Innovative Design Study of 3D Printing Technology in Joints of Wooden Furniture

Zhengkai Niu, Yuxuan Zhang, Minghuan Wang
Sichuan Tourism University, Chengdu 610100, Sichuan, China
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Abstract: For the traditional wooden furniture in the manufacturing process there are production and processing complexity, high process difficulty, long production cycle and other issues. Through the use of 3D printing technology, it can reduce the waste of wood resources, optimize the processing technology, improve the production efficiency, create more diversified and personalized furniture design, and promote the sustainable development of the furniture industry. This design mainly focuses on the innovative design of the shape and connection of wooden furniture connectors, integrating natural elements into wooden furniture connectors, and using 3D printing technology to produce molding, so that it is not only functionally more stable and durable, while shortening the process.
***Keywords*:** additive manufacturing; 3D printing; wooden furniture; connectors; nature

1. Introduction

Traditional wooden furniture joints are usually designed with traditional joints such as mortise and tenon, mortise and tenon joints, nails and screws[1]. These traditional joints require handcrafting and assembly by experienced carpenters, and are cumbersome and prone to errors. Conventional joints require a lot of work and time, and are wasteful of wood[2].

Aiming at the problems existing in the connection structure of traditional wooden furniture, additive manufacturing technology brings new ideas for the design and production of wooden furniture[3]. Through the application of 3D printing technology, the wooden furniture connection structure can be more flexible and diverse, realizing the one-time molding of complex connection methods. Compared with traditional handmade, 3D printing can greatly simplify the manufacturing process, reduce processes and labor input, improve production efficiency while reducing production costs[4]. At the same time, modern consumers' functional and aesthetic demands for furniture continue to rise, and the design of traditional wooden furniture may not be in line with contemporary aesthetic trends and lack diversity and personalization. While 3D printing technology can achieve complex design and customized production, to meet consumer demand for personalized and innovative design, to create more diverse and unique furniture design[5]. Therefore, through the application of 3D printing technology, traditional wooden furniture can be combined with modern technology to promote the development of the wooden furniture industry, and to promote the furniture industry towards a more environmentally friendly, efficient and innovative direction. The innovative design of additive manufacturing technology in the connecting structure of wooden furniture will bring new development opportunities for the wooden furniture industry and promote the industry to the road of sustainable development.

2. Design Concepts

2.1 modular design

Modular design refers to the functional analysis of a certain range of different products based on the division and design of different modules, according to the needs of the modules to select the combination of the formation of different products [6]. Modular furniture can be flexibly assembled and has a high utilization rate of space, which is conducive to easing the contradiction of housing area [7]. For example, the modular design of the sofa's seating surface and cushions can be assembled into different sofa forms according to different needs, so as to make flexible use of space. In addition, changing the combination mode of the sofa and installing storage devices under the sofa's seating surface can improve the utilization of space to a greater extent. Modular design can shorten the product development cycle, and is conducive to product maintenance, recycling and reuse.

2.2 Detachable design

Assembly and disassembly design refers to the design of furniture taking into account the assembly and disassembly of

furniture, in order to ensure that the furniture is firmly and stably jointed and well processed on the basis of the realization of furniture flattening[8].

Furniture on the domestic market mostly use three-in-one eccentric connectors to realize detachable, although easy to install, good concealment, but easy to loosen after repeated use, cumbersome installation. At present, the design and processing of detachable connectors in China is extremely unfavorable to the development of furniture production. Nanjing Forestry University, Wu Wei and other design for the chair legs, door post connection of the detachable structure, such as, from the "Lu Ban lock" mortise and tenon structure improved, the use of mortise and tenon self-locking to ensure the strength and stability. This structure can be disassembled through the mortise and tenon to reduce the use of connectors. 3D printing in the structure design is very flexible, in the replacement of connectors has great potential.

2.3 Green design

Human economic activities have caused great pollution to the natural world, so sustainable development has become an urgent topic for national and social consideration, and the furniture industry is no exception. The concept of green design runs through the design, production and use of products, requiring designers to prioritize resource conservation and energy reduction when designing products, as well as exploring recycling and reuse of products.

The raw materials used for 3D printing (e.g. UV inks, resins) are in line with the green design concept, which is not only less harmful to the human body and the natural environment but also easy to recycle [9]. At the same time, 3D printing technology does not release harmful substances during processing like traditional processing. Whether from the point of view of materials or processing, 3D printing technology is green.

3. Design strategy

3.1 Styling innovations

In the field of furniture design, connecting structures often play a key role, not only do they support the overall structure of the furniture, but also affect the visual aesthetics of the furniture[10]. With the help of additive manufacturing technology, this design is able to make bold innovations in the design of connecting structures, creating both stable and artistic connectors. Additive manufacturing technology is utilized in order to explore more complex and artistic design of the connecting structure, such as incorporating natural elements such as tree texture and plant forms into the connecting structure to create a unique furniture connector shape. By capturing and refining the essence of these natural elements, and skillfully integrating them into the connecting structure, the furniture presents a sense of beauty that is in harmony with nature.

