The Application of Bamboo Weaving in Modern Furniture

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Bamboo material has excellent properties and is suitable for making bamboo furniture. Bamboo furniture is a traditional form of furniture made from bamboo with a low degree of industrialisation. The diverse development methods and profound cultural meanings behind bamboo furniture should be further explored to strengthen inheritance and innovation. This paper first summarises the characteristics and development status of bamboo furniture *via* a brief literature review. Then, through case studies and questionnaire surveys, the aesthetic trends of modern bamboo furniture design were analysed, and various ideas for innovation were proposed. The mode and path of the future development of bamboo weaving were discussed from the perspective of accelerating modernisation. To achieve sustainable development of bamboo furniture, to promote bamboo culture, and to enable bamboo enterprises to establish a good brand image, it is necessary to use the interactive design platform to coordinate the relationship between users, enterprises, and producers, and to grasp the balance between traditional craftsmanship and modern design and manufacture through modern advanced manufacturing technology and parametric design.

Keywords: Bamboo weaving; Modern design; Advanced manufacturing technology; Traditional crafts; Sustainable development

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INTRODUCTION

Bamboo is a natural material with high strength and toughness. Bamboo grows faster than wood, as it takes only 3 to 5 years to grow into an excellent structural material (Yunida *et al.* 2018). Bamboo weaving is a traditional craft, in which bamboo is used as a raw material and woven into patterns or implements by craftsmen using a variety of weaving methods. Bamboo furniture manufacture can include the bamboo weaving process, which is rich in variety and has both practical function and aesthetic value.

Bamboo Furniture Categories

Bamboo woven furniture can be divided into two categories, which include those prepared as a whole and those prepared by the board. Bamboo furniture prepared as a whole is a three-dimensional piece of furniture made entirely of bamboo, which includes the skeleton and the panels. Panel preparation refers to the weaving of parts of the furniture from bamboo materials, such as sitting surfaces and cabinet doors, among others.

Bamboo woven furniture panels can be divided into two categories by their morphology, which include flat woven and curved woven panels (Fig. 1) (Zhu 2020). The artisans usually choose the right bamboo material for the product they are making, and then scrape the knots, scrape the green, break the bamboo, open the pieces, split the strips, treat

the bamboo with three anti-treatment, and dye it to make the raw material ready for weaving. The craftsmen then use these raw materials to weave the furniture panels using different weaving methods. Flat bamboo weave can be divided into geometric and non-geometric forms. In terms of orientation, flat bamboo weaving can be divided into vertical, horizontal, and oblique planes. The flat bamboo weave has serene, stable, and orderly characteristics. In furniture design, it is often used for the tops of tables and cases, seating surfaces for chairs and stools, door panels for cabinets and shelves, and screens, among other furniture. Curved bamboo weave can be spatially divided into geometric and free-form surfaces. Curved surfaces have a soft, intimate, and dynamic feel. In furniture design, they are often used as backrests for chairs, bases for tables and furniture, and screens.

Fig. 1. Images of (a) whole bamboo plait, (b) plane bamboo plait, and (c) curved bamboo plait

Bamboo Furniture Characteristics

Bamboo is a natural green material with good mechanical strength and bending strength, and it is currently being promoted by many designers as a green material in furniture design (Sharma *et al.* 2015; Pan and Miao 2020). Bamboo strips, which are made from raw bamboo, are used as a weaving material and are treated with three types of protection (that makes the bamboo insect, corrosion, and fire resistant) before being woven into the furniture. Bamboo is hard and flexible, and it can be bent and shaped easily. The flexible surface of the bamboo weave fits the body better than hard panels, which makes it practical and comfortable (Ni *et al.* 2019).

The aesthetic value of bamboo weaving is reflected in four aspects, which include material texture, weaving patterns, colour matching, and cultural connotations. Bamboo as a natural material has a special texture on its surface, and woven furniture without excessive decorative treatment brings a natural simplicity, which reflects the natural beauty of Taoist thought (Ding and Zhu 2019). Furniture made of natural bamboo tends to give a warm, cozy sensory experience (Liu and Zhang 2013).

