Strategies for Applying Shape Grammar to Wooden Furniture Design: Taking Traditional Chinese Ming-Style Recessed-Leg Table as an Example

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This paper uses shape grammar to conduct strategic research and innovative translation of existing wooden furniture designs. A traditional Chinese Ming-style recessed-leg table was used as an example to demonstrate its feasibility. The paper applies biological DNA genetic information to furniture products, and combines shape grammar to evolve and mutate them, thereby creating new forms of wooden furniture that maintain the original genes. A DNA gene pool of recessed-leg table was constructed, and an architectural queti replacement pool was constructed based on the rules of shape grammar as backup for subsequent experiments to replace part of the designed genes of the recessed-leg table. Shape grammar was used to deduce the recessed-leg table and generate three plans. A consumer questionnaire was established through the semantic differential method. After evaluating these three design plans, an optimal plan that meets market demand was selected, and modeling, rendering, and concept elaboration were performed. Finally, the paper takes Ming-style recessed-leg table as an example to demonstrate that it is effective and feasible to use shape grammar to guide the design and research of domestic wooden furniture.

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INTRODUCTION

Research Background

The majority of Chinese people have a special affection for wood. They like wood, care for wood, utilize wood, and preserve wood. All this stems from their beautiful impression of solid wood. In the development history of ancient Chinese architecture and ancient furniture, wood was the most commonly used material. Through the development of ancient Chinese architecture and furniture, one can see the development history of Chinese wood craftsmanship. China's ancient buildings and ancient furniture mainly use wood structures, forming unique styles and practices, and also forming the "wooden culture" with unique oriental characteristics. Chinese civilization attaches great importance to the integration of man and nature. People respect, admire, and love nature. Integrating solid wood into life demonstrates the harmonious coexistence of man and nature. Of course, this is consistent with the fact that wood in the forest does not require artificial carving and the ancient philosophy of advocating nature. Therefore, wood plays an important role in Chinese architecture and classical furniture, in sharp contrast to the "stone

culture" of the West. Ancient people also believed that trees were a bridge between heaven and earth, and a way for humans to communicate with heaven and express their wishes. Therefore, the ancients planted trees for forests, cut down trees for wood, used natural trees to build houses, make furniture, etc. All aspects of life are closely related to wood. This practice has been passed down to this day, and people habitually use wood to make furniture. This stems not only from the habits of the older generation, but also from people's love for wood, and is more deeply rooted in the long-standing "wood culture".

In the process of felling wood and making furniture, the ancients not only paid attention to the grain and texture of the wood itself, but also paid attention to the processing skill. It is recorded in the ancient Chinese craft design classic "Records of Examination of Craftsmen": "Natural climate, geographical location, wood beauty, and the craftsmanship, these four make up a good work" (Zhang 2004). Looking back on the long history of Chinese crafts , Ming-style furniture is a model that integrates the spirit of heaven and earth with the ingenuity of materials, art, and craftsmanship. It is considered to be a rare and exquisite wooden furniture craft in the world. Ming-style furniture mostly uses hardwood materials such as rosewood, huanghuali, mahogany, nanmu, walnut, *etc*., so it is also called "hardwood furniture" (Sun and Wen 2020). The furniture produced by the craftsman, with its hard and fine texture, elegant and steady tones, unpredictable natural textures, and simple and beautiful artistic shapes, perfectly demonstrates the harmony between the internal and the external beauty of the work, and it is the mainstream of furniture in the Ming Dynasty. The distinctive features of Ming-style furniture are: (i) generous shape, moderate proportions, concise and stretched outlines; (ii) ingenious and reasonable structure, precise mortise and tenon joints, solid and firm; (iii) good at selecting materials and ingredients, paying attention to the natural texture and color of the wood itself; (iv) proper carving and molding processing; (v) the metal ornaments are exquisite in style and soft in color, playing the role of auxiliary decoration. The artistic characteristics of Ming-style furniture can be summarized in four words, namely "simple, thick, precise and elegant". Ming-style furniture is an artistic achievement formed during the Ming Dynasty in my country. It is praised by the world as a pearl of oriental art and enjoys a high reputation in the world furniture system. Since the 1990s, China's economy has risen steadily. At present, China is the world's largest furniture producer (Xu *et al*. 2020), exporter, and consumer (Yan 2017), and occupies an important position in the global furniture export trade. At present, wood furniture occupies a critical position in the Chinese furniture industry and strongly represents the Chinese furniture industry (Prospective Industry Research Institute 2018). Studying the modern translation of traditional Chinese Ming-style furniture has important inspiration and reference significance for the current development and design of domestic wooden furniture.

Research Status

Chinese consumers have a strong consumer preference for wood furniture, especially with the acceleration of China's urbanization process after 2010, which has further increased the consumer preference for wood furniture in the Chinese market (Lu *et al.* 2020). At present, research on wooden furniture focuses on meeting consumer needs, improving user experience, and thinking about the relationship between furniture and the environment. Pirc Barčić (2021) researched the behavior of consumers, because it helps stakeholders to understand the needs and expectations of the consumers. Chen and Yang (2021) argued that the sustainable development of the wood furniture industry can be promoted through increasing consumers' on-site wood furniture experience by opening

offline furniture exhibitions. Sakagami and Sakaguchi (2022) evaluated individuals' shopping conduct and concluded that consumers are willing to pay an additional ~4% of the sales price for wood products made from wood produced under sustainable forest management. In other words, consumers value environmentally friendly wood products. Bumgardner and Nicholls (2020) suggested that a business model focused on well-designed, emotionally appealing products contributes to the overall lifespan of higher-value furniture products. Longer functional lifespans have positive implications for disposal, carbon storage, and resource use.

