

Gulou Structure Grammar and its Computer Implementation

A computational approach to preserve the ethnic building technique and to guide new designs

Lu Xiong¹, Wei Xiong², Hongxia Zhang³

¹State Key Laboratory of Subtropical Building Science, South China University of Technology, ²Guangxi University, ³Guangzhou Urban Planning and Design Survey Research Institute

¹bbxlarc@gmail.com, ²g.bear@163.com, ³zhxlr@gmail.com

Abstract. *Gulou is a type of building found in ethnic Dong people's settlements in south west China. It plays a significant role in the traditional Dong architecture and shows both social and technical values. In the near future the technique as an intangible culture heritage would face the risk of extinction because of globalization. The paper argues that the use of formal grammar and computer tools could help the preservation and learning of the design knowledge of Gulou Structure and develop Gulou designs which would be adapted to modern needs. A shape grammar called Gulou Structure Grammar (GSG) and its computer implementation are made to achieve the goals of capturing the design knowledge of Gulou structure, generating new Gulou designs and promoting the education of Gulou building techniques.*

Keywords. *Gulou structure; shape grammar; parametric model; ethnic building technique.*

INTRODUCTION

Gulou is a type of building found in ethnic Dong people's settlements in south west China. Dong settlement is composed of the basic family group "Dou", every Dou should have its own Gulou as a symbol for the family group. There trend to be 2 to 4 Gulou in a village (Figure 1). Gulou plays a significant role in the traditional Dong architecture and shows both social and technical values. The wooden tower is the most important public building in a settlement as the village council and the senior statesmen's centre. It also acts as an important place for

social activities and communications. For example, the children should be given their names in Gulou; people gather in the Gulou after work to exchange ideas and chat with each other. All the cultural and social activities of Dong people are related to and influenced by Gulou. The culture identity and value system of Dong people are emerged from the activities carried out in Gulou.

Apart from the social importance and value, Gulou is also famous for the unique uprising shape and the excellent building techniques without using any



Figure 1
Two Gulou in a Dong village.

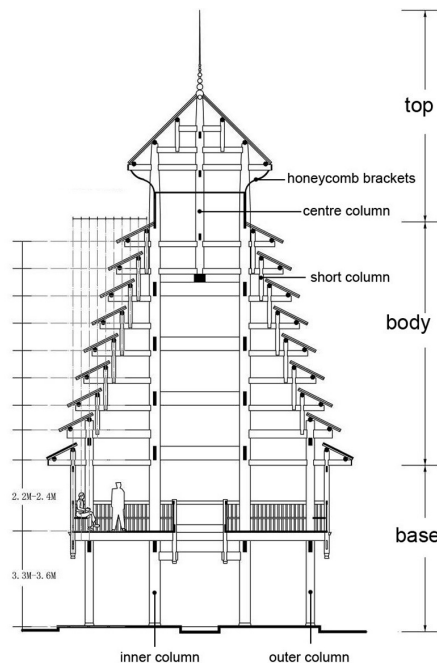


Figure 2
The typical section of Gulou.

metal parts. As an ancient high-rise wooden structure which is still been applied nowadays, Gulou is one of the most excellent traditional Chinese wooden buildings. There are 2 kinds of main columns in Gulou: the inner columns and the outer columns. The inner columns together with the connecting beams play the very similar structure role as the core in the modern high-rise tower. The outer columns are connected to the core by beams which support the multi-level uprising structure. The flexible joint design also enhances the anti-earthquake performance. In terms of ecology, the Gulou technique accumulates the long term low-tech experience of Dong people to avoid the impact of the hot and humid weather condition. For instance, the multi-level roofs could promote ventilation while keep the interior dry from the rains (Figure 2).

Like the other developing regions in China, the old and vernacular building and technique are challenged with globalization. Seldom young men are

willing to learn the technique from the old. In the near future the technique as an intangible culture heritage would face the risk of extinction. Unlike the building and construction manuals for the official Chinese traditional buildings, the rules of Gulou are not originally organized in any written form or drawing. Instead, they are passed down from generations to generations by pithy formulas. While designing and building a Gulou, the craftsman seldom produces any drawing as well. The implicit way of design makes the technique to be difficult to understand and to learn, which also limits the wide spread of the building culture. Although various studies managed to uncover the rules of Gulou building technique, few efforts were made in the area of the formal and computational approach (Cai, 2004).

