevation to conform to unit)

- Based on the amendment and old drawings, new drawings are recreated digitally.

(Figure 4-11).



(Figure 4-11: an example of section drawing with completed elevation as reference)

4.3 Computational modeling

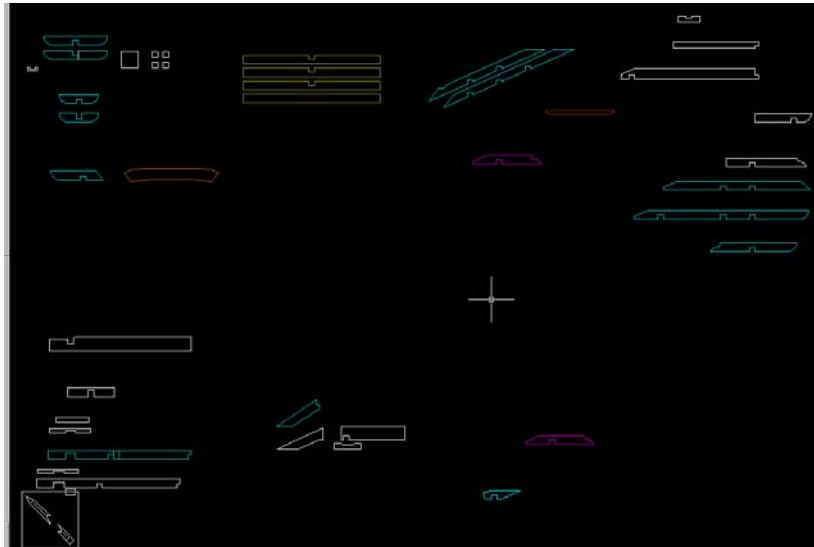
The idea of the computer 3D modeling of the building is similar to the data validation process. The whole process involves review and revision by referring to the previous

drawings, photos and construction principles. It is not adequate to base the 3D model on a 3D perspective drawing alone.

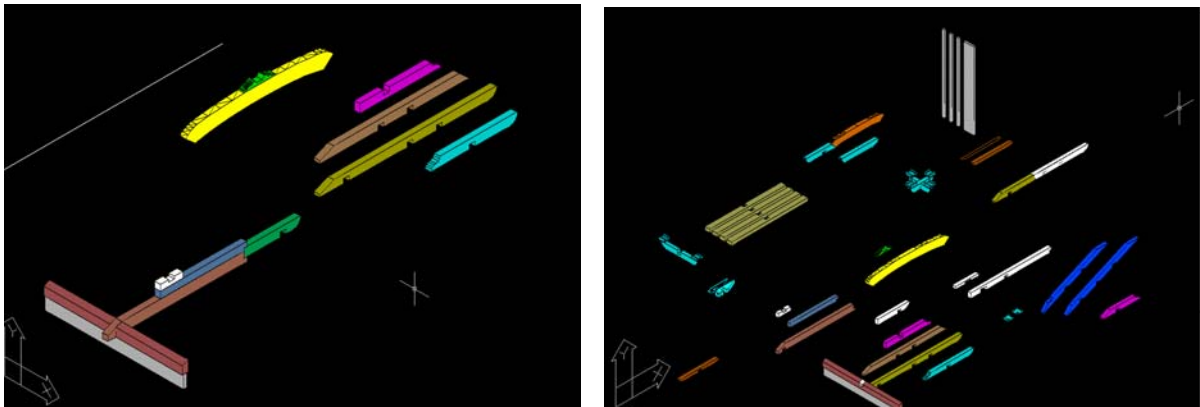
The Foguang Temple is a typical ancient Chinese temple structure - namely, a pre-fabricated assembled structure. The modeling process starts from a single basic element. The whole building can be disassembled to a sum of these single elements. The construction rules are simple and effective to assist in reviewing and revising the model. If elements are not of correct size or shape, or the connectivity is wrong, then the elements cannot join together to make up a segment. And if one segment is not of correct size or shape, or the connectivity is wrong, then the segment cannot join together to make up the complete structure. Different segments and elements must match together perfectly. Only then the computer model can be seen as a digital prototype of the Chinese ancient architecture for it clearly shows the dimensions, shapes of basic elements as well as the connective elements and connectivity of the whole building.

The main procedures for the modeling of the building are:

- Understanding the structural features of the building based on previous documentation and drafts
- Disassembling the building to several segments
- Disassembling different segments to basic elements (Figure 4-12)
- Analysing the assembling connectivity between each element
- Analysing the size and shape of each element
- Computer modeling each element (Figure 4-13, Figure 4-14)



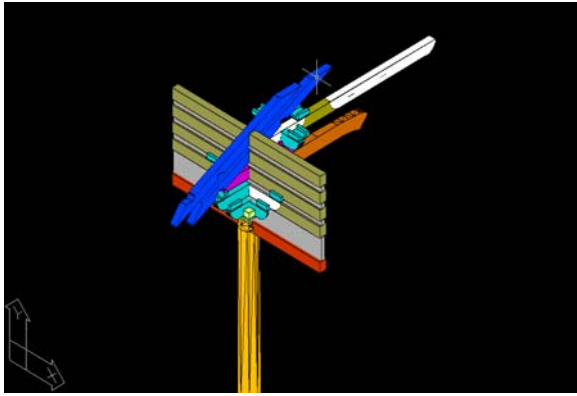
(Figure 4-12: structure components de-constructed)



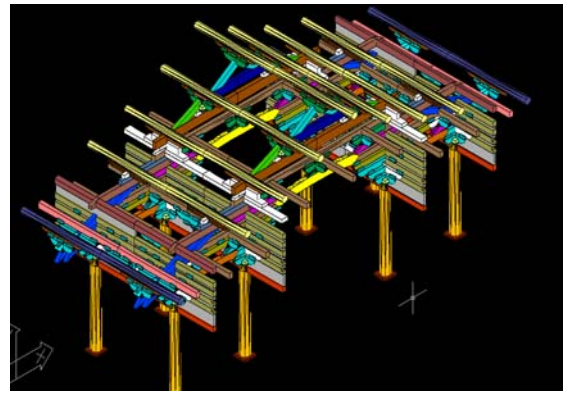
(Figure 4-13, Figure 4-14: Modelling of different elements)

- Joining elements together to make basic segment (Figure 4-15)
- Revising the models and connectivity of different elements within each segment
- Joining different segments together (Figure 4-16)
- Revising the model and connectivity of different segments

Reviewing and revising the whole model by referring to the photos of physical reality and previous documentations.



(Figure 4-15: from elements to segment)



(Figure 4-16: from components to the whole structure)

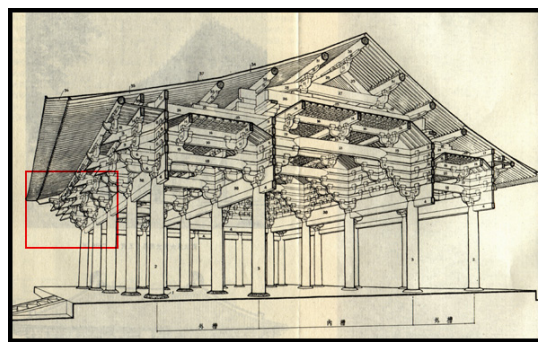
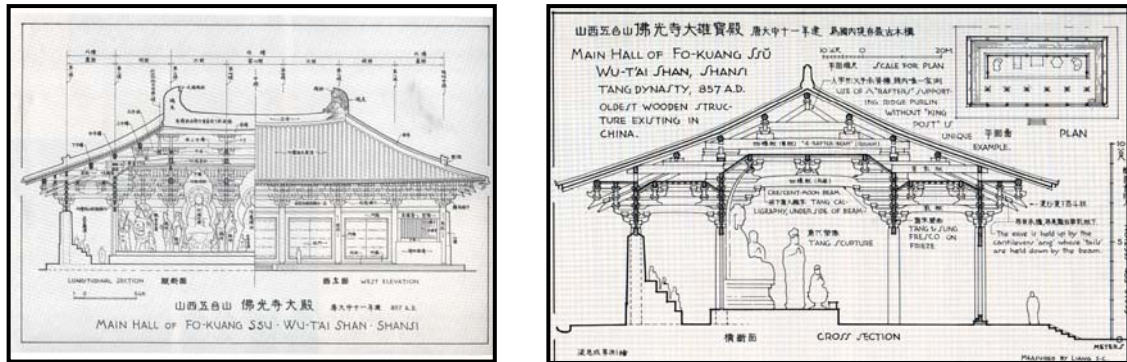
4.4 Modelling the “unknown” part

During the computer modelling process of the Foguang Temple, the corner sections are the hardest part to be simulated due to insufficient information about the construction details. Few deductions of the corner structure assemblage and organisation rules could be made from the previous studies and drawings. One valuable part to understanding their construction is the space between the ceiling and the roof, but this is inaccessible. The informative data available are some photos from the outside (Figure 4-17). We can see the complexity of the construction details here.



(Figure 4-17: photos of the detail)

Together with the previous documentations (Figure 4-18), only a few ideas about the construction details of the corner section can be derived.



(Figure 4-18: previous drafts of the detail)

Historians have long debated details of the structure and elements. I have enquired about the structural details to several traditional Chinese architecture researchers (most of them from the University of TsingHua: Z.Guan, L.Li, Z.Lv) when I was modelling the Foguang Temple. However, except from the drawings by Liang Shicheng, no further information on the construction principles of the corner section can be found. According to Jinxian Zhang (1979), the connection details of traditional Chinese wooden structure might be familiar to the skilled worker. But the documented record was very rare. As stated in the e-mail sent to me by Luke, Li, who is currently a PhD candidate for traditional Chinese architecture study:

“Digital modeling of ancient Chinese architecture relies on detailed measurement data and documented construction rules. The Foguang temple has not ever been disassembled. So the construction details and connectivity is unclear.”

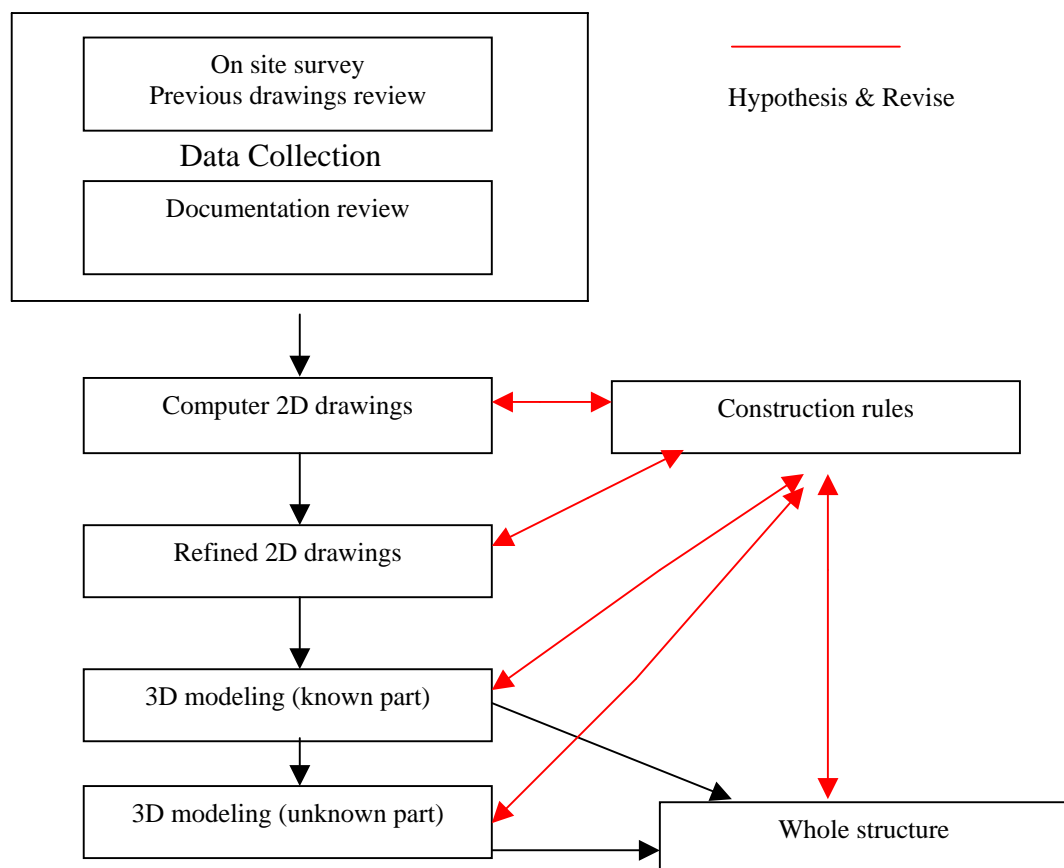
There had been one successful attempt looking at the issue of the structural and connection details. The case study was about the wooden structure of the MeNi hall of the Long Xing temple from Song dynasty. The methodology was to study the structure by disassembling it. However, it is highly unlikely to resume the structure with the original structural elements since all these prefabricated timber elements have more or less changed in shape or size after being there for hundreds of years. After taking them apart, it is not possible to reassemble them. The negative impact is obvious: it is not wise to study the historic architecture wisdom by breaking the historic sites. Till now, there is still not an effective way to ascertain the structural details of traditional Chinese wooden structures without disassembling them.

The Foguang Temple has a history of more than one thousand years and is one of the only two timber structures from the Tang dynasty. It is highly risky to disassemble it. On the other hand, it is definitely an important issue to clarify and to understand its structural details. The involvement of computer modeling seems to be a much better alternative for the study of the traditional Chinese wooden structure. The hypothesis and review of the modeling system based on the shape grammar theory assists in proposing structural clarities. The modeling process introduced in this study is a significant contribution to the research of historic buildings in China.

4.4.1 A Theoretical Model

The shape grammar theory could be a new approach in my research for the modeling and simulation of the unknown part of the Foguang Temple. All dimensions of elements, details and building follow strict construction rules and order. There are

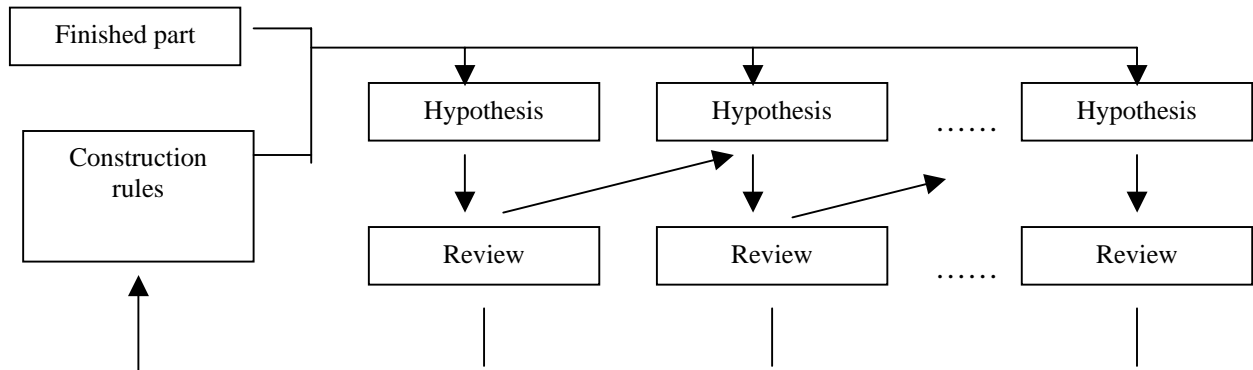
clear construction and connection rules within the timber structure of the Foguang Temple. From the statement by Stiny: “new shape or parameterised shapes can be generated given the shape rules and initial shape”, it is a very reasonable idea to understand the unknown part from the known part, given the construction rules. The following diagram (Figure 4-19) shows the whole concept for the modeling process. However, the new shape derived from the known part and its rules may not be an only ‘truth’. A number of possible construction formats of the unknown part could be achieved.