What's more, research on Ming-style furniture as a specific object focuses on the fields of historical context, design thinking, and creation aesthetics. (i) Feng and Jiang (2022) sorted out the historical development and cultural heritage of the Ming-style spring stool. The paper uses ancient documents to sort out relevant concepts, combines version theory to speculate on the problems that arise in the circulation of versions of the "Luban Classic", uses the visual Gestalt theory in Gestalt psychology to prove the conversion of "Qin" and "Chun", and uses images to analyze the collective unconsciousness shown in the paintings of the Ming Dynasty, and then clarify the cultural connotation of the Ming Dynasty shown in the spring stool. (ii) Cai (2022) discussed the functional adaptability of Ming-style furniture. By displaying the functions and spatial furnishings of Ming-style furniture in history, starting from the functional adaptability characteristics of Ming-style furniture, he explored the design rules of Ming-style furniture through data induction and diagram analysis, and interpret and demonstrate it through Confucian and Taoist philosophy. The relationship between the idea of "body function" and the functional adaptability of Ming-style furniture. (iii) Zhan *et al.* (2021) analyzed the design thinking of reduction. Through the methods of enumeration, comparison, and case analysis, the paper starts with the design concept and design language of Ming-style furniture, and discusses the reduction of shape, material reduction, structure, and process reduction of Ming-style furniture through examples. Reduced design thinking by implication. The awareness of reduction in Ming-style furniture coincides with the green design concept of modern furniture. (iv) Niu (2022) discussed the design rules of Ming-style furniture creations from three aspects: "linearity, volume, and space", revealing that the essence of Ming-style furniture aesthetics is a kind of craftsmanship based on the premise of respecting the natural characteristics of wood and the superb craftsmanship. It is an art form that uses handicraft as a means to materialize the aesthetic consciousness and mainstream ideas of ancient people.

However, the existing research on the innovative approaches to wooden furniture design that meet market needs is rare, and further supplements are needed. For Chinese wood furniture, in view of its long-term active performance in international trade, scholars began to pay attention to its relationship with national traditional culture. Deoxyribonucleic Acid (DNA) provides a conceptional analogy from molecular biology, where it is used to store biological genetic information. Now the concept has been extended to the field of industrial design for the inheritance of product brands. It refers to the design genes that a series of products still inherits after many iterations of innovation (Lu *et al.* 2010). Shape grammar uses auxiliary software in modern computers (such as Adobe Illustrator, Photoshop, CAD, *etc*.) to evolve and mutate the initial shape, thereby creating new shapes that maintain the original DNA gene. This theory was initially mostly used in traditional painting, architecture, *etc*., but has now been expanded and widely used in innovative design fields such as modern industry design and cultural products (Lu *et al.* 2010). DNA genes and shape grammar have been used in the manufacturing industry. This paper

explored a hybrid integration approach. Many scholars in China have devoted themselves to it and applied it to multiple professional fields. On the basis of shape grammar, Xu *et al.* (2021) introduced Peking Opera masks to establish a reference library and designed a new tea set design containing the connotation of Peking Opera; Feng *et al.* (2019) encoded original porcelain, cultural associations, and existing porcelain, and used shape grammar to study the morphological reasoning process to achieve morphological fusion; Bu *et al.* (2021) first conducted a survey on Dunhuang caisson patterns, extracted and deduced the initial patterns to obtain the second-generation patterns, and finally applied them to the design of women's fashion handbags; Sun (2019) used a variety of research methods to analyze Qin embroidery geometry pattern, and the basic elements were extracted and deduced using shape grammar and applied to handbags and stationery decorations.

However, domestic research on furniture design based on morphological grammar is relatively lacking, and the forms of wooden furniture are relatively fixed and outdated. The use of shape grammar can effectively solve the problem of relatively insufficient innovation and uniform appearance of domestic wooden furniture. It proposes a distinct and logical innovative design research method for wooden furniture, scientifically and effectively guides its morphological innovation, thereby designing wooden furniture with rich national cultural characteristics. In this study, shape grammar was applied to the modern translation and design of traditional Ming-style recessed-leg table that meets market needs. Taking Ming-style recessed-leg table as an example, we explore the feasibility of shape grammar in the innovative design of wooden furniture.

EXPERIMENTAL

Research Route

The first step of the paper introduces the background and significance of the topic. Since ancient times, China has advocated wood materials derived from nature and developed a “wood culture” in which man and nature coexist harmoniously. The ancients were accustomed to using solid wood to make furniture. After thousands of years of manufacturing and production experience accumulated by ancient Chinese craftsmen, wooden furniture finally reached the pinnacle of achievements in the Ming Dynasty, and the world-famous Ming-style furniture was born. Considering the current consumer preference for wooden furniture in the Chinese market, studying Ming-style furniture has important reference value and significance for the current research and development of wooden furniture. In the second step, the paper organizes and summarizes the literature and research results in related fields at home and abroad. From the current research status of wooden furniture to the research status of domestic Ming-style furniture to the application research of DNA genes and shape grammar in the field of furniture, it has gradually progressed and deepened layer by layer. Based on the analysis of existing wooden furniture’s problems of uniformity and lack of innovation, this paper proposes to use shape grammar to guide the innovative design of wooden furniture, and takes Ming-style recessed-leg table as an example to discuss its feasibility in the development and design of wooden furniture. The third step of the paper introduces the origin and application rules of shape grammar. According to the rules, the experiment needs to introduce queti (one of the structural components of Chinese wooden architecture) as a backup object. In the fourth step, the paper collects data on Ming-style recessed-leg table and architectural queti respectively. The paper analyzes the macroscopic composition of recessed-leg table

and the internal mortise and tenon structure, explores the origin and characteristics of the architectural queti, and also studies the rationality of introducing queti as backup objects. The fifth step is to start the preparation work before the experiment. The paper compiles the DNA genetic gene library of recessed-leg table and the backup replacement library of queti. The sixth step is to officially start the experiment. The paper uses shape grammar to conduct an innovative interpretation of Ming-style recessed-leg table and generates three plans. The seventh step is to use the semantic differential method to reflect and evaluate the three design plans, and finally determine the optimal plan for modeling and rendering. The design description is elaborated on the five major aspects of shape and function, structure and connection, material and craftsmanship, color and furnishings, art and decoration. Finally, summarize the paper and sublimate the main idea. Shape grammar can indeed effectively guide the research and innovative design of wooden furniture. Not only that, the creation process of Ming-style furniture is in line with the order of heaven and earth, and it can take into account the humanization of details while respecting the laws of nature as a whole. This also inspires our modern furniture industry to actively utilize the wisdom and ingenuity of craftsmen and designers to better give wooden furniture a flexible spirit and fresh vitality.

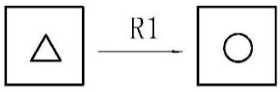
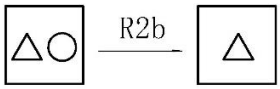
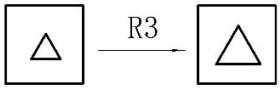
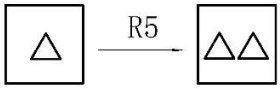
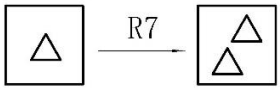
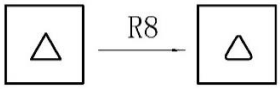
Research Method

In 1972, George Stinney and James Gipps proposed a theory of shape operations - Shape Grammar (SG for short), making innovations based on previous research. In shape grammar, a formula is defined as SG=<S, L, R, I>, where “S” represents a finite set of initial shapes, “L” represents a labeled finite set of shapes, “R” represents a finite set of derivation rules, and “I” represents the initial shape, while SG represents the finite set of shapes derived after the derivation rule operation (Fu *et al.* 2022). The shape grammar system is one of the earliest algorithm analysis systems in the field of modeling design mathematics (Liu 2020). In terms of product innovation and evolution, the deduction of shape grammar plays an important role in design (Braida 2019).