Different knotting and weaving methods are used to create a variety of weaving patterns. Bamboo weaving techniques are varied and follow the "pick" and "press" weaving techniques when weaving two-dimensional planes. The pick is called the "warp," and the weave is the "weft." The "weft" facilitates the interweaving of the bamboo gabions. Traditional bamboo designs can be grouped into three categories, which include geometric shapes, imitations of flora and fauna, and characters.

The colours of bamboo are natural and simple, and many users prefer the original colour of bamboo, which is the most common colour for bamboo furniture. When bamboo is processed into strips, it is sometimes dyed to give the bamboo weave a richer colour. In addition, some furniture is painted after it has been woven. Bamboo furniture colour matching can be done in different combinations of similar, contrasting, and complementary colours using colour composition (Zhu 2020).

Bamboo weaving has a long history and contains the wisdom of countless craftsmen. Bamboo has been used in China since the Yin and Shang dynasties for everyday use, and it was later used in various industries, such as construction, agricultural tools, and furniture upon full understanding of its properties (Shu 2011). Through incorporating bamboo weaving into modern furniture, combining natural materials with modern aesthetics, and encouraging the spirit of craftsmanship, bamboo furniture will continue to evolve with the times and bring people a beautiful feeling of spirituality.

Bamboo Furniture Materials

Table 1. Part of Bamboo Furniture Material

Name of Bamboo Material	Characteristics	Application Parts	Pictures
Water bamboo	Excellent flexibility and toughness, high tensile strength, and pure colour	Used for weaving furniture panels with patterns	
Cichlid bamboo	The colour varies between the different stages; it is lime green in the juvenile stage and yellow in the mature stage	Used to weave panels for beds and sofas and to make small cabinets	
Nan bamboo	Smaller, thicker walled, and more malleable	Used to weave panels that are subject to high forces	

Before making bamboo furniture, the craftsman chooses the right type, age, part, and colour of bamboo according to the requirements of the object to be woven. Even if the same bamboo is used, the nature of the strips obtained from different parts of the bamboo varies. Full understanding of the advantages of each type of bamboo is necessary to allow its optimal use. In choosing bamboo furniture, it is important to ensure that the strength and toughness of the bamboo are up to standard and there are no defects, such as insect infestation; thus, it is usually not advisable to cut it between the spring equinox and the mango season when insect infestation is more serious (Zhang *et al.* 2018). The nature of different types of bamboo determines their use. The bamboo has a dense, smooth skin and soft, tough slices. The small number of nodes, which had a pitch of approximately 20.10 cm to 30.00 cm, make it highly usable and suitable for weaving panels. The colour of the bamboo is pure and suitable for weaving patterns and designs (Chen *et al.* 2012). Cixi bamboo, which is also known as sheep bamboo, has straight poles with inter-node lengths of approximately 20 cm to 40 cm; thus, it is a good structural and weaving material (Li *et al.* 2012). Nan bamboo is tough, strong, and has an internode length of approximately 45 cm to 50 cm and is suitable for weaving heavily stressed panels (Table 1) (Cai and Lin 2020).

TRADITIONAL BAMBOO WEAVING

Table 2. Characteristics of Bamboo Weaving in Different Area

Region	Characteristic Bamboo Weaving	Colour	Features
Zhejiang	Dongyang bamboo weaving	Bamboo in primary colours with a few contrasting colours	Variety and rustic style
	Shengzhou bamboo weaving	Bleached bamboo painted with lacquer	Richly decorated
Sichuan	Bamboo weaving on porcelain	Finely coloured or largely plain	Finely woven with no visible joints
Two Lakes	Yiyang bamboo weaving	The colour of the bamboo weave changes from greenish-blue to reddish-brown	Water bamboo products are durable and soft
	Xiangxi bamboo weaving	/	A wide range of strong and durable products
Fujian	Quanzhou bamboo weaving	/	Geometric and animal shapes are predominant
	Fujian bamboo weaving	Bleached, dyed, and lacquered	The bird's eye method of weaving is used to achieve a hollow and airy effect with a variety of decorative techniques

Characteristics of Bamboo Weaving in Different Regions of China

Bamboo weaving has a long history in China, and the patterns and techniques vary from region to region due to ethnic customs, aesthetics, and other factors (Table 2) (Zhang *et al.* 2018).