3.2 Functional innovations

In addition to modeling innovation, the designers also focus on the functional innovation of the connection structure. Through in-depth understanding of the furniture's usage scenarios and user needs, designers explore the design of more practical and convenient connection structures. For example, connectors with adjustability can be designed to adapt to different users' heights and usage habits, or connecting structures with hidden storage functions can be designed to enhance the practicality and space utilization of the furniture. These functional innovations will make the furniture more in line with the lifestyle and needs of modern people.

3.3 Material Innovation

In terms of materials, innovation is equally sought. Additive manufacturing technologies allow the use of a variety of new materials to manufacture connecting structures, thus enabling optimization and innovation in material properties. It is also possible to explore the use of high-strength, lightweight composite materials to manufacture connecting parts to enhance the robustness and durability of furniture; or to try to use environmentally friendly, recyclable materials to reduce the environmental impact of furniture production. Consideration is also given to using materials with special textures or colors on the connecting structures to increase the visual effect and personalized features of the furniture.

By comparing and analyzing the advantages and disadvantages of different printing materials, in order to meet the design requirements, this design selects PETG, a special 3D printing consumable for Tuozhu in engineering plastics, as the printing consumable.

Table 1. Comparison of the advantages and disadvantages of each material (Form provided by Wang Minghuan)

Materials	Strong point	Weak point
Engineering plastic	Good molding properties and plasticity, light weight, and good impact resistance	Poor mechanical properties make them unsuitable for parts that carry large loads. Flammable and low melting point, limiting use in high temperature environments.
Photosensitive resin	High strength, high temperature resistance, waterproof	Slow processing speed, some pollution
Ceramic materials	High strength, high hardness, high temperature resistance, low density, good chemical stability, corrosion resistance	High preparation cost, difficult quality control, product prone to looseness
Metal material	Metallic properties, ductility, high mechanical depth and surface quality	High preparation cost, difficult quality control, product prone to looseness

3.4 Structural innovations

Structural innovation is the key to improve the performance of furniture connection structure. This design utilizes the advantages of additive manufacturing technology to break through the limitations of traditional manufacturing methods and design a more reasonable and efficient connection structure. By optimizing the layout and geometry of the connectors, the load-bearing capacity and stability of the furniture can be improved. At the same time, production costs and energy consumption are reduced by minimizing unnecessary materials and weight. In addition, the design also tries to adopt new types of connection methods and fixing structures to improve the assembly efficiency and convenience of furniture.

3.5 Technological innovations

Using 3D modeling software, digital models are created from extracted features of natural elements. These models can be very complex curved surfaces and curved structures to fully demonstrate the beauty of the form of the natural elements. In the modeling process, the design also needs to consider the practicality and solidity of the connecting structure to ensure that the furniture can maintain good stability and safety in the process of use. Then, with the help of additive manufacturing technology, these digital models are transformed into solid connectors. The advantage of additive manufacturing technology lies in its ability to accurately create complex surfaces and internal structures, which provides strong support for the design to realize styling innovation in the design of connecting structures. By choosing the right materials and printing parameters, it is possible to design beautiful and practical connectors that add a unique artistic flavor to furniture.

4. Design practice

4.1 Element extraction

This design extracts and abstracts key features and forms of natural elements based on the extraction of relevant natural elements including the texture of trees, the form of plants, and the structure of animals. For example, the shape and structure of octopus in nature is extracted (Figure 1).

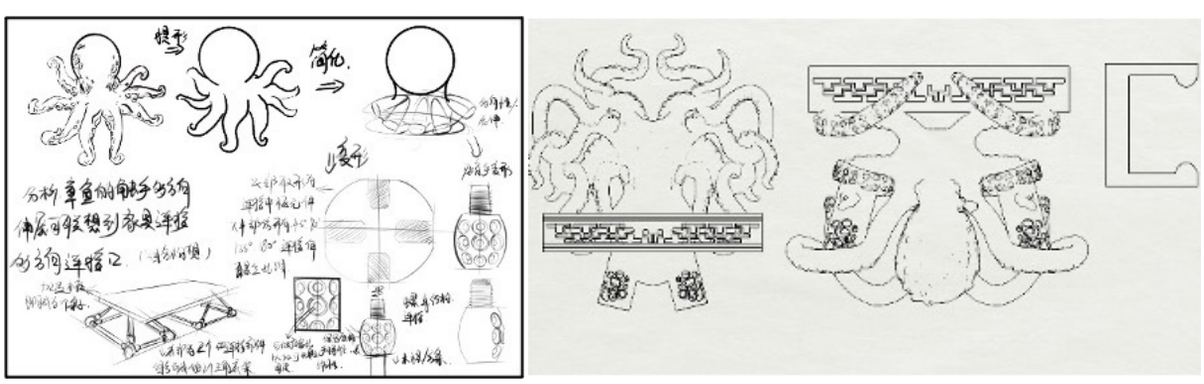

Figure 1. Modeling Extraction (Photo courtesy of Wang Minghuan)

By analyzing the structure of octopus shape, we can get the bionic form connectors with octopus shape as the connection center. Based on the basic features of the octopus and the extension characteristics of the tentacles in different directions, different connection effects can be achieved through different embedded connection methods.