According to the derivation method, the shape grammar theory can be divided into generative and derivative ones. The first is in generative reasoning, where new shapes are generated by changing and replacing the local content of the original shape. This includes two basic commands: replacement commands, and addition and deletion commands. The replacement command displaces the partial contents of the original shape with other shapes. The addition command means adding other shapes to the original shape, while the deletion command means deleting partial content of the original shape. Secondly, derivative reasoning generates new shapes by mutating and changing parts of the original shape. It includes six basic commands: zoom command, mirror command, copy command, rotate command, staggered cut command and Bezier curve command. Among them, the zoom command emphasizes the enlargement or reduction of the original shape in equal proportions. The mirror command makes symmetrical changes according to the axis. The copy command uses the base point as the reference position to make a complete or partial copy. The rotation command uses the base point as the center of the circle to rotate the original shape at different angles. The staggered cut command is used to move a certain point of the original shape in a certain direction. The Bezier curve is used to modify the nodes and curvature of the original shape and smooth it to form a smooth curve. The generative and derivative inference rules of shape grammar are shown in Table 1. It is worth noting that in the generative rules, whether it is a displacement command or an addition command, other shapes need to be involved. In this study, the original shape is the

DNA gene of Ming-style recessed-leg table, while other shapes are derived from the structure of traditional Chinese wooden architecture - queti.

Table 1. The Generative and Derivative Inference Rules of Shape Grammar

Category	Command	Number	Illustration
Generative Reasoning	Replacement Command	R1	
	Addition and Deletion Command	R2a	
		R2b	
Derivative Reasoning	Zoom Command	R3	
	Mirror Command	R4	
	Copy Command	R5	
	Rotate Command	R6	
	Staggered Cut Command	R7	
	Bezier Curve Command	R8	

Data Collection

Overview and analysis of Ming-style recessed-leg table

The Ming-style furniture system can be roughly divided into five categories based on form and function, including chairs and stools, desks, beds, cabinets, and other categories (Wang 2008). Recessed-leg table belongs to the desk category. With the change in lifestyle from sitting on the ground to sitting with one's feet hanging down, the recessed-leg table has begun to occupy an important position in family life and has become a necessity in people's lives. The recessed-leg table is a long and narrow piece of furniture. It is rectangular in form; however, the legs are not positioned at the four corners, but rather recessed from the two ends (Zhang and Song 2016). It is mainly used for appreciating calligraphy, writing, painting, and displaying books, brush holders, and other collections of the literati. In terms of shape, it can be divided into pingtou'an and qiaotou'an (Fig. 1). The Chinese term pingtou'an literally refers to a "flat-surfaced table" without ornamental raised ends. Qiaotou'an is also called "everted-flange table", which is famous for its

everted flanges rising from the two ends. Most have a finely decorated panel fitted between the two legs at each end. The recessed-leg table is made of heavy material and is large in size, making it difficult to move. However, it adopts the modularized design concept that can be assembled and disassembled flexibly, which perfectly fits the background of today's pursuit of green and sustainable development of the times. Research on the modern translation of Ming-style furniture is not only in line with the design responsibility of integrating traditional culture and modern design innovation, but can also create both aesthetic and functional solid wood furniture designs. It also conforms to the ecological design trend of coexistence and mutual interdependence between people and nature.

Fig. 1. Comparison between pingtou'an (left) and qiaotou'an (right)

The shape and structure of recessed-leg table are closely related. Without an in-depth understanding of the connection structure and production process, the design can only become a flashy drawing and cannot be turned into a real object. The structure of the table can be deconstructed from a macro perspective into four parts: the table surface, the "yazi", the legs and feet, and the side stretchers. In terms of mechanical function, the table surface is located at the top of the table. When placing bonsai, antiques, or paintings, it is used to bear the weight and distribute it to the four legs. The table surface is divided into two forms: pingtou and qiaotou in the Chinese terms. "Pingtou" pursues smooth and flat surface and dignified and elegant appearance. The usual manufacturing method is done by first making a groove all around the inner edge of the frame and then inserting the tongue of the panel (Wadum 1998). This process is also called "assembling a mortised-and-tenoned frame with floating panel" (Fig. 2). Therefore, the connection between surfaces is reflected in the connection of the central panel and the surrounding frames. On the contrary, "qiaotou" is different from "pingtou". The two ends of which will rise up and be everted, similar to the upturned eaves in Chinese traditional architectures, forming a soft transition that looks natural. The specific production method is to use a solid wooden board top to make it first, and then cover the sections at both ends of the board with the everted flanges. This method is called "solid board making without a frame" (Fig. 2). The main function of the everted flanges is to cover up flaws at both ends of the board. The legs and feet play a supporting role in the table and are supporting linear components, similar to the load-bearing columns in traditional wooden buildings. The side stretchers are small, decorative, reinforcing pieces used to strengthen the structure between the legs and feet. In Ming-style furniture, stretchers are often used as decoration. However, one needs to pay attention to the position when installing the stretchers. Too low or too high may affect the stability of the legs and feet. The side stretchers are very effective in improving the structural stability

of the recessed-leg table, and also increases the sense of space in the furniture, eliminating the dull feeling of large furniture. "Yazi" in Chinese term refers to the linear component that connects the four legs and the longer side of the table, similar to the imitation beam in architecture. The two ends of the "yazi" are called "yatou", and the middle is called "yatiao". Its function is to keep the angle of the table unchanged, and it also has the functions of fixation and decoration. The overall style is concise and simple, and the details are integrated into artistic aesthetics. The structural diagram of each part of the Ming-style recessed-leg table is shown in Fig. 3.