Traditional Bamboo Weaving Methods

The weaving techniques used in flat and three-dimensional bamboo weaving are different. Commonly used flat weaving techniques include the pick and press method and the through and through method. The different thicknesses of the bamboo strips used to weave the flat patterns and the differences in the gaps between the warp and weft lead to different results. The size of the bamboo strips used for weaving is determined by the needs of the product being woven. For example, fine pieces are often used for weaving handicrafts, while relatively wider pieces are used for weaving furniture panels. Sometimes bamboo strips of different thicknesses are used in combination to give a richer visual effect. The three-dimensional structure of woven furniture has three main processes, which include starting the base, weaving, and locking the mouth (Fig. 2) (Zhang *et al.* 2018). The bottom of the furniture is woven with a certain number of bamboo strips that are similar in thickness to the backbone, and they intersect with each other to weave the bottom; weaving means that after the bottom is woven, the main part of the furniture or the panel is woven, compact, and firm (Wu *et al.* 2020).

Fig. 2. The (a) bottom of the weaving, (b) weaving process, and (c) convergent weave

Traditional Bamboo Weaving Techniques

Bamboo is often used as a raw material for furniture due to its fast production rate, excellent properties, and the low costs incurred in a series of processing processes such as growing, cutting, and drying (Suhaily *et al.* 2020). The production of bamboo weaving materials usually involves seven processes: 1) Bamboo selection: choosing the right bamboo species according to the part and colour of the bamboo furniture; 2) Scraping: using a gimlet knife to smooth out the raised bamboo joints; 3) Scraping the green: scraping off the outermost green layer of the bamboo for subsequent processing; 4) Breaking the bamboo: use a knife to split the bamboo into strips of the same width in turn; 5) Slicing: dividing the bamboo into strips of 2 cm to 5 cm wide according to the desired width of the bamboo strips; 6) Dividing the scorn: splitting the processed bamboo into thinner strips or scorns. The bamboo is split into strips of 2 cm to 5 cm wide. Dividing: the processed bamboo is split into thin strips or scrims of 4 layers for green bamboo and 6 to 8 layers for yellow bamboo; 7) Triple proofing: the processed bamboo is boiled in hydrogen peroxide and then dried to make the strips fireproof, insectproof, and anticorrosive, thus making the furniture more durable (Cai and Lin 2020). The process of breaking, slicing, and gabbing has been shifted from traditional artisanal processing to mechanical processing using

advanced equipment such as automatic feed breakers, thus providing better control over the quality of the bamboo slices.

After the above steps, the strips are ready to be woven. However, depending on the requirements, the strips need to be coloured. There are two methods of colouring the strips. One method is the dying of strips before weaving, a process that both colours the strips and removes insects by steaming and enhances the flexibility of the strips. The second method is lacquering the strips after weaving to complete the colouring process.

EXPERIMENTAL

To identify the market potential of bamboo furniture, understand user perception and demand for bamboo furniture, and to explore the future development direction of bamboo furniture, a questionnaire was created that was entitled "Modern Design and Manufacture of Bamboo Furniture." The research was conducted in the form of an online questionnaire using the "Questionnaire Star" platform. The authors distributed the questionnaire in the student exchange group of Nanjing Forestry University. A total of 200 questionnaires were sent out. A total of 163 people completed the research questionnaire. The people who filled out the questionnaires covered a wide range of occupational attributes such as students, teachers, corporate employees, freelancers, and public officials. Among them, 61.54% were students, 15.38% were corporate employees, 5.49% were teachers, public employees, and freelancers, and 6.59% were other professionals. The target group was young people between the ages of 18 and 35, who will be the main consumers of furniture in the future.

