EXPLORING THE TOPOLOGICAL SYSTEM OF DOUGONG

HAN-TING LIN\(^1\) and JUNE-HAO HOU\(^2\)
\(^1,2\)Graduate Institute of Architecture, National Yang Ming Chiao Tung University.
\(^1\)hantinglin@arch.nycu.edu.tw; 0000-0002-4745-3520
\(^2\)jhou@arch.nycu.edu.tw; 0000-0002-8362-7719

Abstract. The large-span wooden construction project uses a sophisticated tenon joinery system to overcome the limitation on the size of the material. However, making a clear layout and knowledge transfer is an important issue under the complex structure. This research takes “Dougong” as an example to sort out the possible knowledge graph of Dougong. Through the geometric feature classification and the relationship between the joints, we found that the structural relationship of traditional Dougong is like the branch system of the L-system. But it has the characteristic of horizontal connections that make Dougong restrain one another more firmly. Besides a graphical representation of the complex joinery system, it can quickly visualize and adjust the type changes and therefore provide another network related to the building model. Besides computational geometry to traditional wood structure analysis and automation, we also explored two new types of Dougong from a perspective of the traditional wooden structure. So, in this research, we developed automatic digital tools for Dougong and propose new applications of Space Syntax, attempting to break through the existing limitations of Dougong.

Keywords. Dougong joint; Knowledge Graph Visualization; Parametric Design; Space Syntax; SDG 4; SDG 9; SDG 11.

1. Introduction

The role and importance of wooden structures have transformed and shifted. According to Yingzao Fashi (Li, 1920) in the Song dynasty, traditional buildings used special tenon-joining methods and systems to achieve large-span wooden constructions with smaller wooden materials. Since the industrial revolution, cement and steel structures used in place of wood for large projects. During the mid-to-late 20th century, wooden structures inspired some architectural designs even with cement, such as Arata Isozaki’s design of “Clusters in the air” in 1962. Until recently, in response to environmental sustainability, the importance of natural materials was once again emphasized. Shigeru Ban and Kengo Kuma went beyond traditional wooden structural systems in terms of digital tectonics and scale, such as the Tamedia Office Building. And in prospective research, such as the beaver digital wood structure (Cheng and Hou, 2016), which solve physical wooden system’s information into computer language,
and from digital organization to manufacturing. As stated above, the fabrication of unique joinery relationships fascinated different generations. They used the assembly methods or system to respond to the sustainability issues of the environment, culture, and future. And lead to the topological system we will investigate.

According to White’s Concept Sourcebook (1975), architectural design often uses simple diagrams as transferring knowledge which behind them are the beginning of the construction of the system. So, it is necessary to comprehend the complexity of the joinery system through these simple diagrams. In the traditional wooden structure, Dougong is classic tenon joinery for beam-column support systems. It also highlights the craftsmanship in the history of over 2,000 years. And brought out this research takes the Dougong of the Tang Dynasty as an example. During the process, we use the Rhino/Grasshopper to analyze its topological relationships and explore corresponding knowledge graphs such as generating Dougong’s classification, topology map, force transmission graph, and new form suggest for breaking through the perception of traditional Dougong.

2. Research Background

In the past, the stakeout drawing by artisans had important implications, including clear lofting on site, knowledge transfer between artisans, and passing on to the next generation. And now, we recognize the complex wooden joinery’s typology and structure through 3D models or animations. However, whether the sophisticated structure such as Dougong no longer is viewed in the way of classic architecture, but a way of computer understandable topology system. The system not only reduces many calculations or artificial analyses, but also helps users to make the final decision. Currently, there is relatively little research on Dougong’s design methods or systems. The following discusses the topology of components and the selection of digital tools through the literature.

2.1. FROM TYPOLOGY TO TOPOLOGY OF COMPONENTS

The structure of the Dougong is much more complicated than the general tenon joints, so there are many studies to discuss. In order to understand the geometric form and system topology of the Dougong, the following reviews the literature in three aspects: First is the geometric form of the Dougong. Second is the topology of the relationship between the components. Third, the generation rules of Dougong.

- Dougong's geometric form: Di uses Boolean operations such as the size and inner cut of the Dougong on the historical record of digital modeling (Di et al., 2014). In addition, Ranger explores the geometric proportions in the parametric construction of the Dougong and the Chinese palace (Ranger et al., 2020). The above two methods respectively describe the digital meaning of the Dougong and discuss the authenticity of the digital model.

- Components' topology: Jørgensen said that the IFC structure was just the hierarchical relationship of the data but didn’t contain the relationship between the overlapped components. Then, he proposed a schematic diagram of the building components to express the importance of relational topology in the data (Jørgensen,
Furthermore, Li used the transmission of a seismic force of Dougong to draw the concept diagram of the topological properties between the components (Li et al., 2018). Although the above are only conceptual diagrams, they reveal the need for a knowledge graph to describe the relationship between building components.