Fig. 2. Assembling a mortised-and-tenoned frame with floating panel (left) and solid board making without a frame (right)

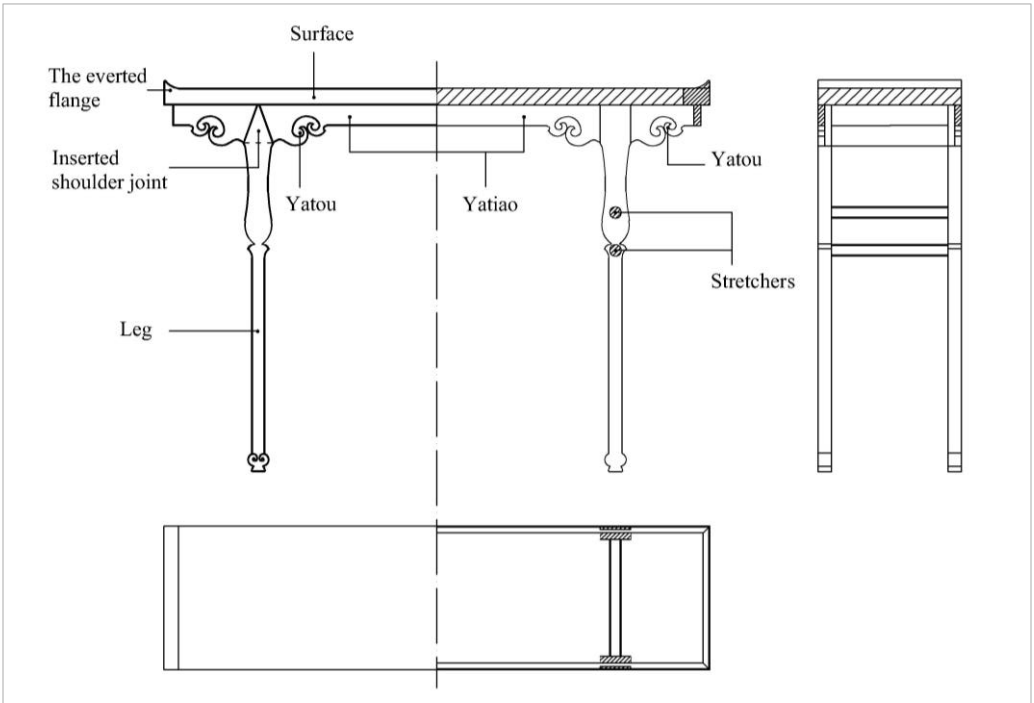


Fig. 3. The deconstructed three views of the recessed-leg table

The internal connection method of these four parts is realized through the concave and convex combination of mortise and tenon structures of different shapes, which play the role of fixation and support. The protruding part is called a tenon; the recessed part is called a mortise, and the engagement of the tenon and the mortise plays a role in connecting two wooden components (Liang *et al.* 2021). This is the main structural method of ancient

Chinese buildings, furniture, and other wooden products. The joint between the table surface and the legs usually adopts the structure of bridle joint and inserted shoulder joint (Fig. 4). These two types of mortise and tenon joints are the most critical supporting components for the upper parts of the legs and feet. The bridle joint was originally developed from architectural structures. Craftsmen in the Song Dynasty applied the beam structure in architecture to table furniture. They made a groove on the upper parts of the legs and feet of the tables, and embedded spandrels in the middle of the groove. Both ends or one side of the spandrels were inverted convex shapes, and they connected with the mortise and tenon joints of the table surface. This structure can distribute the weight of the table to each leg and foot, becoming one of the main supporting components of the table and one of the common forms of the case. The inserted shoulder joint and bridle joint are similar in structure but somewhat different in appearance. The upper part of the leg is split to form two tenoned pieces, the front one is made shoulder-like so that it can be inserted into cavities in the apron. When the joint is in place the surfaces of leg and apron are flush, which is more beautiful. This special geometric shape makes the top parts of the legs and feet more closely integrated and can provide good support. In addition, the greater the pressure exerted on the table surface, the more stable and compact the structure will be.

Fig. 4. Bridle joint (left) and inserted shoulder joint (right)

Overview and analysis of Ming-style recessed-leg table

Under the eaves and above the head, there are gorgeous wooden components carefully carved at the intersection of the pillars and beams to fill the gap between the two, giving people a feeling of brilliant clouds. That is called the queti. Therefore, the queti is regarded as the "skylark fairy" that lives on the eaves and beams of Chinese ancient architectures. It is a special component in Chinese architecture (Fig. 5). It is usually placed at the intersection of the horizontal members (such as beams) and the vertical members (such as pillars) of the architecture (Leng *et al*. 2022). Its function is to shorten the span of the beams, thereby enhancing the load capacity of the beams and reducing the intersection between beams and pillars. The material used to make the queti is determined by the main material used in the architecture. For example, a wood carved angle brace will be used on wooden architectural structures, while stone carved angle brace will be used on stone structures. The system of queti matured relatively late. Although it had begun to take shape during the Northern Wei Dynasty, it was not widely used until the Ming Dynasty, and it continued to develop in terms of composition, eventually becoming a component with a unique style. The shape of the queti is similar to the wings attached to both sides of the

pillar. Its outline and the painted carvings on it have decorative and artistic value, bringing great interest to people. It is the combination of mechanics and aesthetics. Since the Ming Dynasties, the decorative effect of queti's carvings has gradually become more prominent, with various forms such as dragons, phoenixes, cranes, flowers, plants, and birds. Different carving techniques such as round carving, relief carving, and openwork carving have also been used.