The paper argues that the use of formal grammar and computer tools could help the preservation and learning of the design knowledge of Gulou Structure and develop Gulou designs which would

be adapted to modern needs. Shape Grammars were successfully applied in the research of traditional Chinese wooden structures (Li, 2001) and dwellings (Chiou and Ramesh, 1995). In this paper a shape grammar called Gulou Structure Grammar (GSG) and its computer implementation are made to achieve the following aims.

1. Capture the design and construction knowledge of Gulou structure via shape grammar.
2. New Gulou design could be generated with the use of digital tools which are developed based on GSG.
3. GSG and the digital tools could be used in education to facilitate the teaching of the rules of Gulou.
4. The digital tools could be used to explore the performance of Gulou.

THE GENERATION OF GULOU STRUCTURE GRAMMAR

The authors managed to extract the compositional rules of the Gulou wooden structure. The rules were further translated to a shape grammar – Gulou Structure Grammar (GSG).

Analysis of the compositional rules of the Gulou wooden structure

The exterior appearance and interior space of traditional Chinese wooden building are entirely defined by the main wooden structure. The composition of the wooden frame is best demonstrated in sections. The function and plan design of Gulou trend to be simple due to its symbolic meaning in the village. The plan shape is usually a square, a hexagon or an octagon. Therefore the section design plays the most significant and complicated roles in the design of Gulou. During the design process, the master craftsman is in charge of the section drawings rather than plan drawings. The plan provides the guide planes which the sections will be attached on.

Gulou could be classified by the number of main columns which touch the ground. There are 2 types of main columns: Inner column and Outer column. The inner column can be composed of a single col-

umn or multiple columns. Besides the single inner column case, both the number of inner column and outer column should be even number. The research focuses on the most common type of Gulou – the 4 inner columns and 8 outer columns Gulou.

The inner columns are placed at the corners of a square while the outer columns are placed at the corners of an octagon. The relationship between the square and the octagon varies into 2 situations. In the first situation the diagonal lines of the 2 shapes are parallel while the second situation the edges of the 2 shapes are parallel. Different alignment leads to different placement of sections. In the first situation the sections are placed between the corners of 2 shapes and between the corners of the octagon and the edges of the square. In the second situation the sections are only placed between the corners of the 2 shapes (Figure 7).

The section of Gulou can be divided vertically into 3 parts: the base, the body and the top (Figure 2). The structure of the base is composed of the main columns and is rather simple. The body contributes most for the symbolic appearance of the building. It is the most important part and highly reflects the building technique of Dong people. The decorative top with fine structure acts as a balanced visual ending to the building. The following article focuses on the composition of the body and the top.

The wooden frame of the body is composed of inner column, outer column, short column, centre column, rafter and beam. The inner column and outer column are connected with beams which are cantilevered to support the eaves and rafters. A short columns are added to a beam to support its upper level beam and rafter. After several iterations the body grows to its full height and the top columns are connected to a central column by beams. The span of beams decreases level by level therefore each level gets smaller and smaller to form the taper outlook of the tower. When the decreasing reaches to the point when the position of short column will be placed on the inner side of the inner column, a centre column must be added to the section to support the upper level beams (Figure 3). Via the control