RESULTS OF THE QUESTIONNAIRE

The results from the questionnaire are shown in Table 3.

Table 3. Results of the Questionnaire on the Recognition and Usage of Bamboo Furniture

A. Degree of understanding of bamboo furniture (%)	
Know a lot about	1.84
Understand	25.77
Do not know much	69.94
Never heard of	2.45
B. Is there bamboo furniture in your living area? (%)	
Yes	46.01
No	53.99

The questionnaire was divided into three parts. The first part investigated the respondents' recognition of bamboo furniture and the current profile of its use. Analysis of the results showed that 72.4% of the users were somewhat familiar with bamboo furniture and 27.6% were very familiar with it. However, 54.0% of the users did not use bamboo furniture in their homes, offices, or study areas. This showed that the public awareness of

bamboo furniture was high and bamboo furniture has broad development prospects, but the marketing and promotion of bamboo furniture is insufficient. To increase the market share of bamboo furniture, it is important to understand the problems that users think exist in bamboo furniture and propose targeted solutions.

Therefore, the second part of the questionnaire identified the current problems with bamboo furniture as suggested by the respondents. In addition, it investigated the style of bamboo furniture that users preferred to meet their aesthetic needs for bamboo furniture. The results of this part of the research are presented in Table 4. The slow development of the bamboo woven furniture industry is largely due to the fact that the woven patterns have not escaped the limitations of the traditional Chinese style and have not been combined with modern compositional forms to meet modern aesthetic needs. The majority of users believed that bamboo furniture has old-fashioned patterns, monotonous colours, and single materials that restrict its development. In addition, 73.0% of users would like the design of bamboo furniture to be combined with modern ideas, and 65.0% of users suggest that bamboo furniture can be used in conjunction with other materials to avoid monotony. Therefore, the future development of bamboo furniture should focus on the innovative design of bamboo weave patterns, diverse colour choices, and varied material combinations (Table 4).

Table 4. Results of the Questionnaire on the Usage Requirements and Style of Bamboo Furniture

A. User's requirements (%)	
Modeling diversity	73.01
Rich colours	41.72
Material multivariate	65.03
Collaborative design	33.13
After-sales services	12.88

B. User's orientation style (%)	
Chinese style	39.26
New Chinese style	46.01
Austere European style	42.94
Northern Europe	31.29
Japanese style	47.85

The third part of the questionnaire investigated the willingness of the respondents to participate in bamboo weaving cultural experiences. The results of the survey are presented in Table 5. The aim was to examine the possibility of cultural transmission of bamboo weaving handicrafts (Wang *et al.* 2020). Analysis of the questionnaire results showed that over 90% of the users were willing to participate in the design process of bamboo weaving patterns and related cultural experiences (Table 5). Therefore, building a platform for interaction between companies, users, and craftspeople is promising. By involving users in the customisation process, enterprises can help to visualise their ideas, which makes it possible to reduce the communication barriers between designers and users. In addition, such practices could allow them to design products that better meet the aesthetic needs of users, a process which is conducive to promoting the spread and development of bamboo weaving skills and culture.