(Figure 4-19: the modelling process diagram)

To ensure the reliability and validity of the study, a “hypothesis—review” modelling process has also been developed. It is based on the fundamental principle of the structure: it is an assembled timber structure. All the elements are joined together

without space and overlapping. It offers a good way to examine whether a new shape is possible.



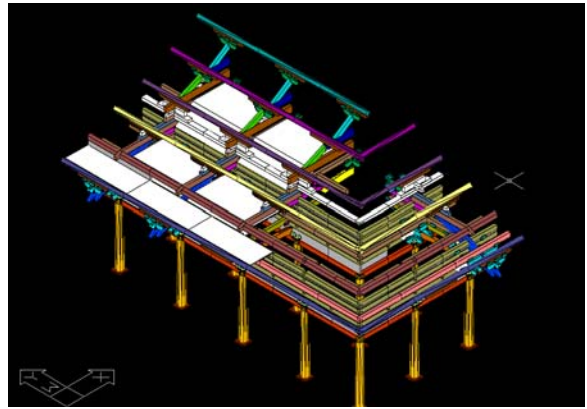
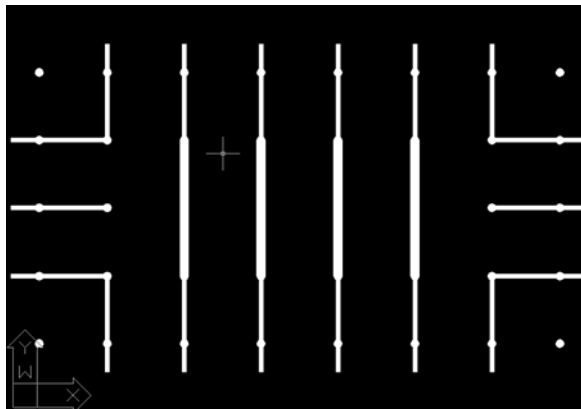
(Figure 4-20: A framework of the “hypothesis-review” modelling system)

Part of the intention of this study is to understand the temple by building an “ideal” digital model, which follows the construction and connection rules. During this process, constant evaluations of the rule applied in the digital model are implemented.

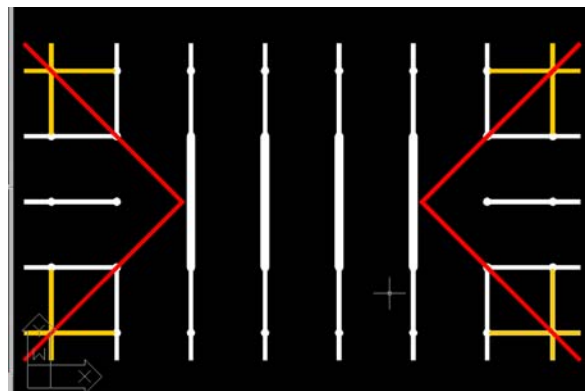
Different from the modeling process of other parts, which started from the basic element, the modeling of an unknown part has to go through a “top to bottom” approach. Since there exist a number of construction rules, the modeling process needs to start with the concept that is concerned with the highest level of structural importance, i.e. the location and dimension of the column. In the practical sense, the modeling process has to go through the construction rules from structure level to segment level, then to element level.

4.4.2 Structural functions of the unknown section

Figure 4-21 to Figure 4-24 are a series of drawings showing a basic analysis of the structural feature of the building. Figure 4-21 and Figure 4-22 show the model before the simulation of the corner section. An analysis of the organisation and constitution of this part has to be implemented from the whole structural approach.



(Figure 4-21, Figure 4-22: the model before the simulation of the corner structure)

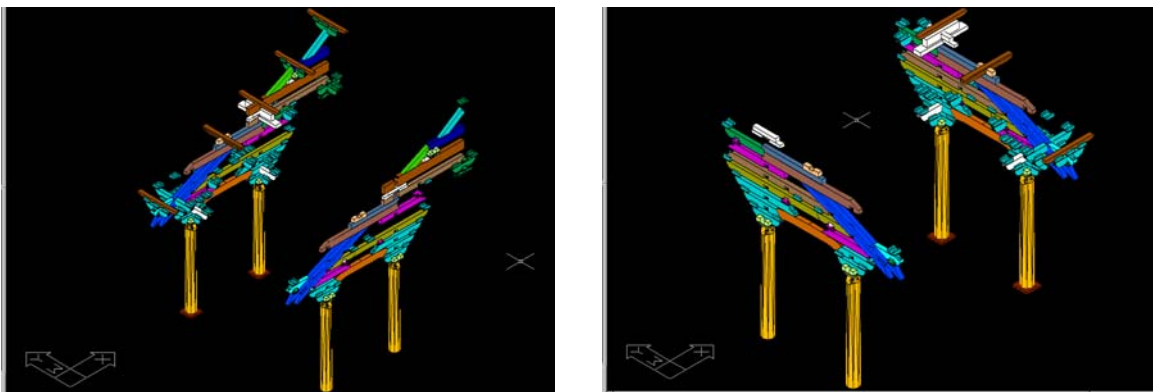


(Figure 4-23, Figure 4-24: hypothesis of the tie-beams)

It needs to be clarified here that the main challenge of the whole modeling process is the roof structure organization. The load of the building goes through the way of: roof – purlin – tie beam – bracket – column. Figure 4-23, 4-24 is a basic analysis of the arrangement of the tie beams within this building. Based on the shape grammar theory, from the existing computer model and limited information sources, it is not hard to draw the hypothesis that there should be two beams resting on each of the corner columns (Figure 4-23). As the roof of the Foguang Temple is in the style of “wu dian”, the corner column needs to withstand the load from the hip rafter as well. Therefore, it is a reasonable hypothesis that the corner column has to bear the load from three beams originating from three directions (Figure 4-24).

4.4.3 Segment organization

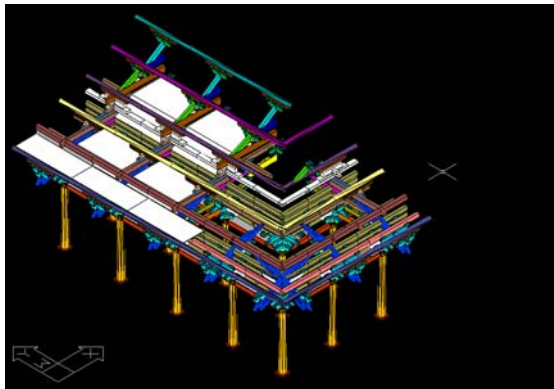
This process is mainly to decide how many elements made up a segment, what they are and their major functions, as well as their basic relationship. In the practical process of this particular part, I will focus on the bracket system which includes the corner column and the tie beams. It is important to study the similar components from other parts of the structure to have an idea of the construction details of this particular bracket system. Two groups of brackets in the X and Y directions on the corner column are quite similar to the brackets on the other columns except for their connection method. Figure 4-25, Figure 4-26 show the bracket system of eave columns from the X and Y direction.



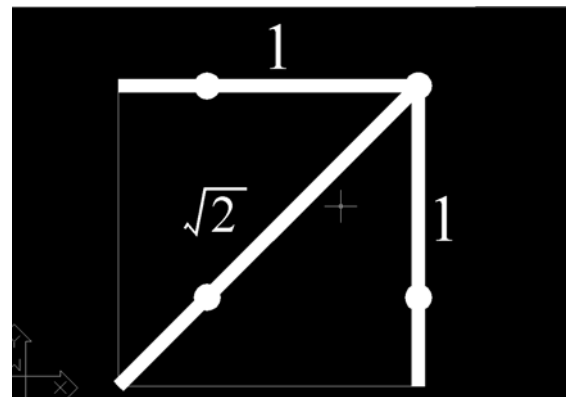
(Figure 4-25, Figure 4-26: the bracket system from the X and Y direction)

To test the possibilities, they are replicated in the corner column. The detailed connection problems will be resolved in the next step. Figure 4-27 shows the final result of this operation. From the picture we can see it seems to be a reasonable solution since there is no structural conflict between the components. The next operation is to introduce the diagonal bracket system; however, it can not be simply copied since the dimension here is different (Figure 4-28). So what needs to be done is

to revise the component by means of extension at the element level before fitting it back to the whole structure.



(Figure 4-27: final effects)

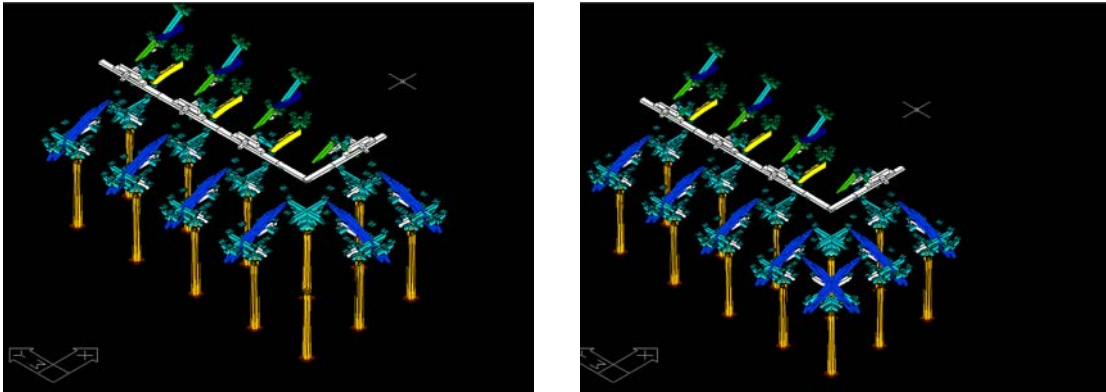


(Figure 4-28: different dimensions according to directions)

4.4.4 Elements dimensions and details

It is necessary to determine in detail the dimensions of each element, their shapes, functions and most importantly, the connectivity details between them. It might be the most challenging part since structural elements from three directions are joined together resting on the corner column. Compared to the connectivity between two elements, the connection here is more complicated. Moreover, valuable information about the connectivity could be obtained from neither the photos of the physical reality nor the previous drawings. As mentioned above, the modeling of the bracket system in the diagonal direction also needs to be implemented here. This is because the decision on which elements need to be re-sized to their accurate dimension is based on the relationship and connections with other elements from other structural components. Figure 4-29 to Figure 4-30 show a brief record and analysis of the main operation in this stage. They show the elements before and after the modeling of the two bracket systems in the X and Y direction, as well as the hypothesis of their

connectivity. The modeling of the bracket system on the diagonal direction could not be performed until a clear hypothesis of the connectivity has been made. This hypothesis will define the key points on each key element, hence confirm their locations and dimensions. The comparison of the possible connection joints of two elements and three elements will be discussed next.



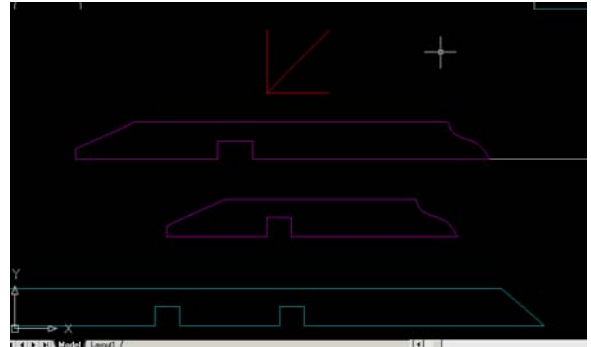
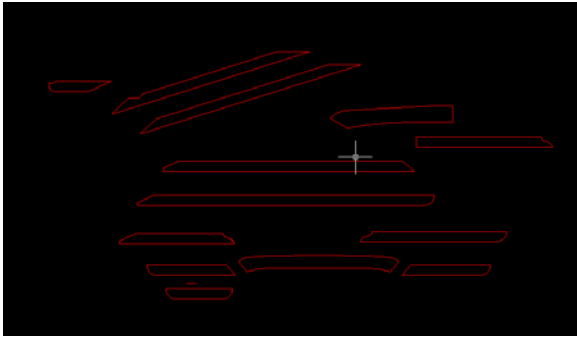
(Figure 4-29, Figure 4-30: the elements changing)

4.4.5 Modelling the unknown part – a step by step record

Computer techniques enable the disassembling and re-construction process to be implemented in the virtual environment as many times as required. That is the reason that the hypothesis – review – revise model was used in this research to take advantage of this capability.