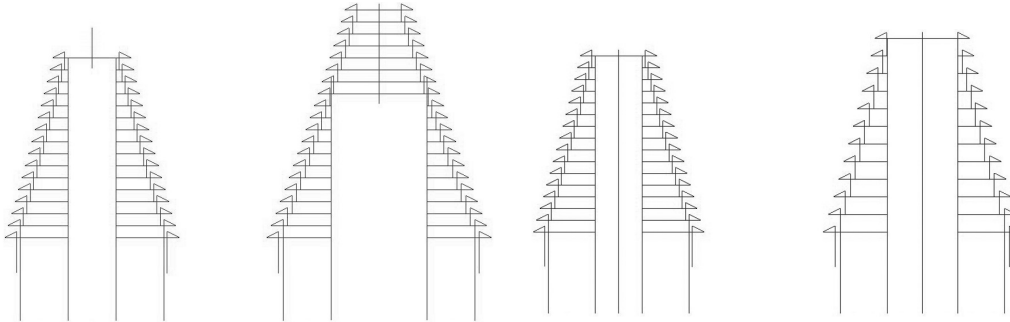


Figure 3
When the decreasing reaches to the point that the position of short column will be placed on the inner side of the inner column, a centre column must be added to the section to support the upper level beams.

Figure 4
By the control of the position of main columns, the number of levels and the height of levels, the facade profile could be adjusted.

of the position of main columns, number of levels, height of levels and the decreasing distance of each level, the facade profile could be adjusted (Figure 4). Equalized decreasing will result in the tilted linear profile while the uneven decreasing will result in curved profile (Figure 5).

The top of the Gulou is also called “honey comb” by the extinguished look (Wu Lin, 2009). It is composed of many layers of overhanging and self-supporting wood pieces. Each layer is subdivided into many segments so the overall structure of the top is a complicated cell-looking system. The composition of the top could be illustrated by the following steps (Table 1):

1. Define the plan profile of the base of the top. In this case the profile is an octagon.
2. Offset the profile to get the shape of each level. In this case the top is composed of 6 level

3. Equally divide each edge of the profile in to N segments and get the division points. In this case $N=10$.
4. Connect the points with the odd number index i on the odd number level to the points with according index on the upper level; connect the points with even number index i on the even number level to the points with according index on the upper level. For instance, point 3 on the 1st level will be connected to point 3 on the 2nd level; point 6 on the 4th level will be connected to point 6 on the 5th level.
5. Connect the points with the odd number index i on the odd number level to the points with index $i + 1$ on the upper level; connect the points with even number index i on the even number level to the points with index $i + 1$ on the upper

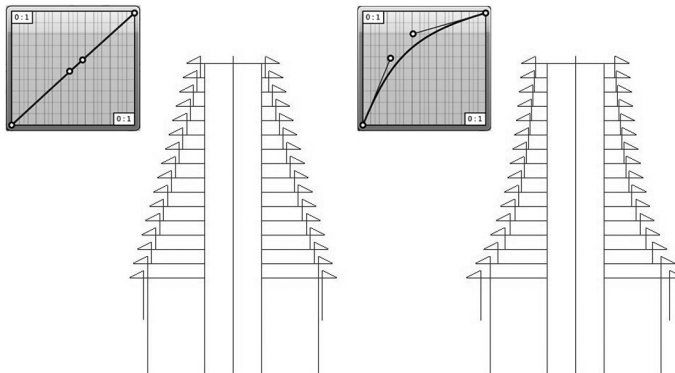
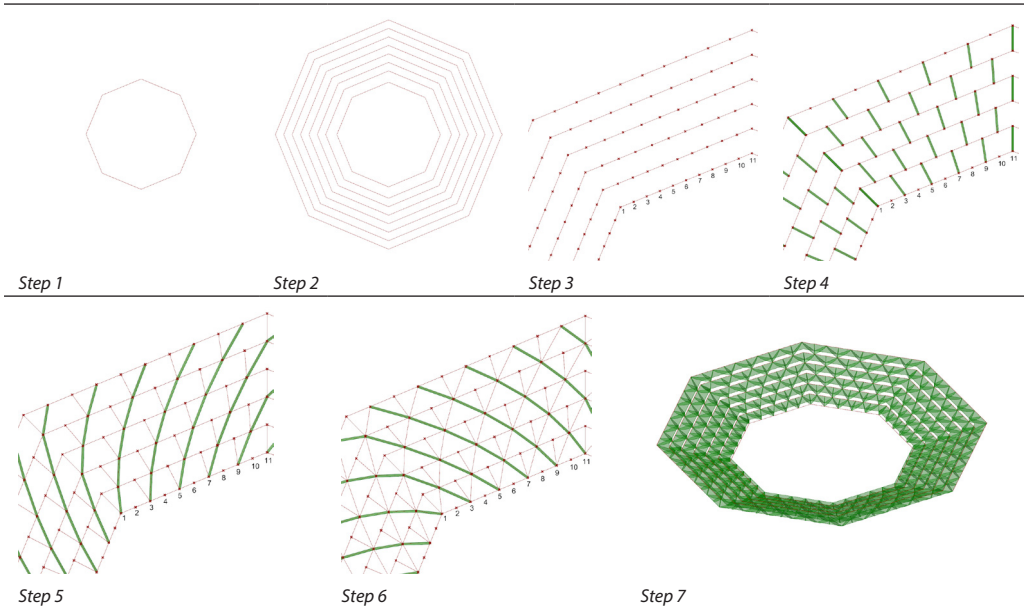