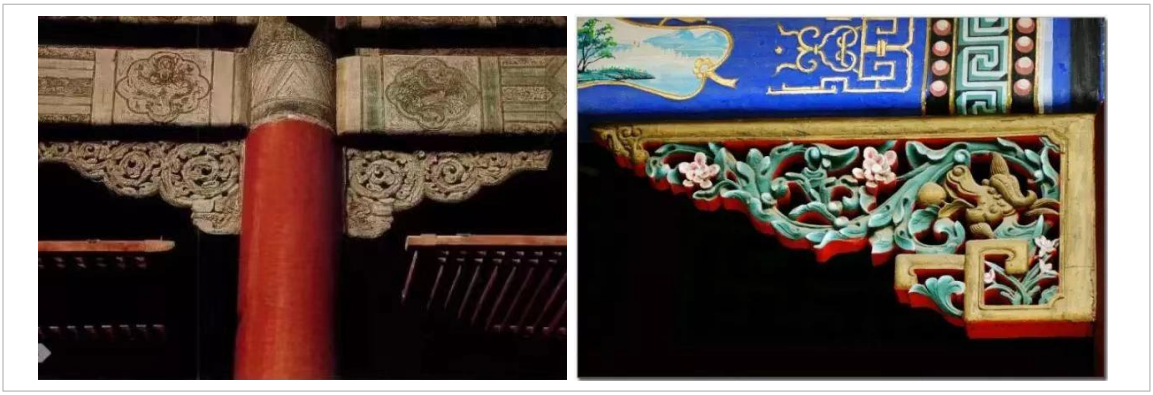


Fig. 5. The images of queti

Queti reflects the unity of mechanics and aesthetics of traditional wooden architecture. With the passage of time, queti has transformed from the original functional structure of architectural support into a product that combines structure and aesthetics, mechanics, and decoration. It has become one of the indispensable and beautiful architectural components in the lives of ancient people. On the one hand, it has important structural functions. In ancient Chinese architecture, queti is a unique component on eaves and beams. Its main function is to increase the shear force at the beam end and reduce the span of the beam frame. There is no doubt that the special brace plays an important role in supporting the beam components. In addition, it can also prevent tilting between horizontal and vertical members. From a structural point of view, the special brace is of certain help to the safety and stability of the architecture, so it is indispensable. On the other hand, the queti also plays a decorative role. Various cultural patterns are carefully crafted and inlaid on its appearance, including realistic, abstract, delicate, and rough, with different shapes. When you get close to it, look up and you will notice this often overlooked beauty. The queti not only solves the monotony and emptiness caused by pillars, but also fills the gaps under the eaves, filling the entire building with infinite tension. The brace was originally created for mechanical reasons, and then developed and expanded due to aesthetic reasons, becoming an independent art form. Judging from the increasingly complex and exquisite patterns and carvings of it, its decorative role is becoming increasingly mature. Studying its decorative art is of great significance for a deep understanding of the aesthetics of Ming-style furniture.

The relationship between Chinese wooden furniture and architecture

An architectural garden is exposed to the outdoors, which represents external, while Ming-style furniture is usually kept indoors, which represents internal. Although they are mutually independent elements, they have a unifying inner relationship. Furniture is a necessary part of the interior of the architectural garden. The internal area of the architecture is based on the size of the furniture, and the scale, proportion, and shape of the

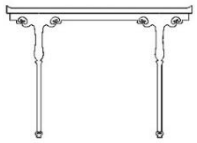
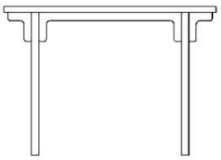
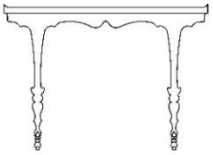
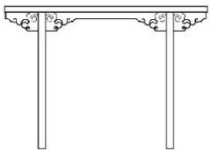
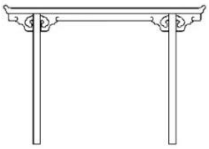
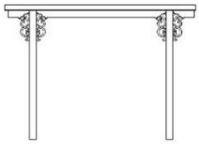
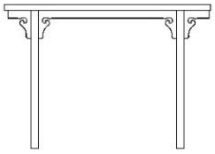
furniture are determined according to the scale of human actions and activities. Furniture and architecture are fundamentally interconnected. Therefore, as one of the traditional wooden building components, it is persuasive and reasonable for this study to choose queti as a replacement library and extract elements from it to replace some genes in Ming-style furniture.

Construction of DNA Gene Pool

Building the DNA gene pool map of the recessed-leg table

Because the top view styles of the recessed-leg tables are basically the same and the side views are almost identical in shape, only the outline lines of the front view that best show the structure of the recessed-leg tables are extracted. After sufficient data preparation work has been done in the early stage, the next step is to start the construction of the recessed-leg table DNA gene pool map (Table 2). One selects a batch of typical and beautiful recessed-leg table and covers as many different types as possible. A total of 8 tables were selected, including 4 pingtou'an and 4 qiaotou'an. These were used as gene pool factors and were coded, giving them the code A, A = {A1, A2, A3, A4, A5, A6, A7, A8}.

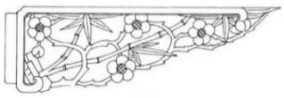
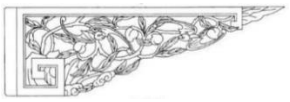
Table 2. The Recessed-Leg Table DNA Gene Pool Map

Number	A1	A2	A3	A4
Name	Beech, inserted shoulder joint, Juan-Yun pattern qiaotou'an	Huanghuali wood, bridle joint, pingtou'an	Black-painted qiaotou'an with sword legs in Mother-of-pearl	Huanghuali wood, bridle joint, Ru-Yi pattern pingtou'an
Prototype				
Line Extraction				
Number	A5	A6	A7	A8
Name	Huanghuali wood, Yun-Qi Ru-Yi pattern, soild board qiaotou'an	Huanghuali wood, Chi-Feng pattern pingtou'an	Huanghuali Wood, Juan-Yun pattern qiaotou'an	Huanghuali wood, Pingtou'an
Prototype				
Line Extraction				

Building the replacement pool map of the queti

The next step is to select a batch of typical and beautiful queti and cover as many different types as possible. The replacement pool map of the queti is built (Table 3). These are given the code B, B = {B1, B2, B3, B4, B5, B6, B7, B8}.

Table 3. The Queti Replacement Pool Map

Number	B1	B2	B3
Name	Gourd pattern queti	Peony pattern queti	Dragon pattern queti
Prototype			
Line Extraction			
Number	B4	B5	B6
Name	Curling grass pattern queti	Plum and bamboo pattern queti	Fu-Shou pattern queti
Prototype			
Line Extraction			

Among the four major characteristics of queti, type characteristics, color characteristics, and pattern characteristics are dominant characteristics, while ideological characteristics are recessive characteristics. Because queti pays more attention to the preservation of the natural color of wood, there is little change in color selection. In addition, the types of it are mainly divided according to the joint structure between beams and columns. Therefore, for the extraction of queti features, the focus consists of two aspects: explicit pattern characteristics and implicit ideological characteristics. Taking into account that Ming-style furniture followed the design concept of the integration of people and nature, and that high-quality groups such as literati and scholars in the Ming Dynasty participated in the design of Ming-style furniture, in this work B5 was selected from the replacement pool for the next experiment.

Based on the pattern and outline of B5, three representative elements were selected: bamboo leaves, plum blossoms, and branches. The bamboo leaf element was given the code b1, whereas the plum blossom element was given the code b2, and the branch element received the code b3, then B5 = {b1, b2, b3}. Then extract their contour lines and perform abstract derivation and deformation. At the same time, the prototype is decolored to facilitate the extraction of local lines. Finally, each element corresponds to 3 derivative forms: b1={b11, b12, b13}, b2={b21, b22, b23}, b3={b31, b32, b33}. The replacement elements of queti B5 is shown in Table 4 (the prototype comes from the "Illustrated Dictionary of Traditional Chinese Ancient Architecture").