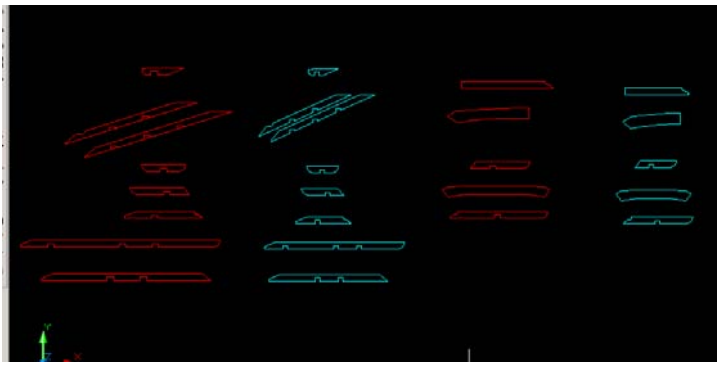
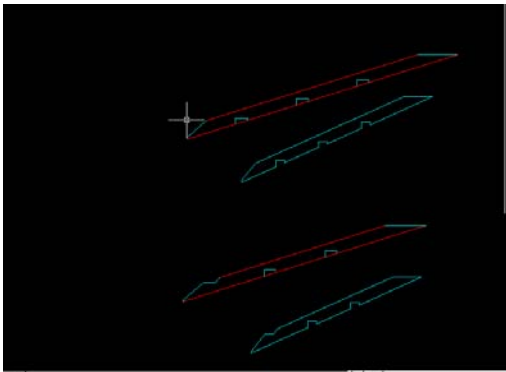
Following this concept, the practical modelling process for this particular part was implemented in the following procedures:

1. Modelling the bracket system in the diagonal direction
 - Figure out the structure elements (figure 4-31)
 - Revise the shape and size of each element by comparing them to the elements from the X and Y direction: the height remains the same, but the length is $\sqrt{2}$ times of the X Y direction (Figure-32)



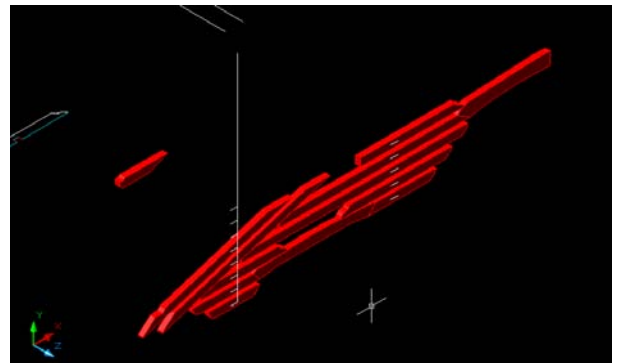
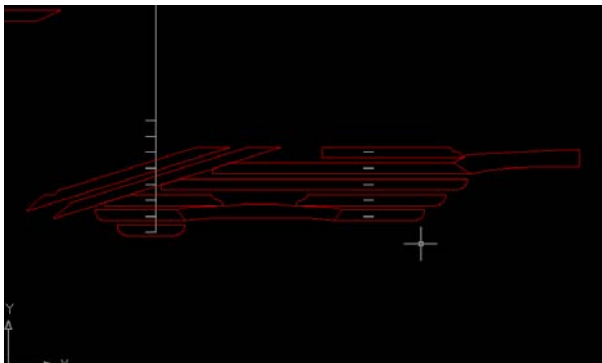
(Figure 4-31, Figure 4-32)

- Elements in the diagonal direction and in XY direction (Figure 4-33, 4-34)



(Figure 4-33, Figure 4-34)

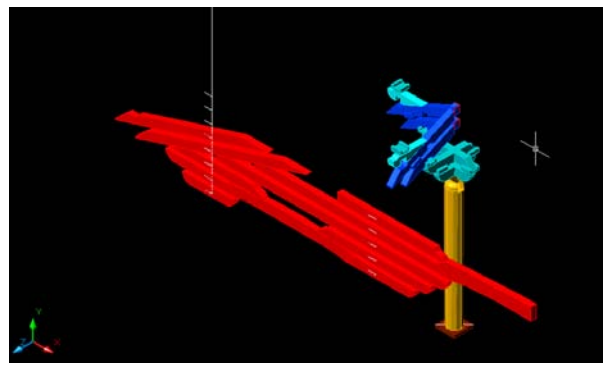
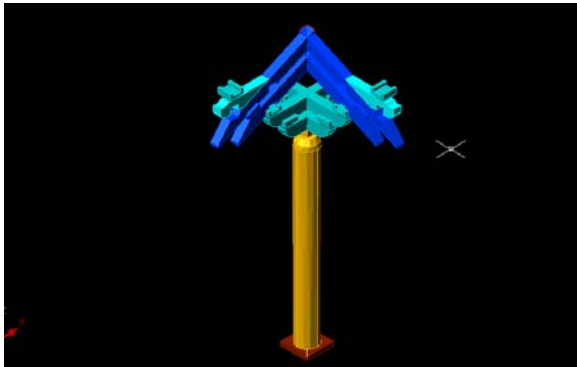
- Structural elements make up the structural segment (Figure 4-35, 4-36)



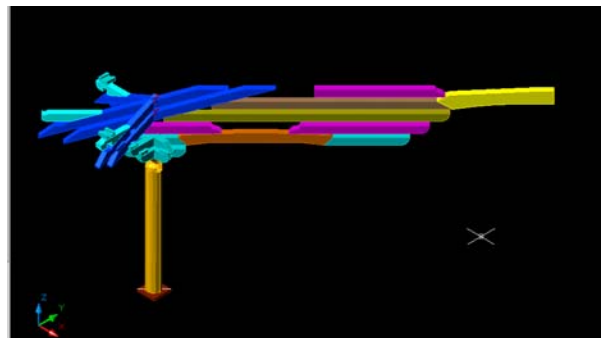
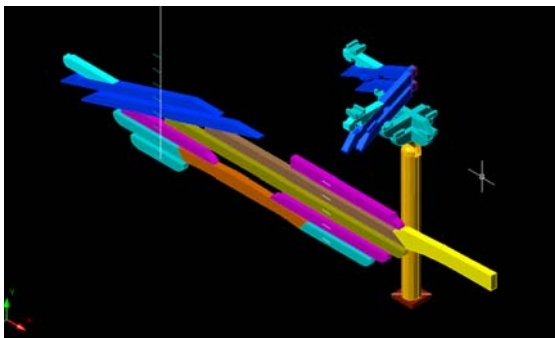
(Figure 4-35, Figure 4-36)

2. Fitting the diagonal bracket system in the whole structure

- Revise the elements of the XY direction (Figure 4-37)
- Set the relations between the bracket system of the diagonal direction and the XY direction (Figure 4-38, 4-39)



(Figure 4-37, Figure 4-38)



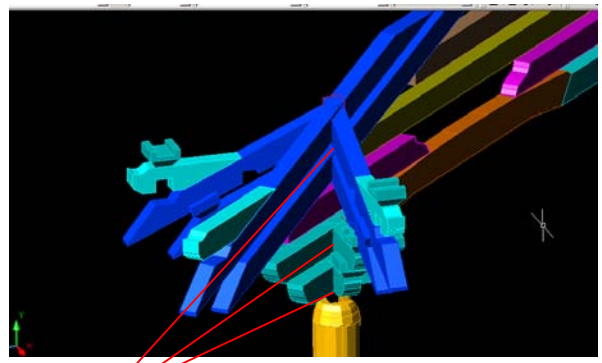
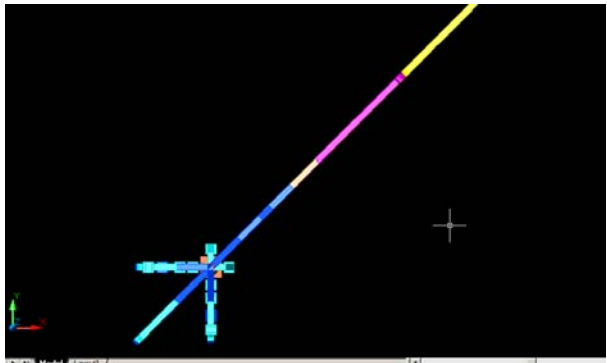
(Figure 4-39, Figure 4-40)

- Combine these bracket systems from the diagonal direction and the XY direction (figure 4-40)

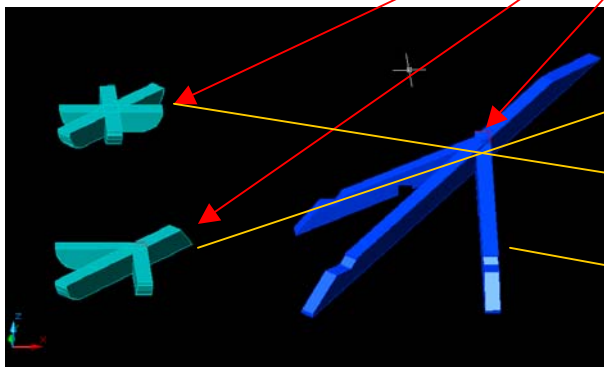
3. Analysing the element connectivity

- Analyse the critical connection joints (Figure 4-41)

- Figure out three main kinds of connections (Figure 4-42, 4-43)



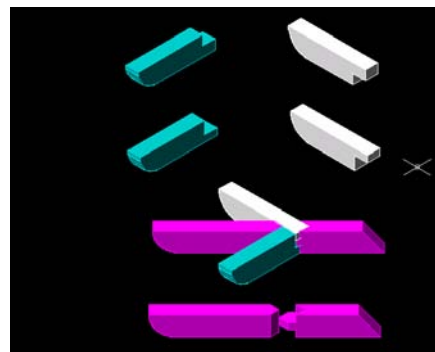
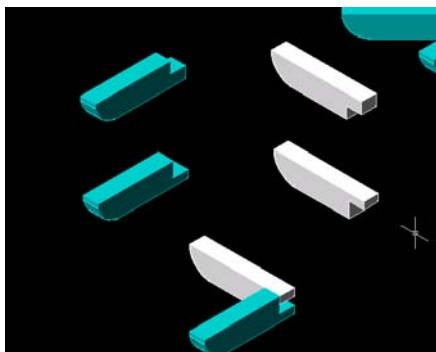
(Figure 4-41, Figure 4-42)



- Joint A
- Joint B
- Joint C

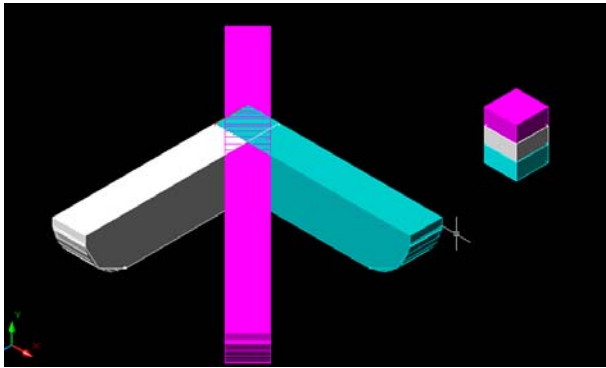
(Figure 4-43)

- Hypothesis I of the connectivity of Joint-A (Figure 4-44, 4-45: unreasonable. The component in the diagonal direction (shown in pink colour) was divided to two parts, hence has no structural function.)

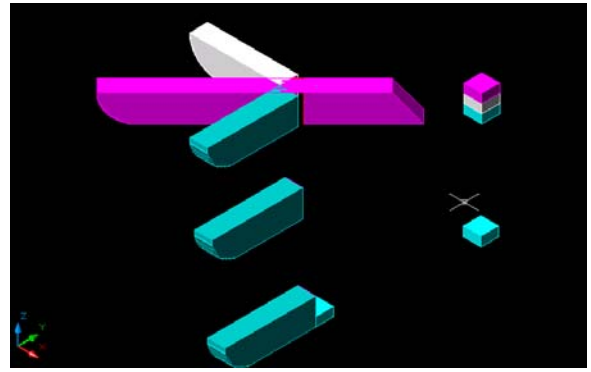
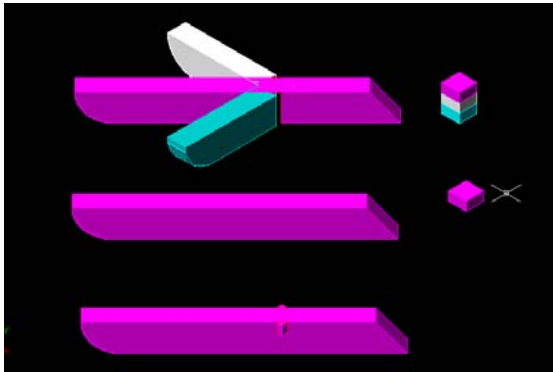
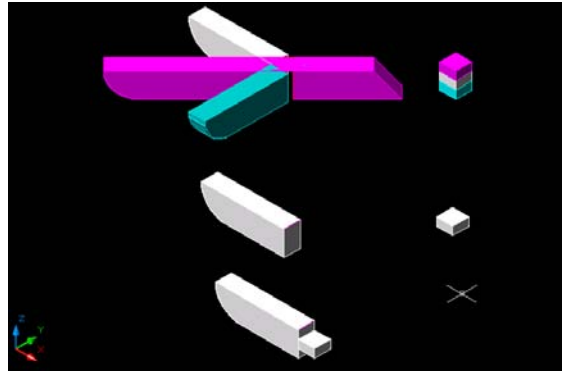


(Figure 4-44, Figure 4-45)

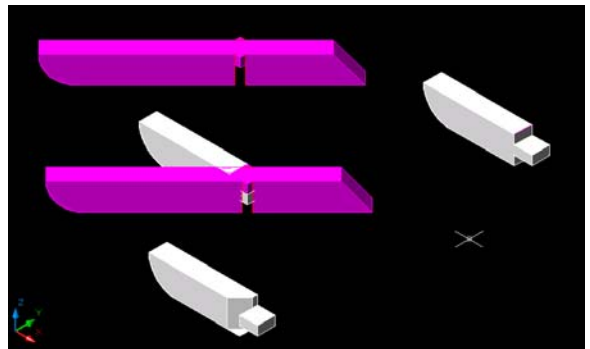
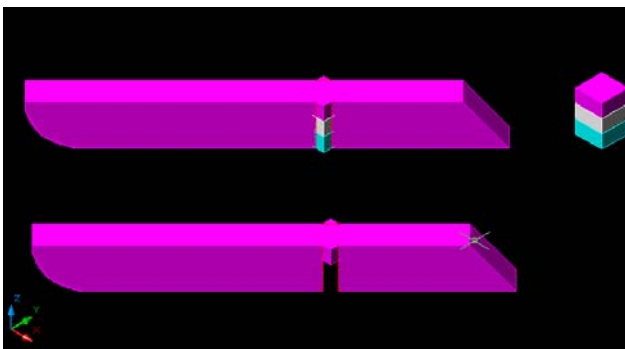
-
- Hypothesis II of the connectivity of Joint-A (Figure 4-46 to Figure 4-54)



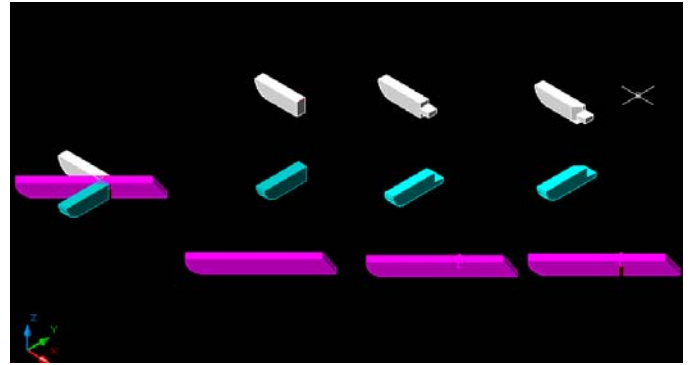
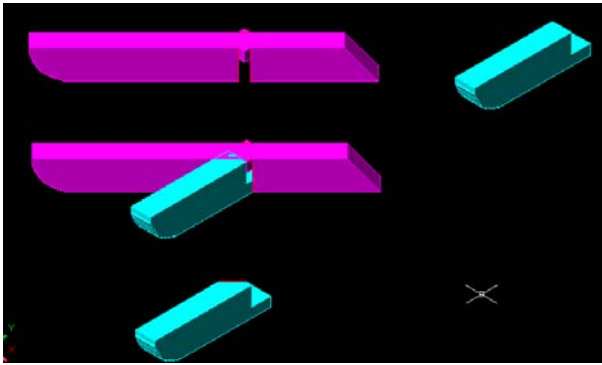
(Figure 4-46, Figure 4-47)