- Dougong's computer generative design: Wu (2003) applied the concept of Shape Grammar (Stiny and Gips, 1971) to find out the logical rules of Dougong and create a set of grammar to generate it. In addition, some studies tried to apply to the parametric design by the growth pattern of the L-system (Prusinkiewicz et al., 1988). Cai et al. (2020) used the Paifangs’ composition system, which transforms a graph and built-in components with L-system grammar derived from architectural rules. Therefore, deconstructing the system of components and applying computer logic to parametric design is a way to inherit the original system and carry out the generative design.

Through the above literature review, we will discuss three aspects of Dougong for integrating into a system for exploring Dougong. The first simplifies the geometric understanding of Dougong. Second, develop the knowledge map of Dougong. Third, expand the possibility of Dougong.

2.2. DIGITAL TOOLKITS

We use Rhino/Grasshopper as the parametric platform, which will facilitate the exploration of Dougong geometry. In addition, we use Syntactic to analyze the relationship of components. Finally, use Wasp to explore the possibilities of Dougong components. Besides the existing tools, we have also developed an automated process in Chapters 3 and 4.

2.2.1. Syntactic: A digital tool for spatial graph theory

According to Space Syntax (Hillier, 2007), Pirouz Nourian developed the Graph Theoretical Methods and a tool: Syntactic in 2016. He reorganized the Space Syntax into algorithms and released them as open source. Syntactic uses Breadth-First Search: BFS to find the relationship value and depth value corresponding to each space. Then, it calculates four different parameters: Integration, Control, Choice, Entropy, and uses visualization to illustrate the mutual space relationships. This tool analyzes Dougong to explore whether the components can correspond to the relevance of the space.

2.2.2. Wasp: A digital Tool for Discrete Modeling

Wasp is an expansion kit proposed by Andrea Rossi research (Rossi and Tessmann, 2018). Its purpose is to aggregate geometric components and apply them to discrete modeling and structural entities that allow assembly and disassembly. However, this tool will be suitable for use because the assembling of the Dougong is just like 3D puzzles. It will break through the imagination of traditional Dougong and provide possible future forms and even topological relationships.
3. **Geometric Analysis of Dougong**

In Rhinoceros3D, objects are constructed and organized mainly by geometric relationships, but lacking the order of composition. To solve this problem, we developed a set of automation processes in this chapter, including sorting, classification, and visualization of Dougong. The purpose is to deal with the arrangement of the Dougong components sequentially rather than structural order and simplify the complicated naming. These processes simplify the comprehension of the Dougong and facilitate subsequent research operations. Then, the following parts discuss the foundation of the Dougong. One is the order of the Dougong assembly. The second is feature classification.

3.1. **INTERLOCK SEQUENCE**

We advanced the sorting function for the components to solve lacking information about the actual structural order of Dougong, which can automatically define IDs. The following process depicts the sorting of the interlock sequence (see Figure 1). First, we adjust the order of the Dougong structure based on the Z value of the center of mass of each component. We found that Ang (the extension member of the Dougong) would break the stacking order and cause the problem of sorting correctly. Therefore, it is necessary to find out the position of Ang. Next, we use the geometric points of each component to perform linear regression for the centerline. Then, identifying Ang by the Z values of the centerlines’ vectors. Finally, we sort and arrange the components to get the correct interlock sequence.

![Figure 1. Automatic sorting diagram of Dougong.](image)

3.2. **FEATURE CLASSIFICATION**

This research also developed the automatic classification function, which can screen the relative characteristics and the numbering of the Dougong components, which will simplify the understanding of the complex structure and multiple naming of the Dougong. We use the Dougong component’s unique geometric characteristics, such as proportion, vector, and section area, to reorganize it. Then test on different Dougong (see Figure 2).
EXPLORING THE TOPOLOGICAL SYSTEM OF DOUGONG

4. Knowledge Graph of Dougong

Continuing from the previous chapter, we developed two tools for automated analysis, including relational topology diagrams and force transmission diagrams, and use Syntactic for inspection and analysis. We explored the knowledge graph of Dougong through three steps: First, put forward three sets of knowledge graphs of the Dougong relationship. Second, use Syntactic for component analysis and visualization. Third, develop a knowledge map of the transmission of the Dougong force. Hence the design of novel wooden structures no longer needs to go through complicated drawings and physical simulation to its trivial details (see Figure 3).

4.1. COMPONENT TOPOLOGY: GET RELATIONSHIP VALUE AND DEPTH VALUE THROUGH VOLUME OVERLAPS

To find out the relationship between the components, the automatic overlap detection of them will find out the others. They overlap each other and generate different relationship diagrams based on their ID relationship values. There are three types of graphics based on the relationship between components.

- Mesh topology graph: We connect the centroids to edges to form the graph \( G = (V, E) \) (Nourian, 2016). In addition to visualizing the edges, the process also records the overlapping relationships between the components. Comparing with topological
studies based on L-system, the system is a cross-linked branch system due to the horizontal connections between chains (see Figure 3).

- Spherical topology graph: We use kangaroo collision and extrusion to get the system topology based on the volume of the component. And then convert it into a sphere to understand the relationship between the component’s connection (see Figure 4).