Figure 5
By the control of the decreasing distance of each level, the facade profile could be adjusted. Equalized decreasing will result in the tilted linear profile while the uneven decreasing will result in curved profile. In this case the decreasing is controlled by a Bezier curve.

Table 1
The steps to generate the
honeycomb top.



- level. For instance, point 3 on the 1st level will be connected to point 4 on the 2nd level; point 6 on the 4th level will be connected to point 7 on the 5th level.
6. Connect the points with the odd number index i on the odd number level to the points with index $i - 1$ on the upper level; connect the points with even number index i on the even number level to the points with index $i - 1$ on the upper level. For instance, point 3 on the 1st level will be connected to point 2 on the 2nd level; point 6 on the 4th level will be connected to point 5 on the 5th level.
7. All the guide lines for the leaf-shaped brackets

are generated from step 4 to 6. The brackets are attached according to the guide lines to form the base part of the honeycomb top.

The content of GSG

After the analysis of the compositional rules of Gulou, GSG was formulated. It consists of 3 initial design and 24 rules. Rules were divided into 3 groups: plan rules (Table 2), body section rules (Table 3) and top rules (Table 4).

THE COMPUTER IMPLEMENTATION OF GSG

A parametric model was built based on GSG. Sev-

Table 2
Rules of plan generation.