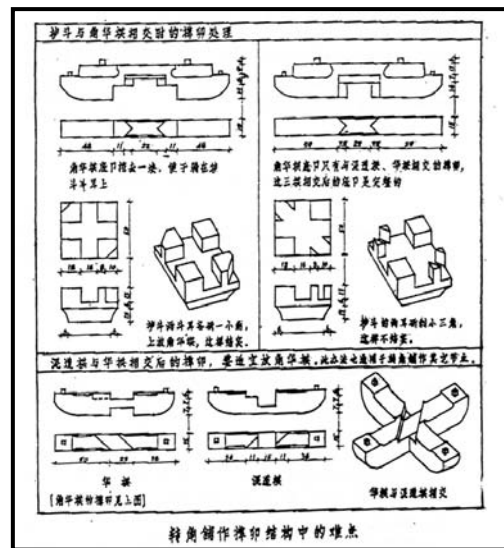
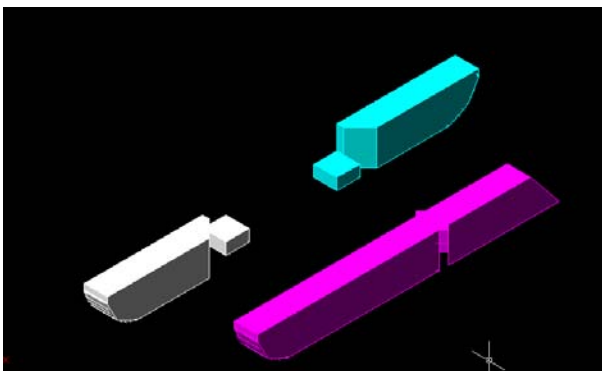
(Figure 4-48, Figure 4-49)



(Figure 4-50, Figure 4-51)



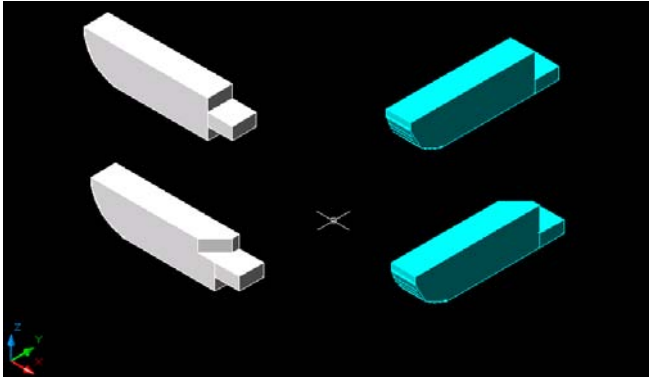
(Figure 4-52, Figure 4-53)



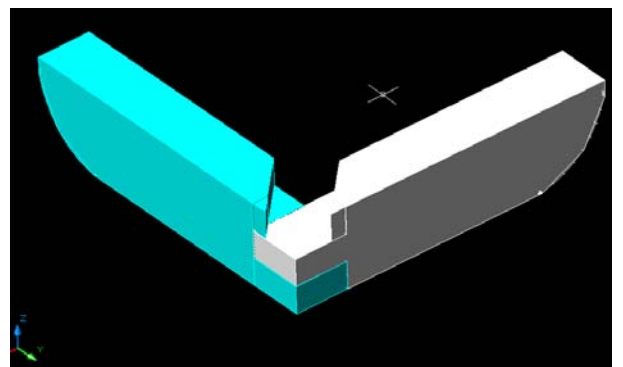
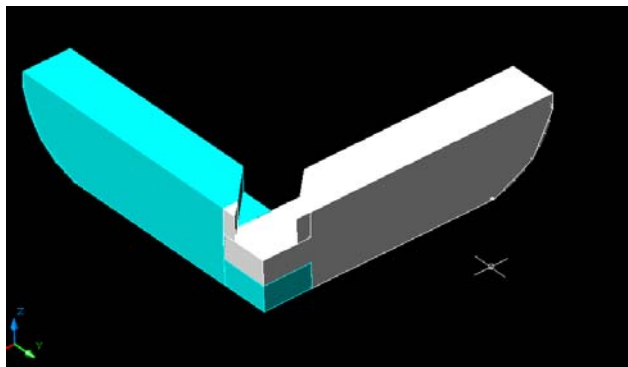
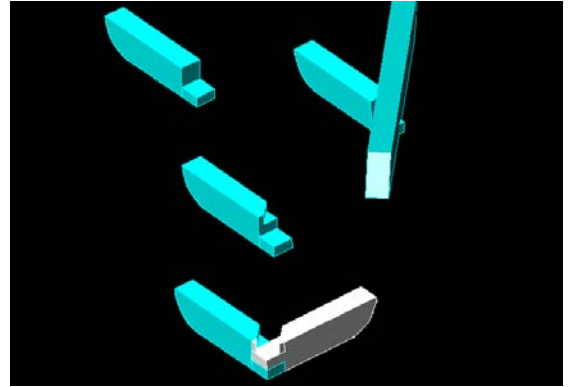
(Figure 4-54, Figure 4-55)

- Hypothesis II seems to be a possible solution. It can solve the structural and joining difficulties. However, the connectivity seems to be too complicated, so does the shape and dimension of each component. It might not be the simplest solution.
- Figure 4-55 is the manual drafting recorded during the reconstruction of the Meni hall of the Longxing Temple. The connectivity details of the corner part of the MeNi hall of the Hongxing Temple from Song dynasty suggests a new idea of the connection patterns of the bracket system on the corner column.

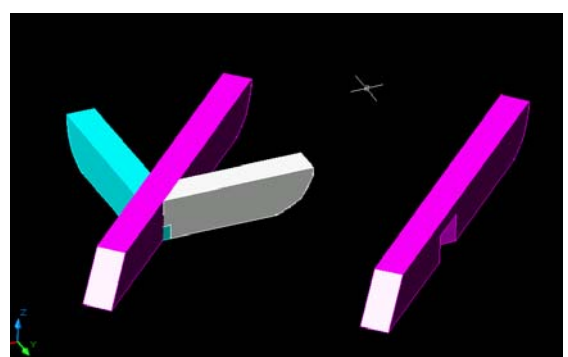
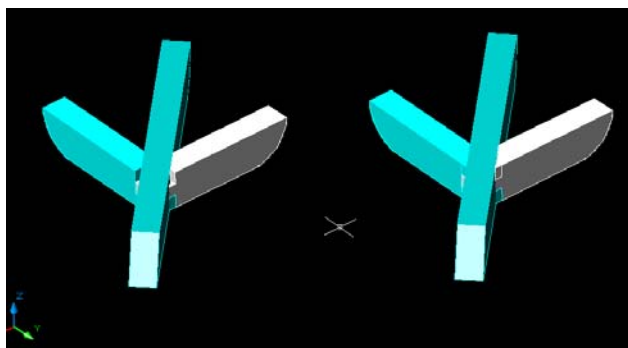
-
- Figure 4-56 to Figure 4-61 represent the process of hypothesis III of the connectivity of Joint-A (the most plausible one)



(Figure 4-56, Figure 4-57)

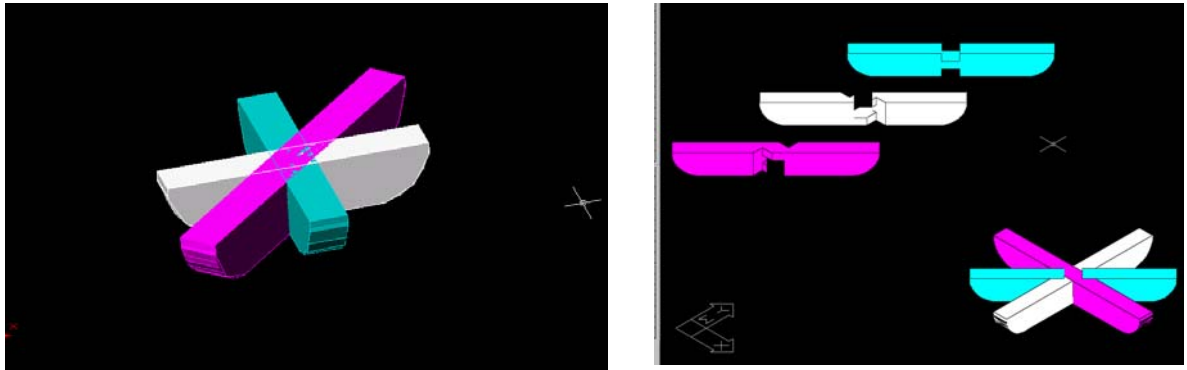


(Figure 4-58, Figure 4-59)



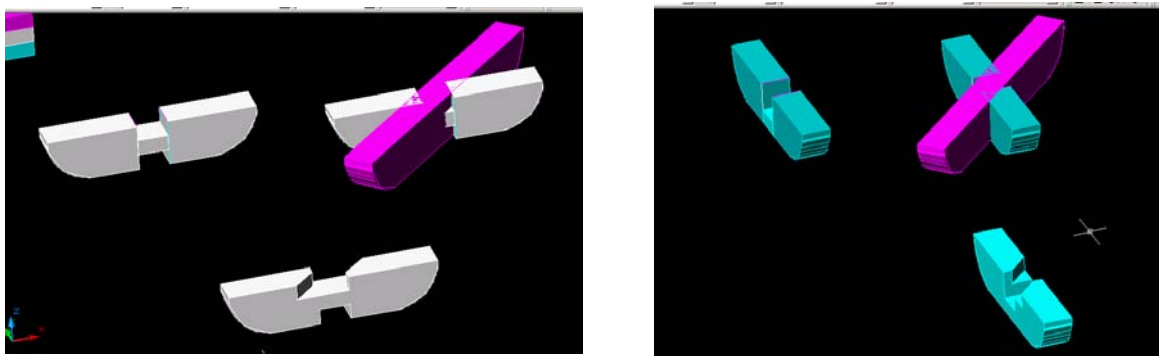
(Figure 4-60, Figure 4-61)

-
- Similarly, possible hypothesis for Joint-B is shown in Figure 4-62, Figure 4-63. However, it does not seem to be very reasonable from the structural approach.

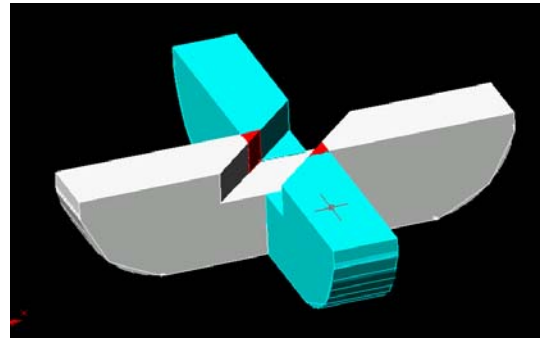
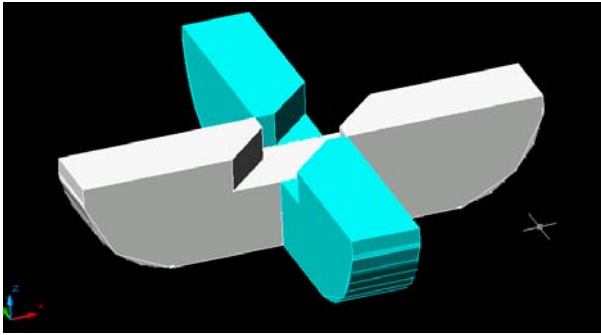


(Figure 4-62, Figure 4-63)

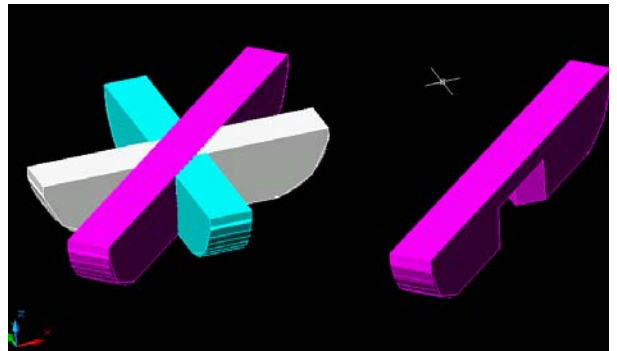
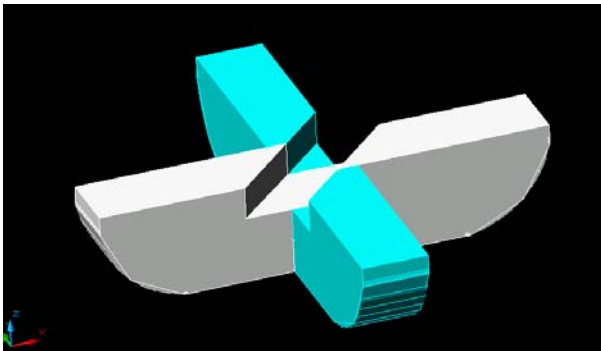
- According to the connectivity details showed in the disassembly record of the Song MeNi hall, Figure 4-64 to Figure 4-69 show the computer simulation records of Joint B in the most likely way.



(Figure 4-64, Figure 4-65)

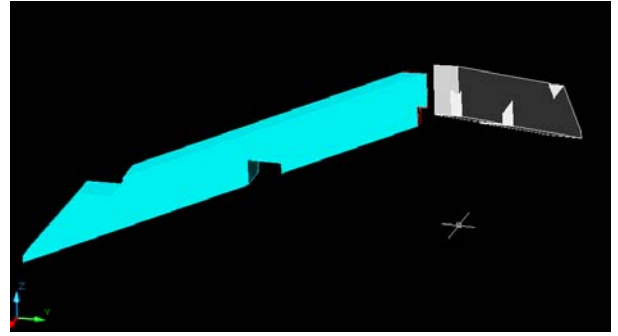
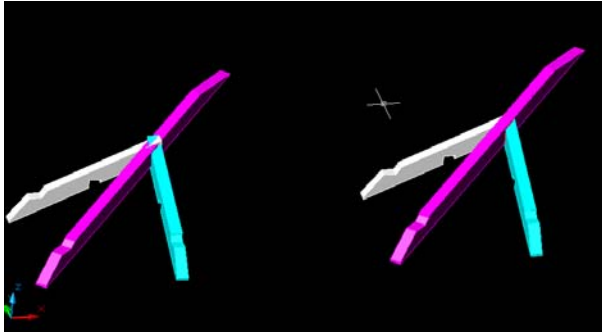


(Figure 4-66, Figure 4-67)

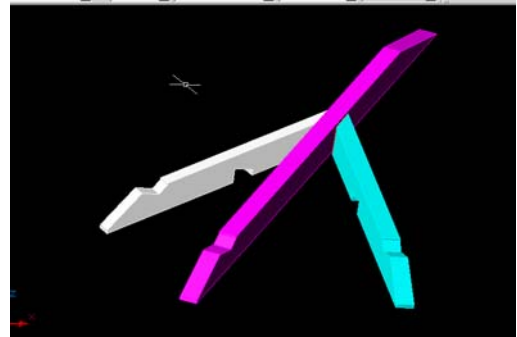
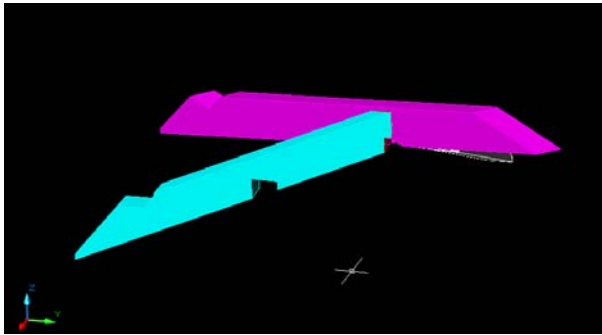


(Figure 4-68, Figure 4-69)

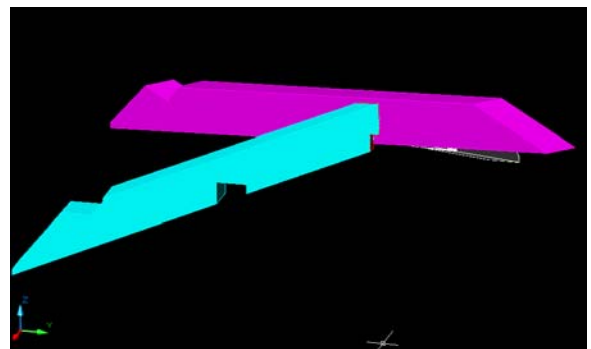
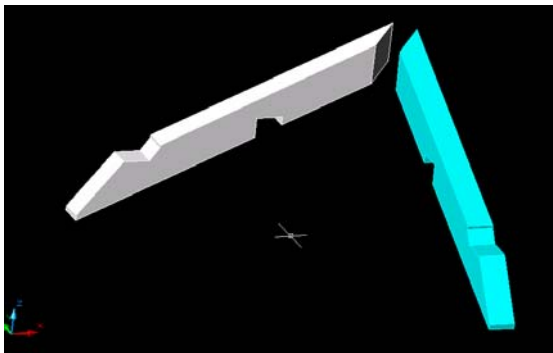
- The later hypothesis of Joint B is very similar to the reference: the MeNi Hall. It is probably the most reasonable hypothesis. Analysing from the shape and shape grammar approach, the connectivity of the whole structure should follow a series of construction rules. Therefore, the possible connection details for Joint-C are shown from Figure 4-70 to Figure 4-75.