Table 4. The Queti Replacement Pool Map

B5	b1	b2	b3
Elements			
b1	b11	b12	b13
Line Extraction			
b2	b21	b22	b23
Line Extraction			
b3	b31	b32	b33
Line Extraction			

RESULTS AND DISCUSSION

Results

A1 was selected randomly from the recessed-leg table DNA gene pool as the original shape, and then 4 patterns were selected from the replacement elements of queti B5, coded as b11, b12, b23, and b31.

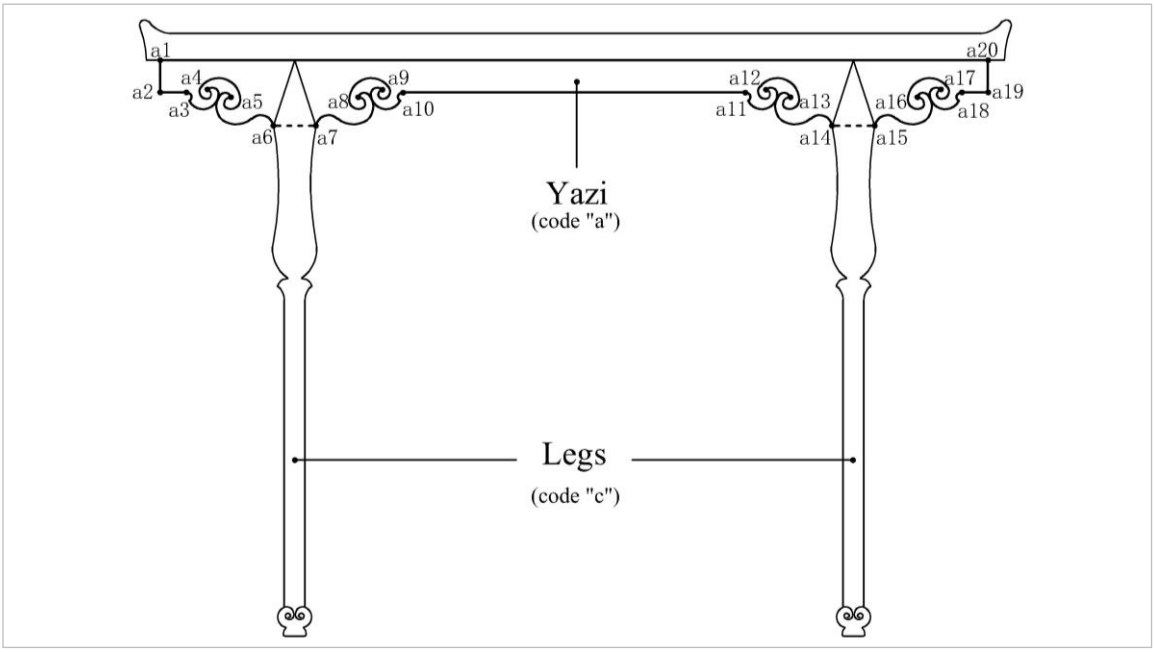


Fig. 6. The deconstruction diagram of the “yazi”. Yazi is coded a, a={a1, a2, a3....a18, a19, a20}. The leg of the table is coded c. The shape is A1 selected from the recessed-leg table DNA gene pool.

The computer-assisted software Adobe Illustrator was used for shape grammar deduction. The process of deduction and the establishment of the plan did not consider color matching factors to avoid becoming an interference factor in the later evaluation stage. Combined with the components of the recessed-leg table mentioned above, the "yazi" was assigned the code a, a={a1, a2, a3....a18, a19, a20} (Fig. 6). The leg of the table was assigned the code c.

Plan A

The continuity of the structure was analyzed, with the symmetry of the lines in the original shape A1. Then items b11, b12, b22, and b31 were selected in the replacement pool of queti B5 as backup to generate the deduced changes of Plan A process. The execution process of deduction is shown in Fig. 7.

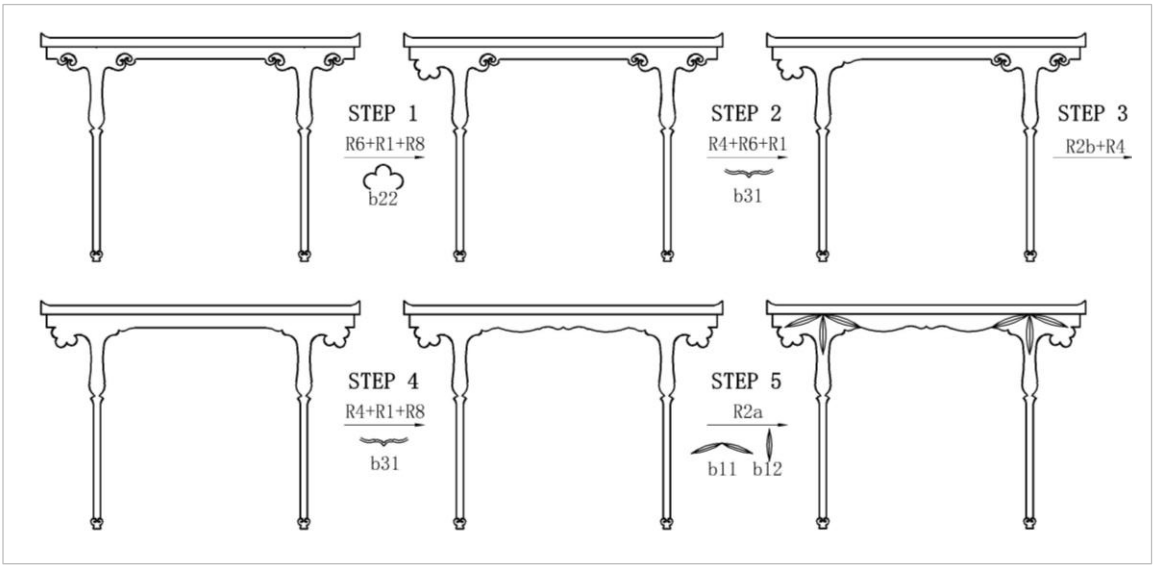


Fig. 7. The derivation steps of Plan A

The following procedure was used:

Step 1. First enter b22, execute command number R6, and rotate B22 135° counter-clockwise with the right end as the center. Then execute command number R1 to replace the three lines a3-a4-a5-a6. Then execute command number R8 and use the Bezier curve to connect the b22 node and the a6 node in a curve.