4.2 Digital modeling

According to the preliminary sketching, the preliminary expression of design ideas. On the basis of the design sketches using rhinoceros modeling software for two kinds of structural sketches for three-dimensional solid drawing. Connection structure in order to avoid secondary processing of wood, will connect the parts interface as a whole is larger than the wood size 1mm processing, at the same time for the sub-parts and the connection of the pivot assembly problem, will connect the hole groove internal measurement increase 0.5mm thickness difference, so that the connection is close to the connection.

The model is drawn through 3D modeling software such as Rhinoceros, which allows visual observation of the presentation of the model. The overall size of the model can be changed by adjusting the size of the connecting parts in the Rhinoceros modeling software. Component 1 as a whole takes the multi-tentacle coiled octopus as the overall modeling, and utilizes the tentacle articulation connection holes and support right angle embedded grooves to make the modeling more natural and smooth (as shown in Figure 2).

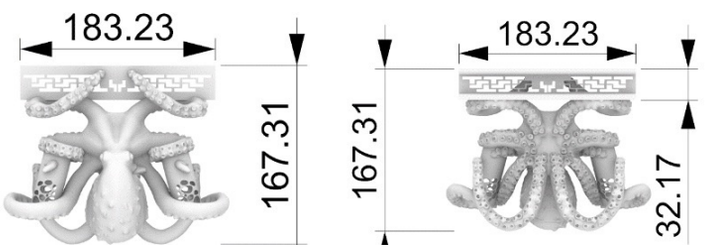

Figure 2. Digital Model Components (Photo courtesy of Wang Minghuan)

Component 2 takes the flat octopus as its overall shape, and utilizes the octopus head articulation connection holes and support right-angled embedded grooves to form a spatial contrast with Component 1 in terms of shape. Through the multiple displays of biased three-dimensional and biased planar, it shows the flexibility and feasibility of 3D printing technology used in complex modeling (Figure 3).

Figure 3. Portfolio of numerical models (Photo courtesy of Wang Minghuan)

4.3 Final rendering

The connecting structure sample is printed in 1:1 scale (Figure 4) and utilizes the connecting structure to connect the board to the bench legs. The gray printing consumables are matched with the original wood color beech to present a better visual effect.

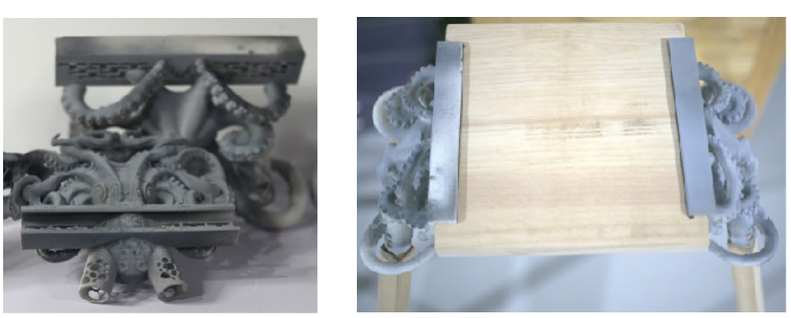

Figure 4. Final rendering (Photo courtesy of Wang Minghuan)

5. Discussion

In this design process of additive manufacturing technology in wooden furniture connection structure, the design experienced a challenging design exploration. The initial intention of the design is to utilize the advantages of additive manufacturing technology to innovate the furniture connection structure and improve its environmental friendliness, functionality and aesthetics. During the design process, the selection and optimization of materials were first considered, and attempts were made to reduce the overall weight and material consumption of the furniture by using environmentally friendly materials and lightweight design. To strike a balance between material properties and structural stability, an in-depth understanding of material properties and additive manufacturing processes is necessary.

In addition, designers have also tried the strategy of design flexibility and structural optimization, and explored connection structures with different morphologies and layouts through methods such as parametric design and topology optimization. However, in practice, it is found that there is a certain contradiction between design flexibility and structural stability, and more in-depth research and experiments are needed to find the optimal solution. In the choice of solutions, this design tries the strategy of integrated functional design and modular design, hoping to improve the practicality and convenience of the furniture by integrating the connection structure with other functions.

Overall, this design process has provided a deeper understanding of the application of additive manufacturing technology in furniture design, and has also realized the challenges and opportunities involved. Through continuous reflection and learning, we believe we can continuously improve our design ability and create more innovative and practical works.

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