(Figure 4-70, Figure 4-71)

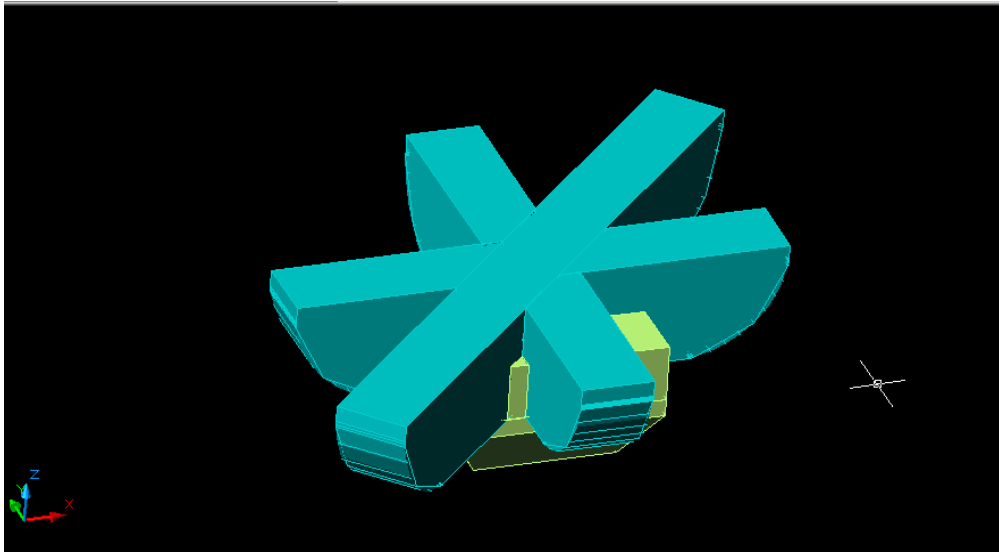


(Figure 4-72, Figure 4-73)

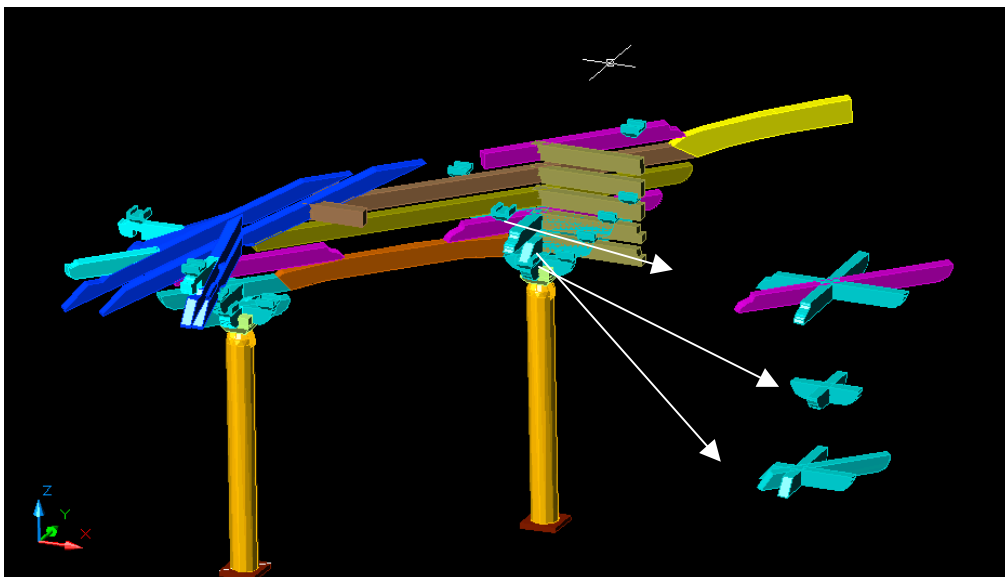


(Figure 4-74, Figure 4-75)

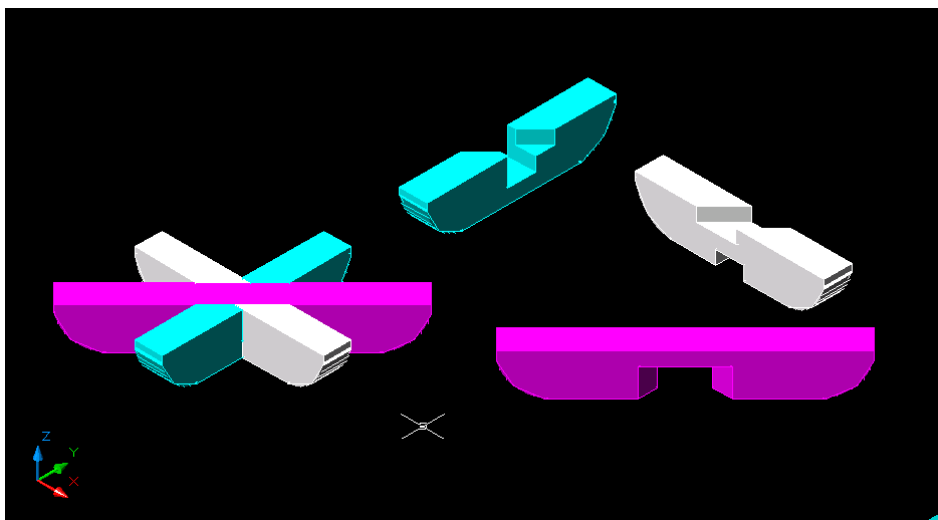
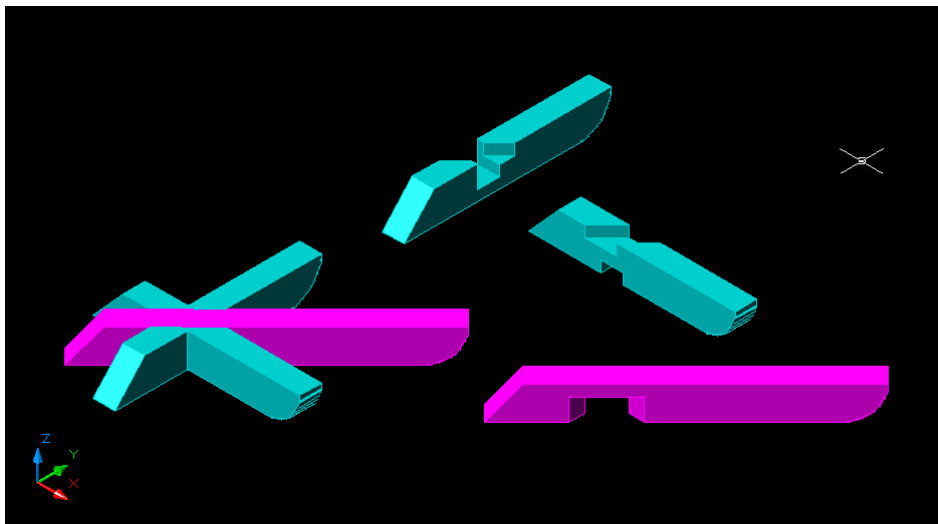
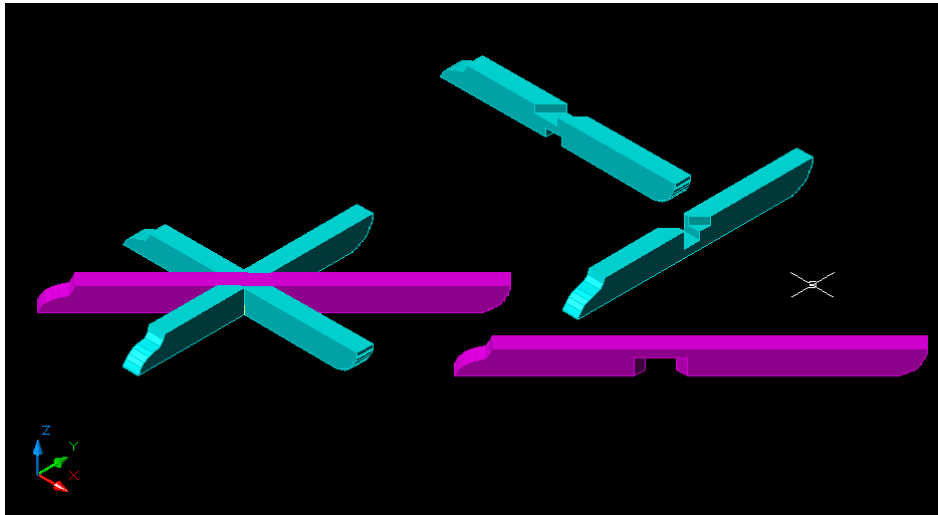
Led by this idea, the followings are a brief graphic record of the computer modelling of the critical parts:



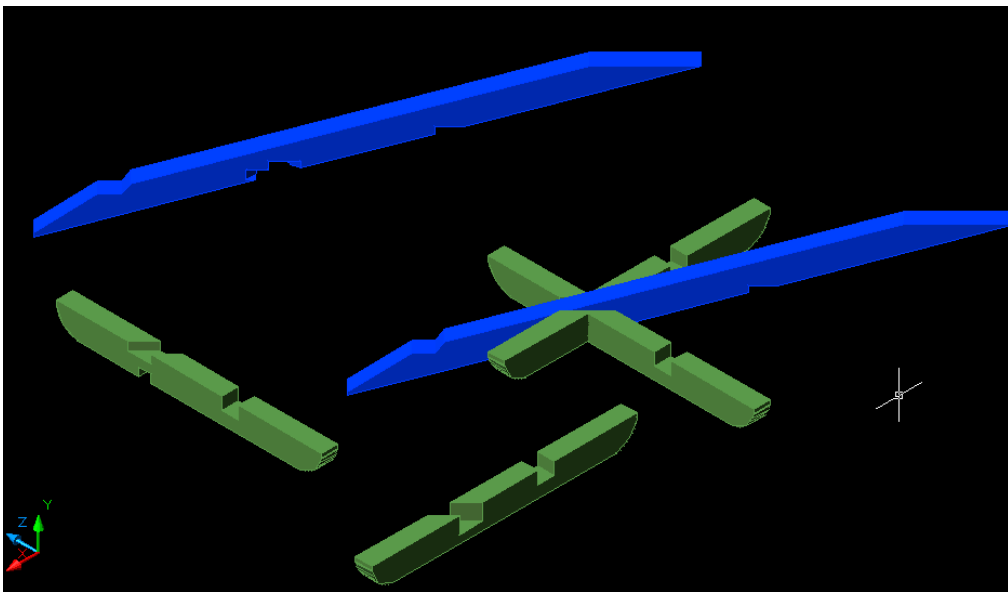
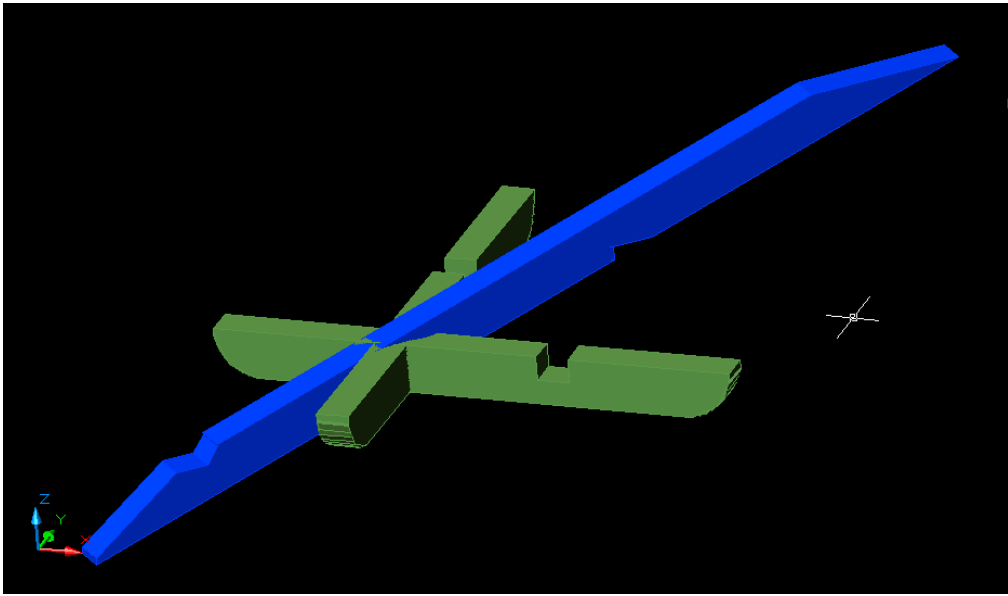
(Figure 4-76: structural details of the capital-block)