Table 5. Willingness of Users to Participate in the Bamboo Custom Design Process and Bamboo Weaving Craft Experience

	Willing (%)	Unwilling (%)
Willingness of users to participate in the bamboo custom design process	93.25%	6.75%
Willingness of users to participate in the bamboo weaving craft experience	90.18%	9.82%

DESIGN ASPECTS

Modern and Innovative Design Methods

One of the main reasons for the current resistance to the development of bamboo furniture is the subconscious belief that bamboo weaving is merely a traditional craft and that its weaving patterns do not meet modern aesthetic standards. To break through this barrier, it is necessary to consider new ways of pattern composition (Zhang 2019). The fundamental difference between modern and traditional patterns is the difference in imagery, as traditional motifs are often figurative images of flora and fauna, auspicious birds and animals, and other images that can hold good wishes in traditional Chinese motifs; in contrast, modern patterns are often conceptually designed by extracting the available elements from the figurative images (Gao and Gu 2020). Therefore, innovative design of bamboo weaving patterns can be achieved by drawing inspiration from traditional patterns and selecting suitable elements from them. Composition can also be considered in the context of the furniture as a whole. Modern modular furniture is made up of multiple pieces, so combinations of different pieces can be designed to achieve a variety of outcomes.

The colours and combinations of bamboo furniture are determined by the overall style. A comprehensive analysis of the results of the questionnaire showed that users had different preferences for furniture styles. Therefore, the choice of colour needs to be determined in addition to achieving innovation in the individual bamboo panels, and innovation in the specific style. For example, Chinese and neo-Chinese styles can use the original colour of bamboo without excessive dyeing, or the old mahogany colour can be dyed to match the overall style (Lin and Xu 2019). Simple European and Scandinavian styles can use a variety of low-saturation Morandi colours or use one colour as the main colour and mixed colours as a complementary treatment, as such styles are simple and in line with the aesthetic tastes of contemporary youth. Japanese styles could use more of the original colour of bamboo or use bleaching and dyeing processes to achieve a bright and warm effect.

Stylistic innovations in bamboo furniture can also be achieved by using a diverse mix of materials (Fig. 3). Bamboo furniture does not necessarily mean that the whole piece of furniture is made of bamboo, as bamboo can be combined with other materials. Different combinations of materials can bring different effects to the presentation, and the design can convey different emotions to the user (Zhang and Xu 2019). Bamboo combined with soft materials, such as fabric and leather, can provide a soft and comfortable appearance. Bamboo combined with hard materials, such as metal, could offer a modern sense of

softness and harmony. Finally, bamboo combined with transparent materials, such as glass, could bring about a sense of transparency and individuality.

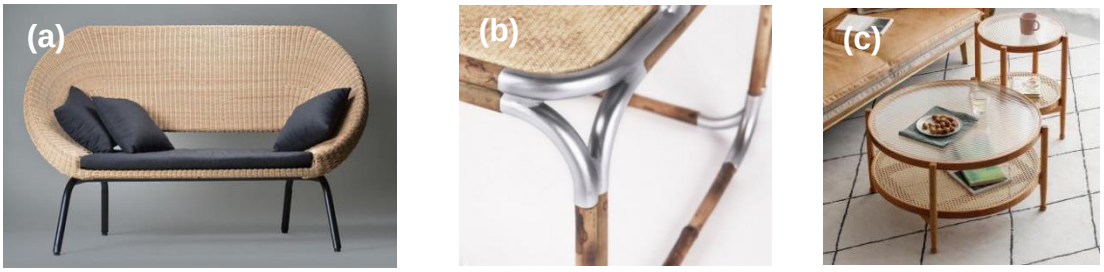

Fig. 3. Images of (a) soft bag and bamboo, (b) metal and bamboo, and (c) glass and bamboo

A fusion of Scandinavian and Moroccan styles, Kristian's Nomad chair is made of bamboo with a simple frame and a light, airy back with a seat made of woven bamboo mesh. The addition of leather upholstery to the seat and neck rest of the chair echoes the colour of the bamboo and adds to the overall colour of the chair, and the combination of the two materials improves the comfort of the chair (Fig. 4).