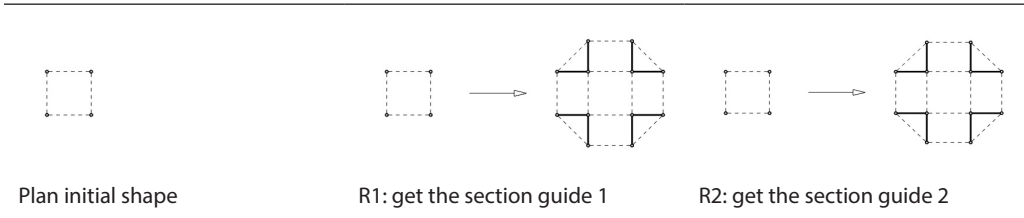
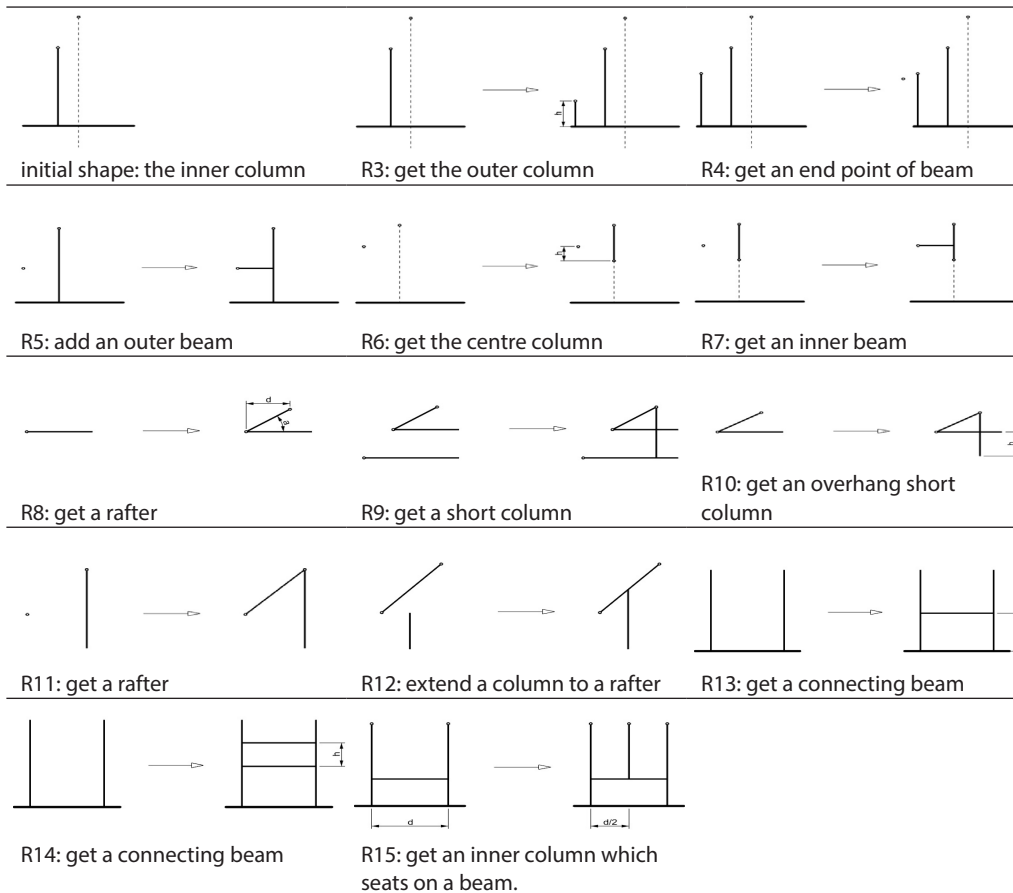


Table 3
Rules of section generation.



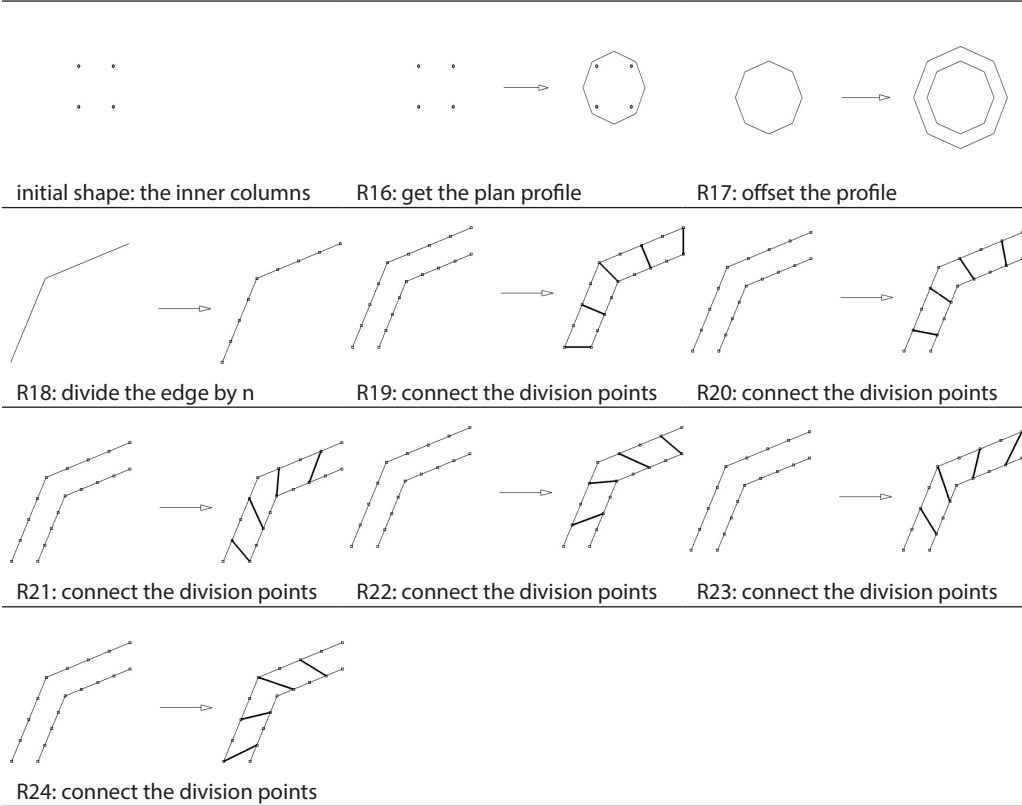
eral key parameters were identified: type of plan, distance between inner columns, distance between inner and outer columns, height of the base, body level height, number of body level, a Bezier curve to control the span decreasing of each body level, top level height, number of top level and the increase span of each top level. Detailed parameters were also defined: cantilevered distance of beams, rafter angle, and column lower extension length. Dimension parameters were added to determine the size of the components such as the radius of columns and the height of the beams. Grasshopper in Rhi-