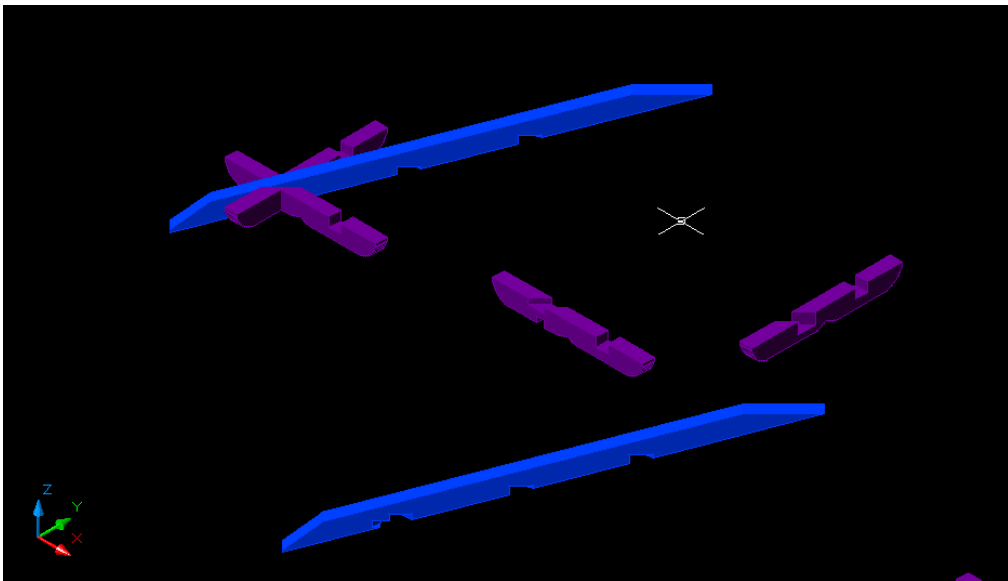
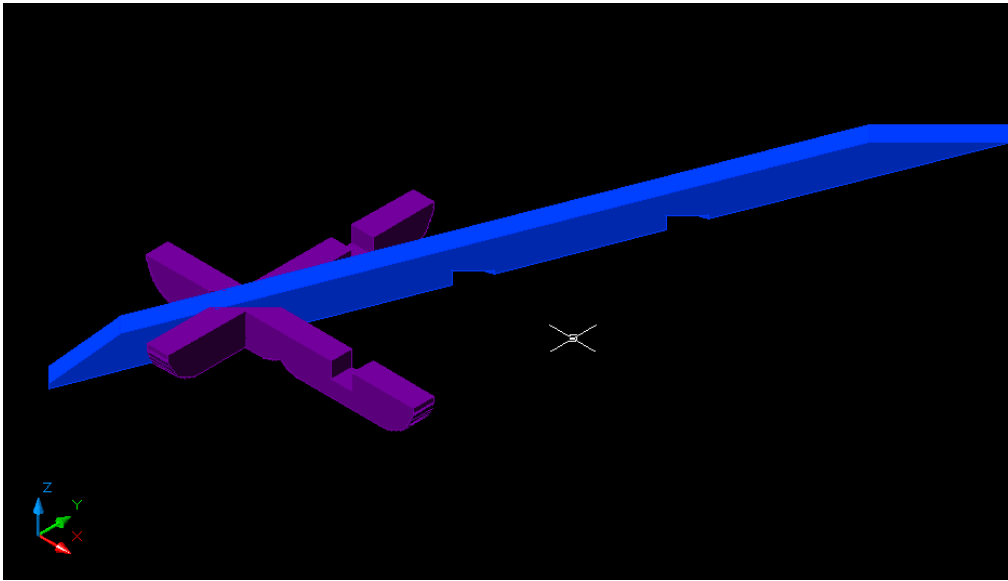
(Figure 4-77: three types of joint of the bracket system of the interior corner column)



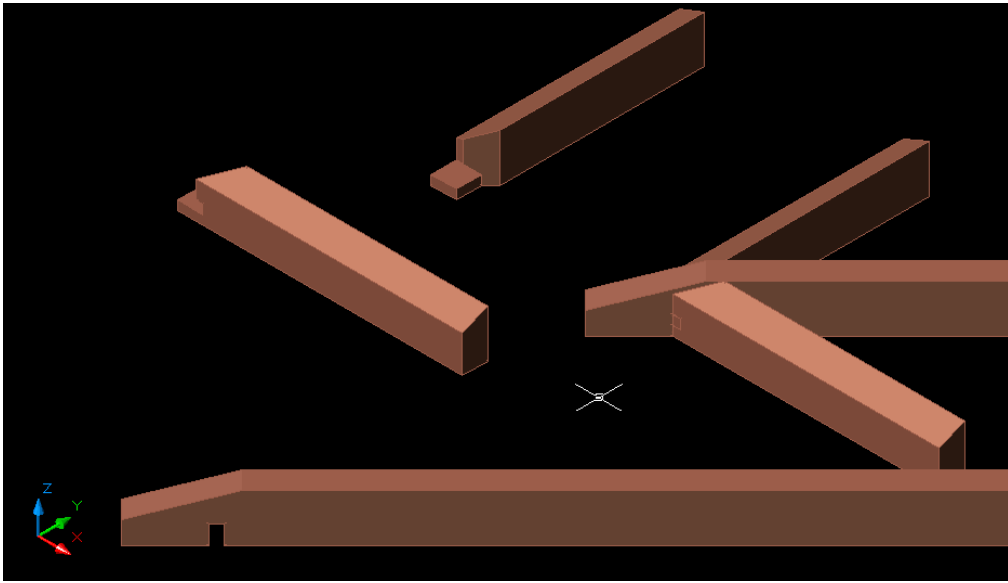
(Figure 4-78, Figure 4-79, Figure 4-80: structural details of these joints)



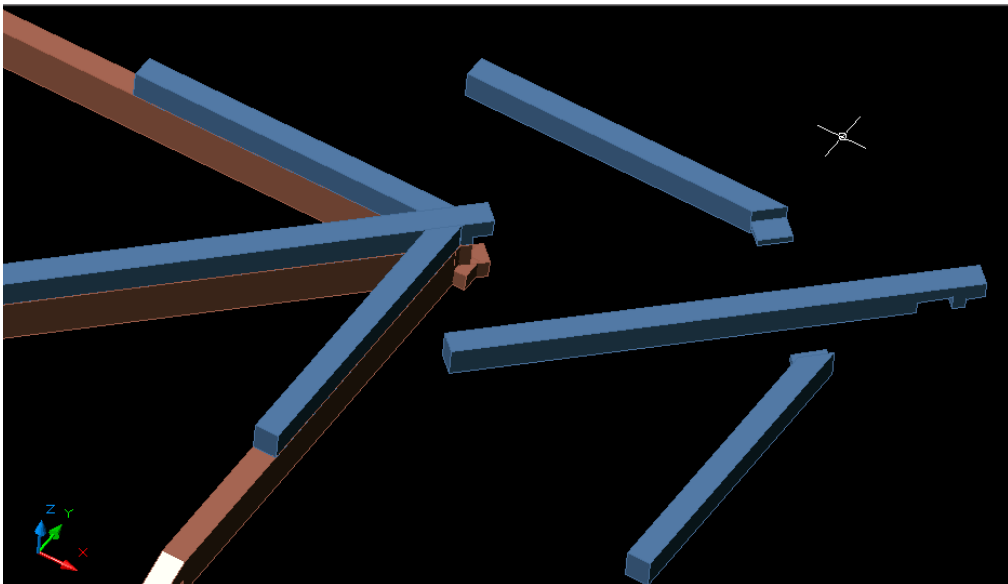
(Figure 4-81, Figure 4-82: structural details of the joint between gua zi gong and xia ang on the eave corner column)



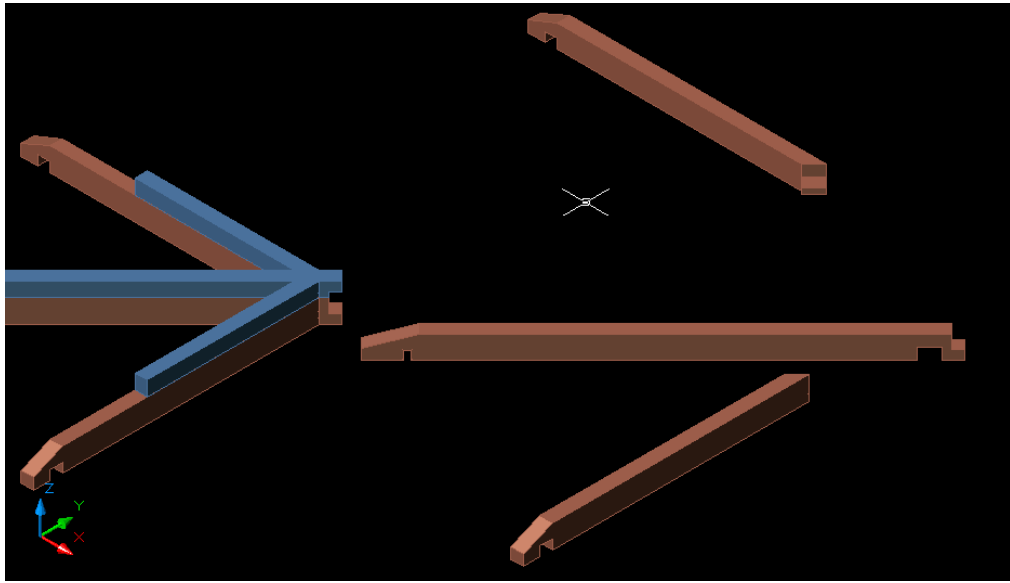
(Figure 4-83, Figure 4-84: structural details of the joint between man gong and xia ang on the eave corner column)



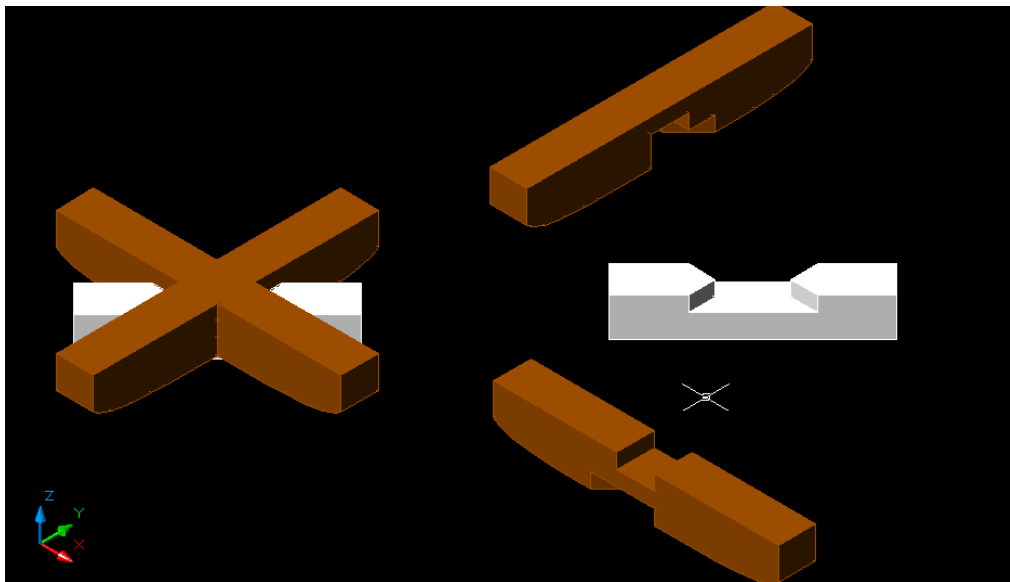
(Figure 4-85: structural details of the joint between cao ro fu and ya cao fang on the eave corner column)



(Figure 4-86: structural details of the joint between jiao bei on the interior corner column)



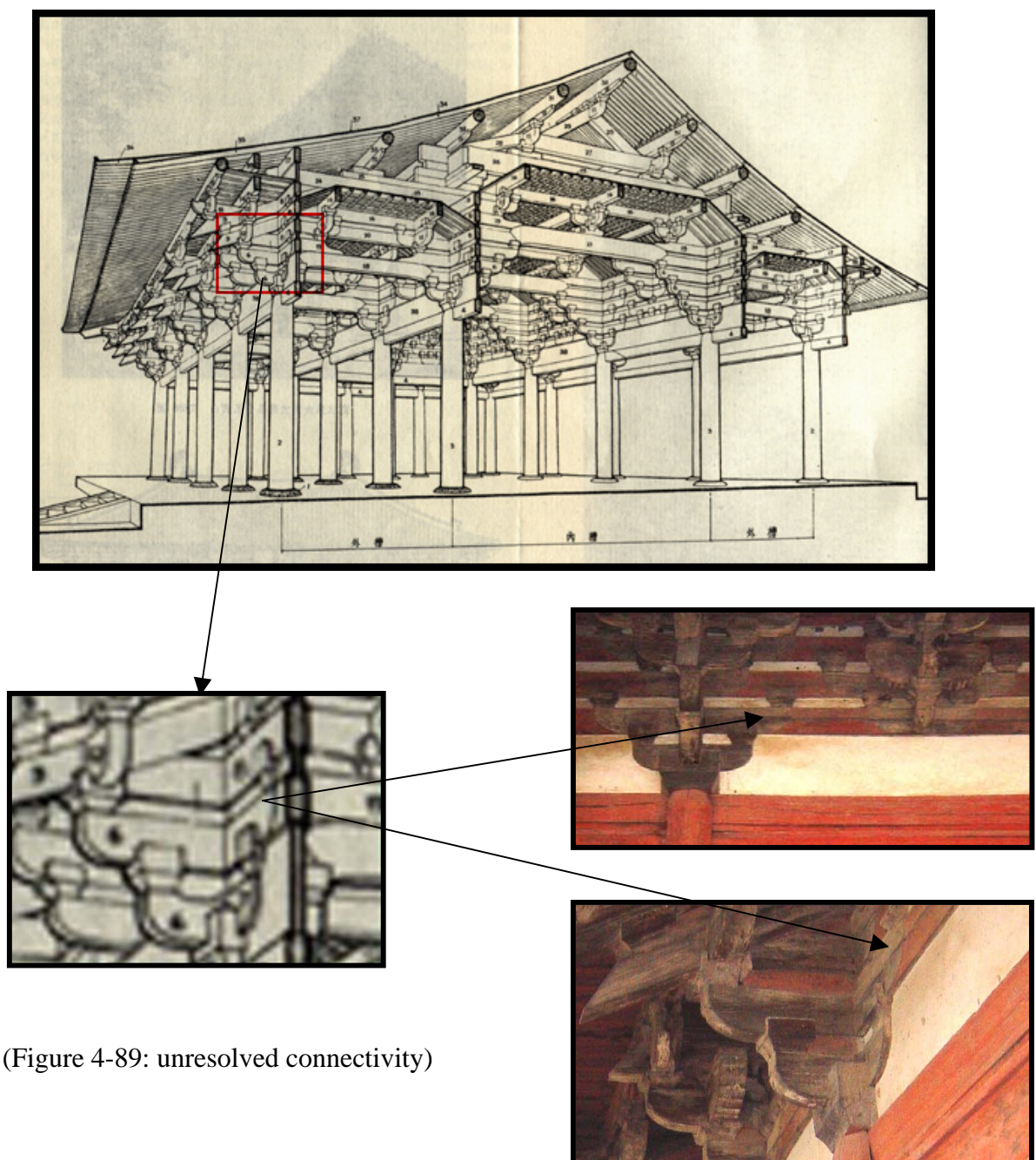
(Figure 4-87: structural details of the joint between cao ro fu on the interior corner column)



(Figure 4-88: structural details of the joint between jiao bei on the interior corner column)

4.4.6 An unresolved issue: the connectivity of Nidaogong and Lan'e

The whole structure of the Foguang Temple is an assembly of timber components. In the structure, all the elements are perfectly joined together, no overlapping, no space. In the computer modelling, I also use this rule to simulate some unknown parts and to test the accuracy of the model. However, at one part of the structure, the connectivity (of Nidaogong – longitudinal tie-beam, and Lan'e – architrave or connecting-beam) has not been fully understood and resolved (Figure 4-89).