- Depth topology graph: According to the ID relationship values above, the BFS algorithm calculates the shortest number of nodes for the depth value corresponding to each component. For example, the column reached through three or five nodes to Arch. So, the gong is at the third depth of the column. And conversely, the column is also at the third depth. According to the relationship, each component would derive a depth map (see Figure 5).

4.2. COMPONENT RELATIONS: THE NUMERICAL MEANINGS IN SYNTACTIC

To respond to whether the four relational values in Chapter 2 can apply to traditional wood structural systems. We used Syntactic for inspection and analysis based on the ID relation value and depth value of Dougong. And then reinterpret the component meaning of this value and visualize it (see Figure 6).
• Integration: The degree of proximity is a measure of the central component. The higher the value, the closer it is to the core position.

• Choice: Indicates the importance of a node, which is the total number of times that a component is located between other components. The higher it is, the more important it is.

• Control: It is the sum of the reciprocal of the depth values between the components. The higher the number, the more controlled and the harder it is to move.

• Entropy: The higher the value, the more difficult it is to connect its components to others.

Figure 6. Visualization of Dougong with four numerical values.

Through the integration and the choice, we found Ang is the center of the overall composition and found its slope is significantly higher than other components. In addition, from the visualization of the control value, the middle gong is the maximum value of all. However, the topological diagram in section 4.2 cannot express the particularity of Ang. This phenomenon also leads to the need for a system topology with slope characteristics.

4.3. COMPONENT SYSTEM: BRANCHING AND FORCE TRANSMISSION

In the previous paragraph’s conclusion, the three topology graphs can’t read out Ang’s information. So, we turn the link of Dougong components’ centroid points into a centerlines connection; we found it is essentially close to the branch system. Because of the characteristics of the horizontal connection, it’s more like a cross-linked branch system and maybe more in line with the topological relationship between the components. Through the relationship between the branch system and gravity extrusion, Dougong components clamp each other to resist the seismic force. The following explores its system and force transmission in three parts (see Figure 7).

• Branch system diagram: Organize into three specific branch states to understand Dougong’s system. (1) Vertical branch: bearing capacity. (2) Horizontal branch: the centerlines of the components. (3) Special branches: form a network of fixed vertical and horizontal branches and extend them.

• Force conduction vector diagram: According to the contact points of different branches, the force conduction simulation got by projection.
5. Alternative Applications

Besides exploring the traditional system topology of Dougong, this research also attempts to extend the wooden structure to new applications. We discuss with Dous and Gongs, which are the representative components of Dougong. Therefore, we will not discuss clamp wood. The following is the trend of the two types of Dougong. One is the discrete digital Dougong; the other is that we use Dougong in the frame system.

5.1. SYSTEM FRAMEWORK OF DOUGONG

Dougong is a node of a wooden structure system that can share the gravity of the roof and beams. So, this section shows the construction method of a large-scale frame system. We develop a digital tool for inputting the frame lines and finding the nodes to produce the wooden structure. This process can improve the flexibility of the angle of the Dougong and reduce its vertical and horizontal restrictions (see Figure 8).

5.2. DISCRETE MODELING OF DOUGONG

Discrete modeling and generative design are new possibilities for architectural design in using modular components for parametric construction. This section exhibits an assembly method based on the tenon joint relationship. We use the external expansion kit Wasp of Grasshopper to perform this operation and take the component’s center point and the vector line for the discrete algorithm modeling. There are three types of attempts below: one is the discrete modeling of an individual component, the other is
the modeling of Dous and Gongs, and the last is the discrete modeling of composite components of Dougong (see Figure 9).

![Discrete modeling of Dougong](image)

5.3. EXPERIMENT OF TESTING THE TOPOLOGY SYSTEM

We brought the discrete one into the automatic toolkit mentioned in Chapters 3 and 4. It can form sequence relationships, relationship id value, and depth value. The Syntactic tool can use to calculate the relationship between components. This experiment shows that the above knowledge graph system can apply to the complex assembly of Dougong components (see Figure 10).

![The flow of discrete Dougong's knowledge graph](image)

6. Conclusion and Further Research

In this research, we presented a knowledge graph that humans and computers can easily understand in Dougong through our process; in the analysis process, we developed a set of automatic sorting and classification methods for Dougong through geometric features. Then, we generated the knowledge graph and visualization of the relationship among the Dougong components and extended the application of the Syntactic toolkit to the traditional wooden systems. In addition, we explored two generative examples.
and have tested one of them with the process of geometric analysis and knowledge graphing. Through the test, we found the process can use in different components’ overlap. We expect the Dougong topological system as a prototype to promote the application of knowledge transfer and potentially provide a digital way of traditional construction. However, this article only studies the relationship between wood structures and has not discussed the details of wood tenoning. Therefore, presenting the knowledge graph of tenon joints is the next step that needs to be promoted.

7. Acknowledgments

We thank the technical support and resources provided by the GIA Architectural Informatics Lab, National Yang Ming Chiao Tung University. This research was supported by the Ministry of Science and Technology (MOST 110-2634-F-009-018).

References


Li, Jie. (1920). Ying zao fa shi.