no3d is chosen as the platform to develop the parametric model. Both the axis and the solid model of the wooden frame pieces can be obtained from the model (Figure 6).

THE APPLICATION OF GSG AND THE PARAMETRIC MODEL

As an ancient building type oriented from the Ming dynasty (1368–1644), Gulou is still being built and is playing an important role in the life of Dong people nowadays. It is also widely used in public parks and tourism sites in non-Dong areas for its distinguished

Table 4
Rules of bracket axis genera-
tion.



symbolic form and strong landmark effect. From the modern use of Gulou, it could be identified as a type of contemporary architecture. However, both its design and construction are still based on the old manual approaches. Digital technologies could serve the design and construction of Gulou as new instrument, therefore Gulou could evolve and be adapted to the information age.

The parametric Gulou model was used in the design of a landmark structure in a resort area in Sanjiang, Guangxi province. The famous Dong craftsman Wu Shikang was invited as a design consultant for the project. During the design process, a series of design models were generated with the help of the parametric tool (Figure 7). Wu gave a positive re-

view of the tool. He held the view that the tool could rapidly generate designs according to the rules and parameters, therefore the communication with client could be carried out efficiently. Also the model provided all the dimensions of the main structure pieces and a spread sheet of the use of material. The work used to take months to do could be compressed to be finished in days.

GSG is also used in the teaching of the course: *Guangxi ethical buildings* in the architecture school of Guangxi University. Gulou is an important topic of the course. GSG and the parametric model are introduced to unveil the design rules and construction process of Gulou. The students can learn the rules from GSG in a graphic and formal way. Then design

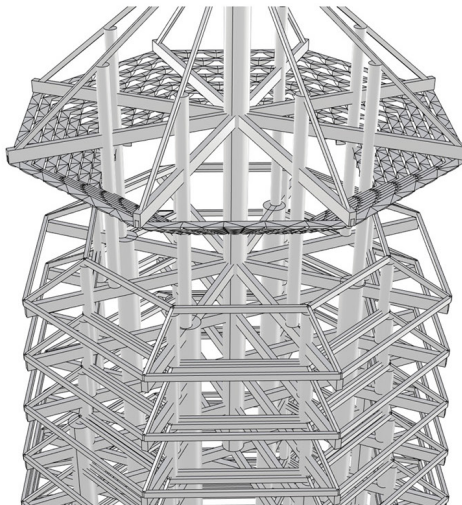
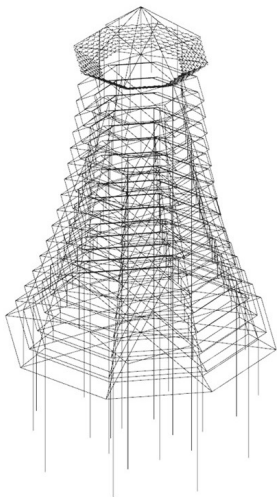


Figure 6
Both the axis and the solid model of the wooden frame pieces can be obtained from the parametric model.

experiments could be carried out. Students use their own set of parameters to generate designs with the parametric model. The vivid digital way of teaching encourages the students to analyze traditional Chinese buildings in a computational point of view, and to explore new designs based on the traditional building techniques.