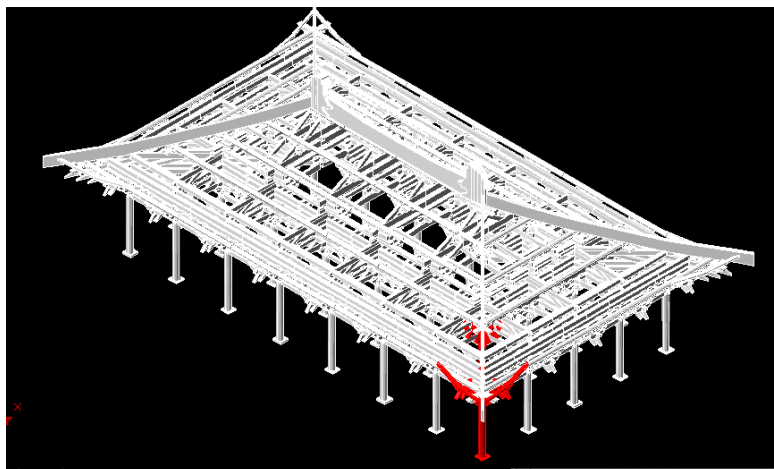


(Figure 4-89: unresolved connectivity)

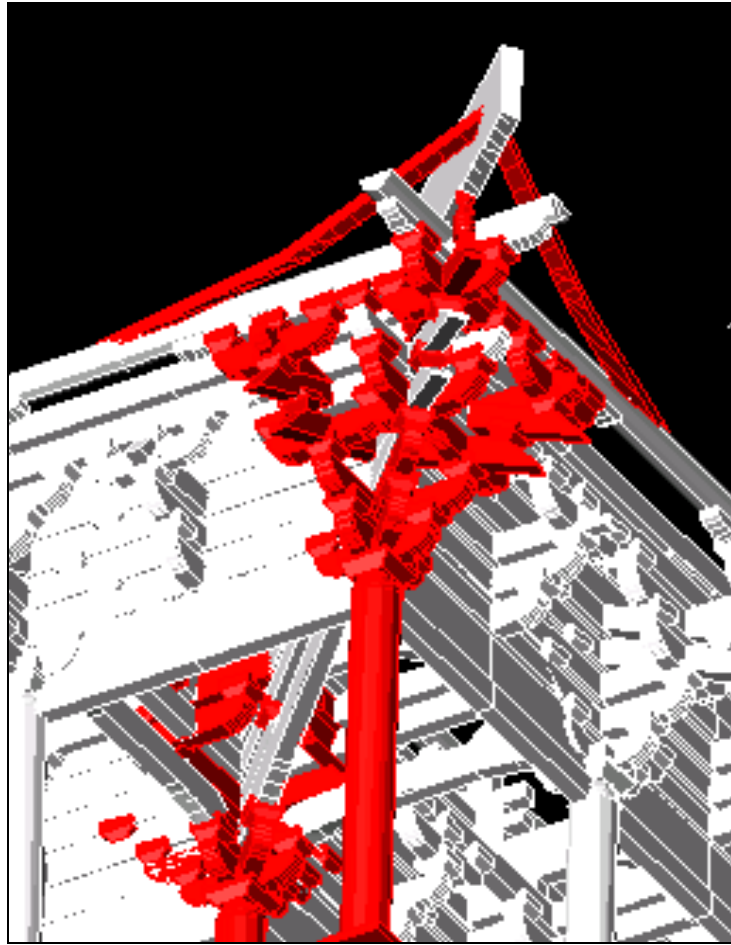
These two components –Nidaogong (element 7) and Lan’e (element 4) - are of the same height and thickness (Y and Z dimension). Seen from both the previous drawing and the photos, they are placed in the same position. Since Nidaogong has a much shorter length than Lan’e (X dimension), so it is included in Lan’e, or in other words, they are overlapping. It is extremely hard to make a hypothesis of the connectivity between the two components. I would rather regard them as one component here. Analysing from the structural approach, there is no need for a Nidaogong to be placed here. This difficulty occurred 36 places in the modeling of the structure in this research. What has been done to deal with it is to keep Lan’e and model Nidaogong in a separate layer for review. A possible explanation is there is not such a component as Nidaogong. It is just a painting of the same shape of it. However, further research needs to be done to clarify this issue.

4.4.7 Final effect and representation of the digital structure

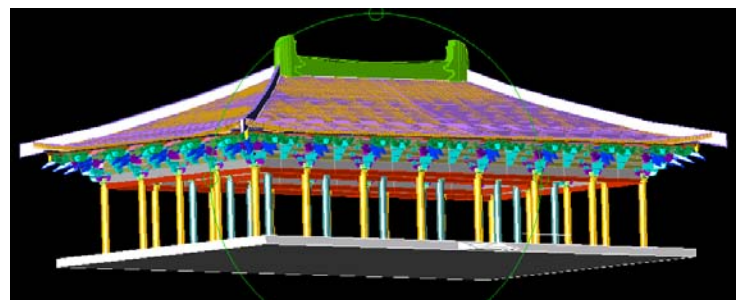
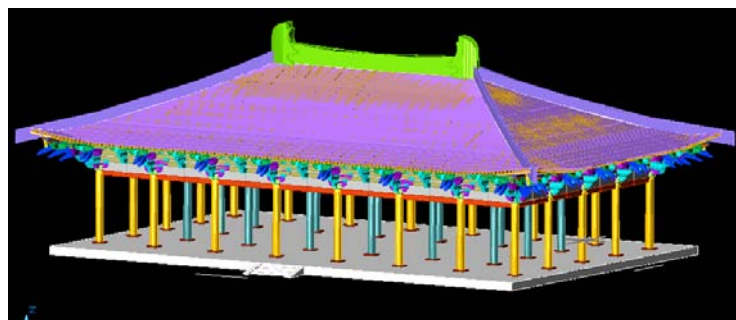
A real size digital model has been made following the process mentioned above. The following images and descriptions show out the structural detail of the “unknown part” and the overall visualization effects of the whole model (Figure 4-90 to Figure 4-93).



(Figure 4-90: the “unknown part” (shown in red color) and the whole structure)



(Figure 4-91: more details of the “unknown part” (shown in red color))



(Figure 4-92, Figure 4-93: the final visualisation effects of the whole structure)

Many more images and descriptions, and animations are contained in the CD which is attached to this thesis. The structure of the CD is designed to be an interactive web page format. It starts with a home page linking to the sub pages that contains a brief summary of the study from different aspects, including: the Foguang temple, the simulation methodology, the modelling process, the structural components and the final visual effects. The structure component part and the final visual effect part are the most important and valuable parts of the CD, since they provide the idea of the representation of the structure. To make it easy to understand, this part is categorized to four levels according to the modelling process:

- The visual effect of each component. This links to the database associated with the digital model which provide the physical information of each components in more details.
- The 3D animation of assembling a group of components to structural segment
- The 3D animation of assembling the three structural segments to the structure
- The visual effect of the whole structure: bird's view, sections and simulation of reconstruction.

4.5 Creating the database

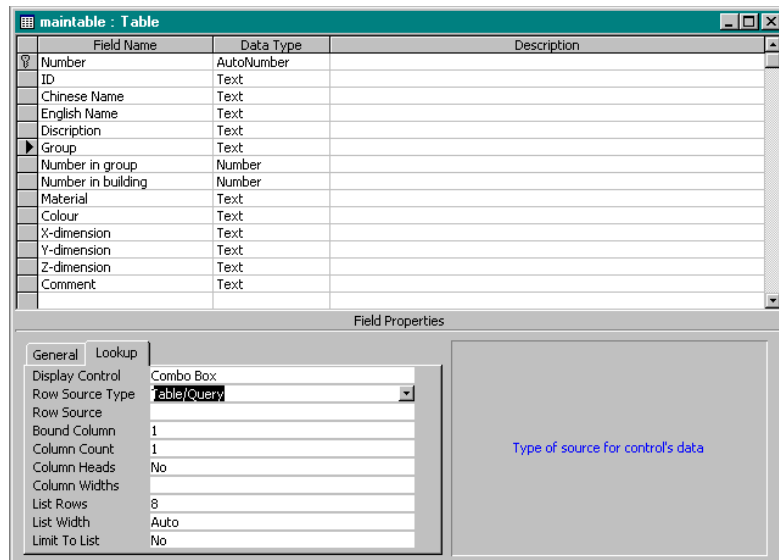
A database is created while the structure is being modelled. As discussed earlier, the concept of building such a database is to set up a logical source of information for ancient Chinese architecture research. It also follows the idea of “building the ideal model” because the database is solely based on the information contained in the digital model rather than the structure as built. The process of creating the database is as follows:

- Design the structure of the database in an interlinked tabular format that starts from the basic structural component.
- Figure out a list of structural components (Figure 4-94)

Number	Chinese Name	English Name
1	zhu chu	plinth
2	yan zhu	eave column
3	nei yan zhu	interior or hypostyle column
4	lan e	architrave or connecting-beam, lintel, girder
5	lu dou	capital-block
6	hua gong	transversal bracket-arm
7	ni dao gong	longitudinal bracket-arm
8	zhu tou fang	tie-beam or axial tie-beam
9	xia ang	down-pointing cantilever
10	shua tou	wooden member parallel to and on topmost
11	ling gong	longitudinal bracket-arm of intermediate
12	gua zi gong	longitudinal bracket-arm of shortest length
13	man gong	longitudinal bracket-arm of longest length
14	luo han fang	luohan tie-beam
15	ti mu	wooden support between longitudinal
16	ping qi fang	paneled ceiling tie-beam
17	ya cao fang	wooden members on which the main-beam
18	ming ru fu	exposed tie-beam
19	ban tuo feng	semi-camel's-hump-shaped support
20	su fang	plain tie-beam
21	si chuan ming fu	four-rafter exposed tie-beam
22	tuo feng	camel's-hump-shaped support
23	ping an	lattice ceiling
24	cao ro fu	rough tie-beam
25	jjiao bei	wood support above rough tie-beam
26	si chuan cao fu	four-rafter rough tie-beam placed above
27	ping liang	cross-beam
28	tuo jiao	side brace connecting cross-beam with purlin
29	cha shou	inverted V-shape brace
30	ji tuan	ridge purlin
31	shang ping tuan	upper purlin
32	zhong ping tuan	intermediate purlin
33	xia ping tuan	lower purlin
34	chuan	rafter
35	yan chuan	eave rafter
36	fei zi	flying rafter or cantilever eave rafter
37	wang ban	roof board
38	gong yan bi	board onto which bracket sets adhere
39	niu ji fang	ox-spine tie beam

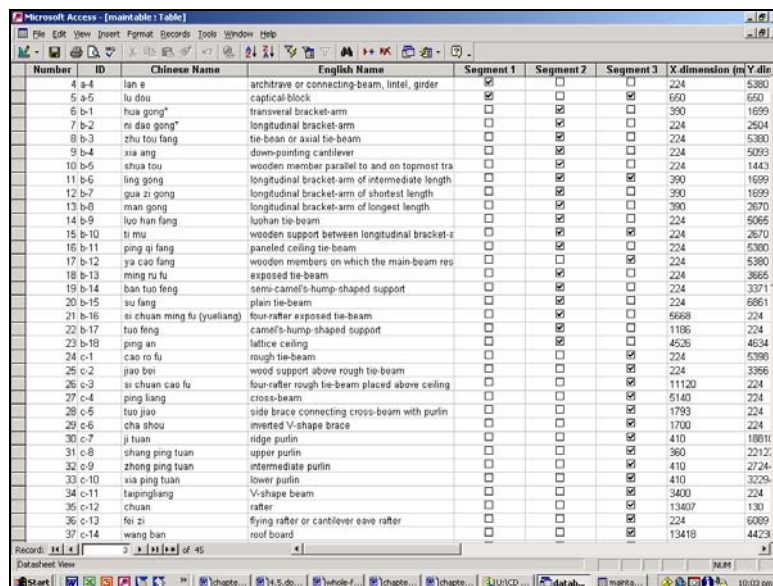
(Figure 4-94: list of structural components)

- Identify the information fields that represent the features of each component, including: name, description, location, and the relation to the structural segment (Figure 4-95)



(Figure 4-95)

- Set a main table with all these information fields as the textual source of information (Figure 4-96)



(Figure 4-96)

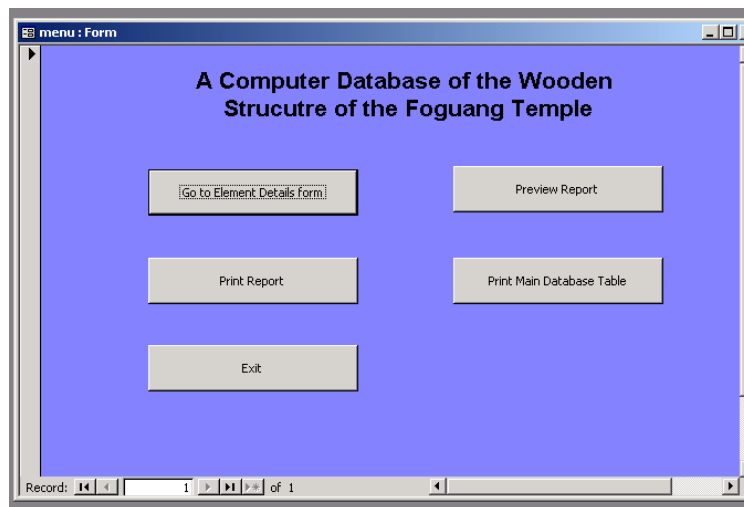
- Design a form for each component which contains its information from the main table (Figure 4-97)

(Figure 4-97)

- Derive the graphic information of each component from the digital model, including shapes and dimensions,
- Add the graphic information to the form of each component (Figure 4-98).

(Figure 4-98)

-
- Design an user interface (Figure 4-99)



(Figure 4-99)

In this way, the database is set which contains all the components of the structure. For each component, there is a specific form containing the related information both textual and graphical. It is available for revision and development by further research.

4.6 Review and revise the model

The digital model has to be reviewed constantly while it is being built. The review of the model follows the concepts of shape and grammar. By reviewing the new generated shapes, it shows whether they conflict with the construction rules, and at which level they fail to follow the rules. Revision is called for implausible solutions. This process needs to be implemented from the element level. Verification of the basic connectivity and dimension of the corner construction can be carried out by referring to the photos, and the model is then reviewed and revised, if necessary.

Chapter 5 Discussion

Computer modelling of ancient Chinese wooden structures is still at its infancy. Only a few previous studies and attempts can be found. Hence, understandably, there is currently no agreed evaluation standard for such models.

This chapter assesses the validity and reliability of the modelling as well as the database associated with it. It also reviews the modelling process and defines the limitations for its application range in ancient Chinese wooden structure research. In addition, this section introduces a number of issues found in the previous studies, namely the components naming system and the validity of construction data.