Fig. 4. Nomad chair

Bamboo Furniture Interactive Design Platform

The weaving of bamboo patterns is usually completed by interweaving warp and weft, in which the pressed bamboo threads are the "warp," and the woven bamboo threads are the "weft." The geometrical rules of composition can be analysed and summarized in combination with digital tools to form the company's own design system, which allows the intelligent design and weaving of bamboo strips. In addition, it establishes an interactive platform in line with the customisation trend, which makes communication between users and designers more direct and effective (Zhou *et al.* 2015). Currently, the main software tools available for the parametric design of bamboo weaving are CAD (computer aided design) and Rhinoceros. There are many different methods of bamboo weaving, and it is difficult for non-professionals to master the weaving process and achieve industrial production. The development of a professional parametric bamboo weaving program will enable the free combination and switching of different sizes of bamboo filaments. Further, combining advanced manufacturing technologies such as 3D printing to achieve personalised design (Wu and Zhang 2017), standardised production, and mass customisation, would enable the bamboo weaving industry to keep pace with "Industry 4.0."

Modern Processing Technology of Bamboo Weaving

Modern bamboo processing is characterised by low resource utilisation, small-scale enterprises, unreasonable processing techniques, and low levels of equipment automation. The process of processing bamboo strips consists of: selection → cutting → scraping → breaking → opening → splitting → fine planning. The machines used in the processes include bamboo sawing machines, sorting machines, and strip cutting machines, among others. Compared to the wood furniture industry, the bamboo furniture industry is much less automated and intelligent, as the sawing and sorting processes still require workers to load and unload the material, which affects production efficiency and poses a safety hazard (Shen *et al.* 2019). The production lines of many bamboo enterprises imitate those of wood processing, and no efficient bamboo production lines have been developed specifically for the characteristics of bamboo. Therefore, in the future, bamboo processing processes should be designed according to scientific and technological research, sound bamboo processing standards should be established, and efficient bamboo processing technology should be developed (Li *et al.* 2018). The automatic-feeding and fast-centering CNC bamboo breaking machine developed by Chang *et al.* (2019) does not require workers to load and unload, which saves labour costs and automates the bamboo breaking process in the bamboo pre-processing section. The machine improves the processing efficiency of the pre-processing section and lays the foundation for subsequent processes, such as slicing and splitting (Chang *et al.* 2019).

CONCLUSIONS

1. When designing bamboo woven patterns and furniture shapes, designers should follow current trends, integrate modern aesthetic tastes, and consider users' needs for shapes, colours, and materials.
2. To further promote the modernisation of the bamboo furniture industry, bamboo furniture should be user-centered in the future development process, and an effective interaction platform should be built according to user usage and aesthetic needs. The construction of the interaction platform should consider the effective and correct flow of information. In addition, a digital design resource library for bamboo products should be built to facilitate design communication between the three parties to optimise the influencing factors in design communication. Further, an evaluation system for effective design communication (a user feedback module) should be established to ensure timely feedback from users so that manufacturers can make timely corrections to problems in the design process and maintain their corporate reputations.
3. In the process of modernisation, the development of bamboo furniture should encourage craftsmanship and the dissemination and promotion of traditional bamboo culture. Collaborative design methods can be used in the promotion and marketing process of bamboo furniture. Currently, users are not satisfied with the process of buying products directly and are more willing to participate in the process of product customisation and innovation. Therefore, the design could be led by the enterprise, and users, designers, and craftspeople could collaborate. In this process, users in need can parameterise customised weaving patterns with the help of designers and can be taught by craftspeople so that users can experience bamboo weaving culture. Users are encouraged to participate in the design process to complete personalised bamboo

weaving patterns, which enables the promotion of bamboo weaving culture and the improvement of the craftsmen's living conditions.

4. In the future, the modern processing of bamboo materials should focus on the establishment of continuous production lines, improving the current disconnected production chain and single-machine operation mode, reducing the proportion of manual labour, and realising mechanised intelligent manufacturing. As the special warp and weft weaving method of bamboo weaving conforms to the mathematical geometry model, parametric design can be developed, and enterprises can systematically sort out the bamboo weaving pattern *via* parametric programming and realise the digital manufacturing of bamboo furniture through new production technologies, such as mechanical production lines and 3D printing.

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