DISCUSSION AND FUTURE WORK

The shape grammar of Gulou structure was formulated as shown by the paper and a computer tool was made to assist the design and education of the ethnic building. However, the potential of GSG and its computer implementation is not fully explored. The paper serves as a start point for the long term

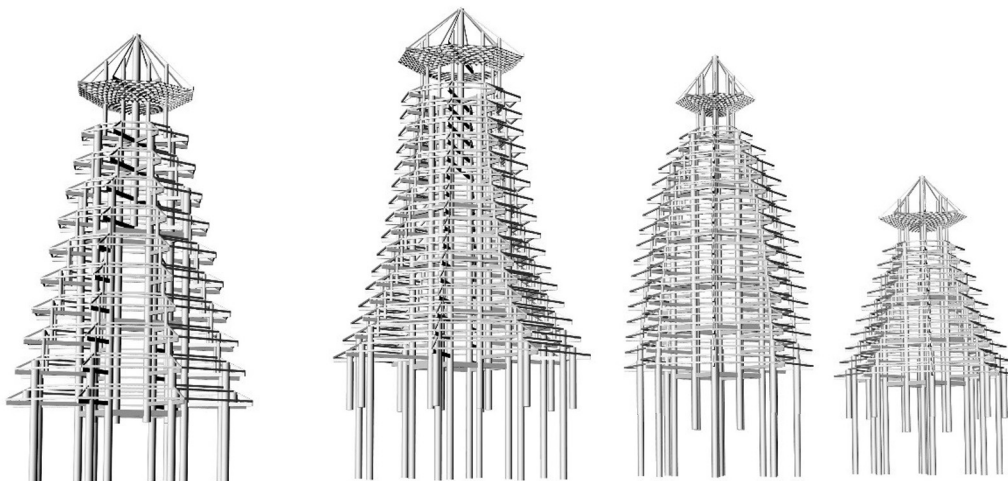


Figure 7
4 different designs are generated for the project in a tourist site.

study of the building techniques of Gulou. The future work based on GSG would address the issue of building performance evaluation, the detail wooden structure of Gulou and its implication to contemporary architecture.

The building performance of Gulou mainly contains 2 aspects: the structural performance and the passive solar comfort. The performance evaluation of Gulou should take the considerations of the culture and activities of Dong people. In this paper the structural performance is focused on material consumption. The material for building Gulou is fir. On one hand, Dong people are willing to travel hundreds of kilometers to find the right and divine fir and transport it back via man labor. On the other hand, nowadays the forest resources in China are getting more and more precious. The two factors require the size, length and numbers of the fir for Gulou construction to be carefully calculated in order to minimize the material usages while achieving the design purposes. Future work will study the relationship between the form and the structural performance of Gulou.

Passive solar comfort evaluation consists of the assessment of daylight factor, solar radiation and ventilation. They are related to the overall dimensions of the tower and the openings. There is one unique factor of thermal comfort in Gulou: there is always a fire place in the centre of the ground floor. It is a symbol of energy in Dong culture. The fire place plays the role of a heat source and will affect the air flow in the chimney-shape of the inner space. Multi-level roofs could encourage the use of daylight and natural ventilation while keep the interior dry away from the rains. Advanced performance

simulation software would be introduced in future studies to unveil the ecological means in Gulou building techniques.

The detail joint design plays a significant role in the wooden structure. The sophisticated tenon-and-mortise work connects all the wooden pieces together without using any nail or metal part. The design grammar of the detail wooden structure will be carried out in the further study.

The aesthetic, structural, ecological and detailed design features of Gulou would have great implication to the design of contemporary architecture. The features could be further explored and applied to new designs. Further design experiments and practices will be carried out with the considerations of the features of Gulou. We believe that the computational design approach will help us adopt and apply the characters of ethnic building for the emergence of the new architecture.

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