Step 2. First enter b31, execute command number R4, and mirror b31 with the X axis as the symmetry axis. Then execute command number R6 to rotate 30° counterclockwise with the left end as the center. Then execute command number R1 to replace the three lines a7-a8-a9-a10.

Step 3. First execute command number R2b to delete the three lines a11-a12-a13-a14 and the three lines a15-a16-a17-a18. Then execute command number R4 to mirror the three lines a3-a4-a5-a6 and the three lines a7-a8-a9-a10 with the center line of the original graphic as the symmetry axis, and fall at the previously deleted line segment;

Step 4. First enter b31, execute command number R4, and mirror b31 with the X axis as the symmetry axis. Then execute command number R1 to replace a section of lines a10-a11. Then execute command number R8 and use the Bezier curve to connect the two end nodes of b31 with the a10 and a11 nodes in a curve.

Step 5. Enter b11, execute command number R2a, and add b11 to a. Enter b12, execute command number R2a, and add b12 to c.

Plan B

The continuity of the structure was analyzed, with the symmetry of the lines in the original shape A1, and select b12, b22 and b31 in the replacement pool of queti B5 as backup to generate the deduced changes of Plan B process. The execution process of deduction is given in Fig. 8.

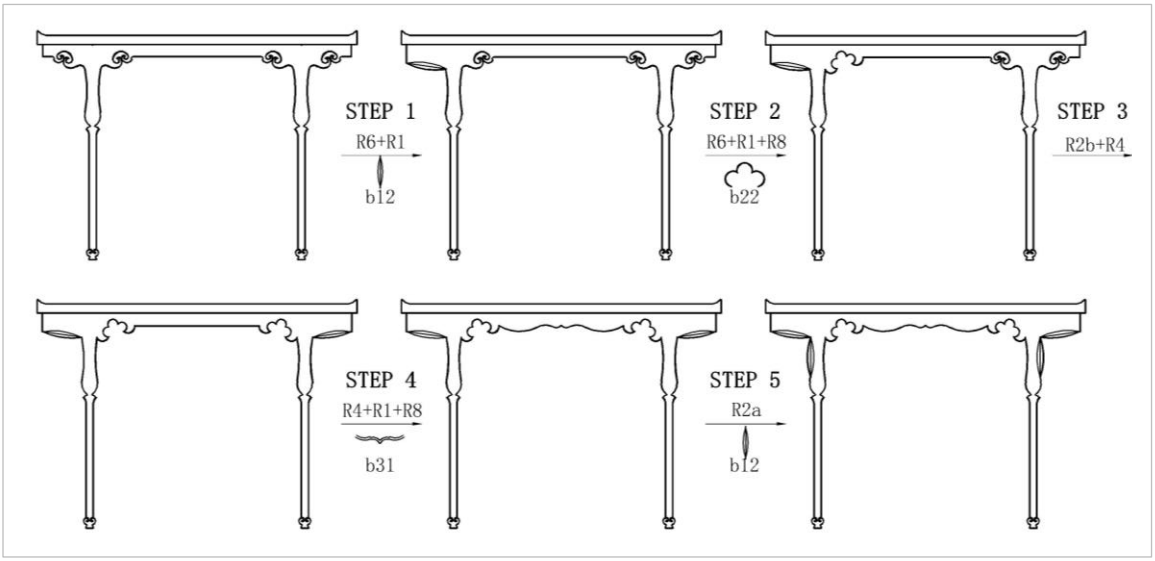


Fig. 8. The derivation steps of Plan B

Step 1. First enter b12, execute command number R6, and rotate b12 10° counter-clockwise with the bottom as the center. Then execute command number R1 to replace the four lines a2-a3-a4-a5-a6.

Step 2. First enter b22, execute command number R6, and rotate b22 40° counter-clockwise with the right end as the center. Then execute command number R1 to replace the three lines a7-a8-a9-a10. Then execute command number R8 and use the Bezier curve to connect the b22 node with the a7 and a10 nodes.

Step 3. First execute command number R2b to delete the three lines a11-a12-a13-a14 and the four lines a15-a16-a17-a18-a19. Then execute command number R4 to mirror the four-segment line a2-a3-a4-a5-a6 and the three-segment line a7-a8-a9-a10 with the center line of the original graphic as the symmetry axis, and fall on the previously deleted line segment.

Step 4. First enter b31, execute command number R4, and mirror b31 with the X axis as the symmetry axis. Then execute command number R1 to replace a section of lines a10-a11. Then execute command number R8, and use the Bezier curve to connect the two end nodes of b31 with the a10 and a11 nodes.

Step 5. Enter b12, execute command number R2a, and add b12 to c.

Plan C

The continuity of the structure was analyzed, with the symmetry of the lines in the original shape A1, and select b11, b12, b23 and b31 in the replacement pool of queti B5 as

backup to generate the deduced changes of Plan C process. The execution process of deduction is detailed in Fig. 9.

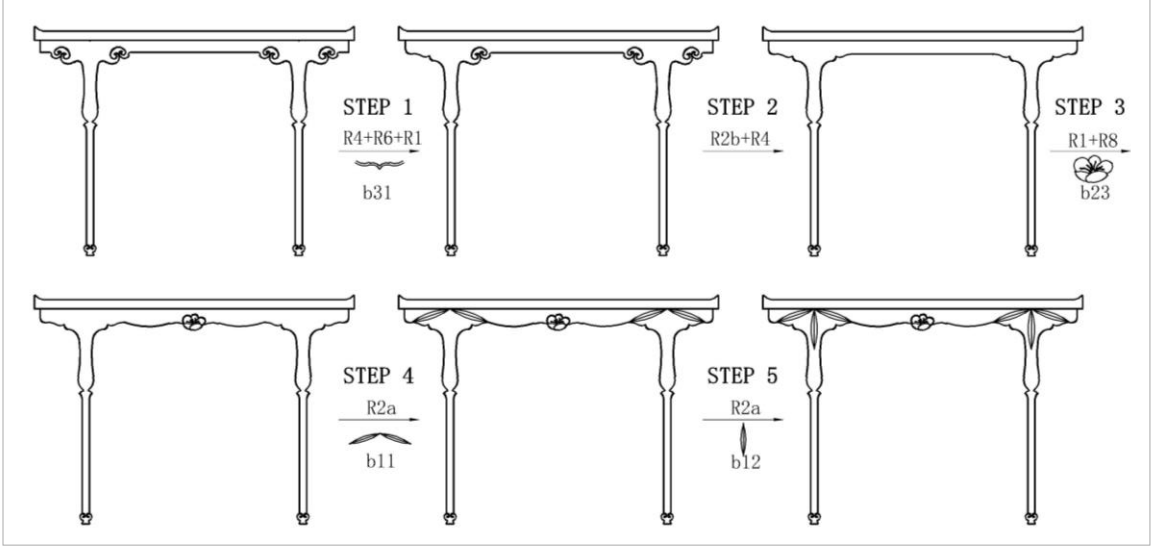


Fig. 9. The derivation steps of Plan C

Step 1. First enter b31, execute command number R4, and mirror b31 with the X axis as the symmetry axis. Then execute command number R6 to rotate b31 45° clockwise with the right end as the center. Then execute command number R1 to replace the three lines a3-a4-a5-a6.