5.1 An assessment of the model and modeling process

5.1.1 Evaluation of the model

Following the computer modelling procedures specified in the previous chapter, a full size computer model of the main hall of the Foguang Temple is created. What is the academic value of the model to architectural research and by what standard should we judge it? How can this digital model be used in the study and research of ancient Chinese architecture?

It is important to specify the main purposes of the modelling process and the main functions and features of the model. As mentioned earlier, the computer model was not planned to be a digital copy of the physical reality. The idea is to build it as a digital prototype for ancient Chinese wooden structure. After thousand of years' development, the traditional Chinese architecture has experienced a wide range of evolutions and has accomplished a great variety of achievements in its art, science and technology. For instance, there are numerous categories applicable to the wooden

structures from different territories and eras. Therefore, the computer model is not designed to be a common prototype for all the ancient Chinese wooden structures, but just for the type of wooden structures which share similar background with the Foguang Temple. The main purposes for the modelling process are as follows:

- To explore the digital modelling approach to the study of traditional architecture
- To build an ideal model of the wooden structure for this specified style of ancient buildings based on the physical reality of the main hall of the Foguang Temple.
- To better understand the structural features and constructional rules

Accordingly, the digital model that finished with the modelling process is designed to meet the following requirements:

- For the visualisation of the timber structure of this ancient building
- For reference to further academic researches on ancient wooden structures based on it.

A computational model in the study of historic architecture, does not only serve in terms of explaining structural features, but also narrates the materials, colours, ornamentations and techniques of the building.

Compared to the physical reality, the most important outcome is that the model carries the same construction and structural rules. The evaluation is applied from the following aspects:

- The relationship with the physical reality

As discussed before, this computer model can be defined as a conceptual digital model of the main hall of the Foguang Temple. From the element shape to structural connectivity, every step of the modelling process takes the physical structure as the

basis, and strictly adheres to it. However, since the dimension of each element follows that of the previous drawings, there might be discrepancies in dimensions between the computer model and the real building. They are, however, absolutely based on the same construction and connection rules. The model is conceptual in that it looks at the design concept of the building rather than its physical reality. The physical construction has minor differences from the design idea.

- Validity and reliability of the model

Validity and reliability are the key factors that determine the value of the computer model. Looking carefully at the modelling process, it can be seen that the model is based on mainly the previous drawings. Moreover, to ensure validity and reliability, the previous construction “grammar books” and the real building are taken as the reference for a step-by-step review. For the part which has no preliminary modelling information (the bracket system on the corner column), the modelling involves a series of very careful hypotheses and constructs it in the most reasonable way according to the construction rules and architectural sense. The digital model of this part is therefore the “most reasonable” hypothesis and solution. Every procedure of the modelling process is to ensure the validity and reliability of the computer model.

- Its academic value for ancient Chinese architecture research

From an academic approach, the model is built to act as a tool for the representation of the structure and a digital database for further study of the structure. For the representation purpose, it has to have a strong visualisation benefit. The model can be used to simulate the whole construction process. Due to the flexibility that is offered by digital techniques, this computer model is even more valuable for understanding the construction than the real structure in that it enables the disassembling of the structure.

For the academic research purpose, the model is valid to support further research on ancient Chinese wooden structure since it contains the valid construction information of the building as well as connection rules. Moreover, the attached database is a valuable summary of the information, managed by a database management system.

5.1.2 A review of the computer modelling process: strengths and limitations

The modelling process has experienced a review-summarise-hypothesis-revise procedure. A review of the process is necessary to verify the strengths and limitations of this study.

The strengths of the study include:

- It justifiably serves as a reliable source of information because it is based on widely accepted documentation and on-site survey.
- It proposes the formation of a methodological procedure of modelling techniques.
- It introduces a database system within the model system.

The model and the database in this study, however, are narrow, concerning specifically the structural construction and elements of the main hall of the Foguang Temple.

5.1.3 3D modelling based database

The involvement of a database system in this research is an attempt to manage, organize and represent the large amount of information of the structure studied. As introduced in chapter 4, the database created in this research is based on the finished digital model and the understanding of its construction rules. Similar to any other data processing system, the database of the structure also includes a number of structural components that contains the type of information which is highly repetitive. The basic structure is a table listing all the components with the fields that contain the related

physical and spatial information. In addition, a table of the structural segments is created. The database focuses on showing the structural function and relations of each component by linking these two tables together. The hierarchy relations of the structure and its component are presented through this.

For each component, a form has been built to specify its information. Due to the limitation that it is hard for a tabular data system to store and manage graphic information, a new graphic field has been added to the form which provides a visual view of each component. Therefore, the database used in this research directly indicates the relationship and connections of the graphic and digital data, linking the graphics to textual information.

5.2 Some issues generated during the modeling process

During the modelling process, a series of issues about the ancient temple and the previous study on this building have been raised. Some of the issues seem to be helpful for us to understand ancient Chinese architecture structure and construction. Most current studies, including this study, on Chinese ancient architecture are based on earlier drawings and measurement (mainly by Liang shicheng). However, through understanding the building more in the modelling process, I found that there are some previous drawings and studies which might not be quite proper for the research of ancient Chinese architecture. It might be valuable for us to discuss and think about these following issues when doing the research:

5.2.1 The naming system of the building

The original naming system of ancient Chinese architecture is an ordered regulated system for the structural elements. Most of the element names are transferred between the skilled technicians from one generation to another. The naming system is used in a

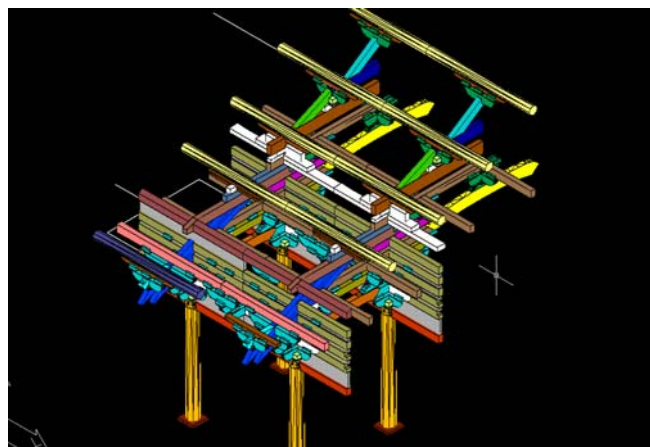
variety of areas of ancient architecture of different eras and places. People are familiar with it. Moreover, a lot of information about the element is contained within a single name. For example: the element Si Chuan Cao Fu stands for four-rafter rough tie beam placed above ceiling.

In this study of the Foguang Temple, this original naming system poses some difficulties for the understanding of the building:

- The current naming system lacks the hierarchical relationship of the structure. As mentioned above, the whole structure of the building is made up of several segments, and for each segment, they comprise of a number of the same or different basic elements. However, it is hard to differentiate this using the current naming system.

- Some structural elements are not named by previous researchers

The modelling process needs to be as accurate as possible. Therefore, every single element in the structure is modelled. A small number of elements, which have clear structural functions, are not named, or at least are not specified in the previous drawings (Figure 5-1).

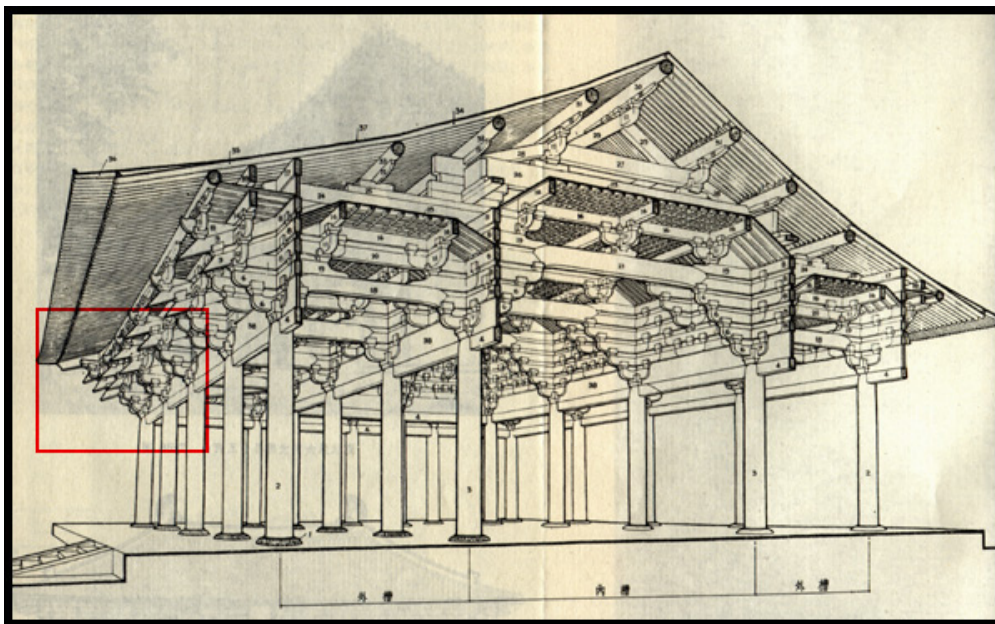


(Figure 5-1: the elements in white color were not named in previous studies)

For the organization of the computer database system in my research, this naming system has to be updated to show several layers of structural relationship and the connectivity between different elements, and new names have to be introduced for those elements that are not specified in previous studies.

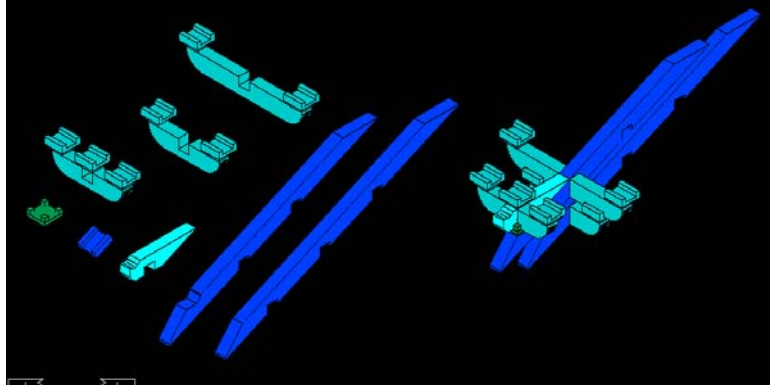
5.2.2 Ambiguity in drawings

The most difficult part for computer modelling of Foguang Temple is the roof. The reason is that there is not enough information available. During my on-site investigation, only viewing from the inside was allowed. However, the important parts are between the ceiling and roof that could not be seen from the inside. Liang did have the chance to measure the inside of the roof, unfortunately, for the hardest area, that is the four corners, there lacks clues and details of construction in his drawings (Figure 5-2).



(Figure 5-2: the important part, the corner was not detailed)

The connectivity between different elements is another important point in the research. However, from the section, elevation and perspective drawings, this connectivity details are not suggested (Figure 5-3).



(Figure 5-3: the complex element connections)

Chapter 6 Conclusion

This final chapter summarizes the process and addresses a possible evolution of the research. It focuses on how the research questions are answered and the related issues for future studies.

6.1 A review of the study process

6.1.1 Research framework

The initial concept of this study was to try to address the use of computer techniques in the study of traditional Chinese timber structure, and hence, to explore the knowledge of linking the latest digital techniques with the research on historic architecture. Because of the great complexities of Chinese structures which are from various territories and different eras, each with different architectural features, the study can not possibly encompass all. It thus focuses only on the Foguang Temple, specifically the Main Hall of the temple.

The research proposes a way of data collection, information validation and computer modelling. Finally, the study finishes with a full size digital model of the studied timber structure.

6.1.2 Standards of judging

There are two aspects of this study: the computer model and the knowledge of computer modelling. How can we assess these outcomes? Effective evaluation is based on a reasonable standard. Setting up the relevant standard of judging is an essential step to processing an accurate evaluation. It is important to link the assessment with the initial research approach. As discussed above, the purpose of this study is to explore the application of computer techniques in the area of historic

architecture research. In this sense, this research is a study of methodology rather than a study of historic architecture. Therefore, the evaluation shall look more at the contribution to the development of research methodology rather than the digital model itself.

Following the idea of focusing at the methodology, the following section reviews this study from the following three levels: the computer model, the methodology for Chinese traditional architecture study, and the methodology for historic architecture study in general.

6.2 Some contributions from this study

6.2.1 A computer model for ancient Chinese building

The digital model established in this study is a computer simulation of traditional Chinese timber structure. From the modelling process it can be seen this model is set up based on the most accessible evidence of the historic site and is established with details starting from the element level. Compared to the computer models from other related research, this model is a detailed virtual representation of components of traditional Chinese architecture to support future studies. In terms of detailed shapes and dimensions, the computer model is an idealised representation of the historic structure. However, it contains all the construction rules, element relationship and connectivities. The study also explores the methodology of computer modelling with insufficient information.

With this computer model, a structural component database is developed. It contains all the spatial data and physical features of the structural elements offering an efficient and easy way to assist in the understanding of ancient Chinese architecture

The true size computer model along with the element database could serve as basis for further studies of similar timber structures. In the area of computer-aided historic Chinese architecture research, this model could be the first ‘virtual reality’ with such level of details and information database.

6.2.2 Digital techniques and historic Chinese architecture studies

The methodology in this study explores a digital approach for historic Chinese architecture study. It suggests the possibilities of applying computer techniques to assist in the understanding of historic Chinese architecture language and grammar. Following this idea, other existing or info-accessible historic timber structures are possible to be computer simulated. It demonstrates the feasibility of applying the methodology to the research of ancient urban design and Chinese traditional gardens since their designs and constructions follow consistent rules as well.

In the research of traditional Chinese architecture, one of the most critical issues is how could we understand the variety of architecture from different eras with various backgrounds. The computer approach outlined in this study might be an efficient tool to store, identify and manage these great quantities of data, which with sufficient database record in the future could be used to identify the development of ancient Chinese architecture.

6.2.3 Digital techniques & historic architecture studies

With the development of globalisation, finding national identities from their traditional heritage might be a more important and meaningful research issue than before. The development of digital techniques has become increasingly concerned with the study of historical architecture, providing computer models for site simulation, visualization and analysis. Computer-aided simulation of historic

architecture is not a new concept. In historic architecture research, the lack of information has been the most common difficulty faced. The hypothesis-test simulation approach explored in this study may be a reasonable option to the solution of this problem.

6.3 Further research

The computer model set up in this study is a detailed source of information for the study and understanding of the timber structure of the Foguang Temple. The computer model with the element catalogue makes up the entire digital database of this historic structure. It is highly recommended that many more studies on other ancient Chinese architecture site be implemented in a similar way. Following this idea, an ancient Chinese architecture digital database can be developed. The value of such a database to the research of the development of ancient Chinese architecture and its evolution is unquantifiable.

This study can be summarized as a research of new methodology for existing issues. It proposes the possibilities of making digital techniques more involved in the study of historic architecture. More works can be done in terms of identifying the relevant methods for the application of digital techniques at the different stages of their model building process.

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Appendix A: CD of Visualization Effects

CD is included with print copy of thesis in the University of Adelaide Library.