Step 2. First execute command number R2b to delete the three lines a7-a8-a9-a10. Then execute command number R4 to mirror the three line segments a3-a4-a5-a6 with the center line of the left leg of the original graphic as the symmetry axis, and fall on the deleted line segment.

Step 3. First enter b23, execute command number R1, and replace the line a10-a11. Then execute command number R8, and use the Bezier curve to connect the two end nodes of b23 with the a10 and a11 nodes.

Step 4. Enter b11, execute command number R2a, and add b11 to a.

Step 5. Enter b12, execute command number R2a, and add b12 to c.

DISCUSSION

Evaluation and Reflection

Three effective solutions were obtained based on shape grammar. They need to be evaluated separately to select the optimal solution to ensure that the design research results satisfy the market as much as possible and gain favor from consumers. The semantic differential method is a psychological research method invented by the American psycholinguist Osgood in the 1950s. In actual use, a pair of antonymous adjectives are used as the two poles of the evaluation form and the ruler is made. The interviewee is asked to mark an "×" on the ruler to obtain his or her emotional preference for this group of adjectives. This study uses the semantic differential method and invites 5 researchers who study furniture products. Combined with the Ming-style furniture aesthetics as the basis

for evaluation, a 6-point equivalent Semantic Differential Scale was developed. This survey questionnaire was distributed to 20 consumers with furniture purchasing experience. The questionnaires were collected and summarized. The comprehensive evaluation results are summarized in Table 5. The quantitative calculation results show that the average score of option one is 1.51, the average score of option two is 1.65, and the average score of option three is 1.42. In summary, plan B has the highest average score.

Table 5. The Comprehensive Evaluation Results

Number	Characteristics	Plan A	Plan B	Plan C
S1	Simple - Complex	1.56	1.64	1.27
S2	Elegant - Meretricious	1.43	1.88	1.45
S3	Light - Heavy	1.19	1.47	1.51
S4	Modern -Traditional	1.49	1.95	1.38
S5	Implicit - Explicit	1.68	1.33	1.26
S6	Delicate - Crude	1.72	1.60	1.65
Average Score		1.51	1.65	1.42

Modeling and Applying Colors

Fig. 10. Image rendering of the model

Design Description

First of all, in terms of shape and function, the design incorporates the simplified patterns of plum blossoms and bamboo leaves extracted from the queti. The subtle fragrance of the plum blossoms, blooming alone in the cold weather, complements the noble and elegant character of the literati and scholars. The cool breeze and tranquility of the bamboo leaves give Ming-style furniture a graceful and vigorous vitality. Secondly, the connecting structure of the design adopts the ingenious mortise and tenon structure. The classic method called "Assembling a mortised-and-tenoned frame with floating panel" is

adopted on the table surface. Inserted shoulder joint structure is often used at the joint between the legs and the table surface. The spandrels are generally located at the intersection of horizontal and vertical timbers, and are connected to the legs by making a groove. Thirdly, pure natural solid beech wood is selected in terms of material and craftsmanship. It already has beautiful and natural wood grain texture without excessive modification. Moreover, In the design and production of Ming-style furniture, generally no paint or glue is used to highlight the fresh, simple, simple and generous beauty of natural materials contained in the furniture, which conforms to the contemporary people's mentality of returning to the beauty of nature (Sun and Zheng 2021). Fourth, in terms of color and furnishings, Ming-style tables are painted with wood wax oil of different colors. Such treatments can achieve beautiful and pleasing effects while protecting the stable performance of wood. In addition, recessed-leg table is also very particular about the interior furnishings. It is usually placed on the north wall in the middle of the hall. If there is a screen in front of the hall, then the recessed-leg table should be placed in front of the screen, with vases, incense burners, brush holders, stones and other furnishings placed on the table. Fifth, in terms of art and decoration, the decorative pattern of plum blossoms consisting of three petals on the left and right and two petals in the middle symbolizes the noble gentleman's posture. It embodies the elegance of Ming-style furniture, and the fragrance of wood; while the bamboo leaves stand with three leaves at the top of the legs and feet, as if they are growing on the treetops, embodying the meaning that career is rising step by step like the growing bamboo. It also has a furniture aesthetic that is as beautiful as a quiet bamboo forest with elegance and calm.

CONCLUSIONS

1. This paper is based on the construction of the Ming-style recessed-leg table DNA gene pool and the construction of the queti replacement pool, using the recessed-leg table DNA gene as the initial shape and the queti as the backup shape. Secondly, in the process of deducing the recessed-leg table using shape grammar, new architectural elements are constantly integrated to create new Ming-style furniture that maintains the original DNA. Finally, a consumer questionnaire was established using the semantic differential method to ensure that the new shape meets consumer needs.
2. The advantage of this method is that after many iterations of innovation, it can still inherit the design genes inherited from Ming-style recessed-leg table. Not only that, it also incorporates new cultural elements from other fields with the help of shape grammar, realizing the cross-field integration of wooden architecture and wooden furniture, allowing more people to see the possibility and practicality of cultural intersection. The innovation strategy of Chinese wooden furniture not only relies on breakthroughs in technology and materials, but also relies on the design inheritance of traditional culture. Only when a piece of furniture embodies the national characteristics of Chinese culture can it stand out internationally.
3. Since all Ming-style furniture is connected and assembled by mortise and tenon joints without any nails or chemical adhesives, it embodies the modular and ecological manufacturing concept and can provide a reference for the green design and sustainable development of wooden furniture. It is also in line with the ecological design trend of coexistence and mutual interdependence between man and nature. The goal of creating

Heidegger's "poetic dwelling" and "elegant life" has become a realistic necessity (Wang and Ren 2022).

4. Of course, this article also has some shortcomings and limitations. The experimental plan is only suitable for reasoning and deduction of two-dimensional grammar. In the future in-depth research, attempts and breakthroughs will be made in three-dimensional grammar.

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