

Integrating Color Theory in Eco-Friendly Design of Reconstituted Decorative Thin Wood

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With the increasing emphasis on green home furnishing and ecological environment, reconstituted decorative thin wood is being used more widely as a new material with excellent performance and beautiful appearance. This paper discusses applying the color theory of reconstituted decorative thin wood from the perspective of green ecology. First, academic achievements are summarized related to reconstituted decorative thin wood and its color theory, exploring its research direction and future development trends. Secondly, this paper outlines the classical color system and theory, at the same time, based on the K-means algorithm, color extraction of reconstituted decorative thin wood samples, and establishes the color relationship network model. Using the basic theory and design method of prototype typology, the texture types of reconstituted decorative thin wood are classified, and the texture characteristics and texture composition of reconstituted artistic modeling thin wood are studied. Through data analysis of 96 questionnaires and summarizing and analyzing the results of the respondents' perceived preferences for the experimental samples, the feasibility of the restructured decorative thin wood design scheme was verified based on the CNCSCOLOR color palette theory of color matching design. Then the degree of choice and the degree of willingness to purchase of the restructured decorative thin wood scheme and its application of the customized closet effect were evaluated through the Likert Scale.

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INTRODUCTION

Human consideration of the environment has grown, and this is a main driver of increased interest in wood decorative material. Owing to its fairly good performance and attractive appearance, many fields, including decoration, engineering, and furniture, among others, have applied reconstituted decorative thin wood to their material portfolio. To further protect forest resources, China has promoted green homes, formed a series of policies to encourage eco-friendly practices, and driven the low carbon development of the industry (Song *et al.* 2018). China announced that it will try to reach a carbon peak in 2030 and achieve carbon neutrality in 2060 (Huang *et al.* 2024). This target provides a clear goal: China needs to establish the industrial system step by step with the characteristics of low

environmental impacts, low carbon, and circular development in different departments.

In August 2022, the Ministry of Industry and Information Technology jointly released with other four departments the Action Plan to Promote High-quality Development of Household Industry, which is the first instructive document that gives clear indications to strengthen the promotion and application of green materials, technology, equipment, and processes (Zhang *et al.* 2018; Zyryanov *et al.* 2024). The aim is to promote high-quality development for the home industry while using environmentally friendly products. China's requirements for energy conservation and environmental protection in furniture production are expected to increase, and the carbon emission index of wood and bamboo building materials products has been included in the green building materials standard system (Liu *et al.* 2020).

The upgrading of energy-saving practices has brought higher requirements for the environmental performance of wood products and green production. Likewise, the continual upgrading of environmental protection materials at the product end will force the furniture industry to pay more attention to the quality of the system and promote the quality of the household industry chain (Myronycheva *et al.* 2025). This means that the market share will be concentrated in the outstanding leading enterprises with qualified system supply capabilities, green production and manufacturing capabilities, and research and development capabilities (Zhang *et al.* 2024). At the same time, with the environmental health, green, and harmless consumption concepts deeply rooted in people's hearts, consumers' demand for healthy homes is becoming more prominent (Yang *et al.* 2024a).

Due to its physical properties and environmental advantages, wood is favored by the market, which creates a demand to maintain growth. Under the goal of double carbon policy, the green industrial production mode of saving consumption, reducing emissions, and reducing costs has been an inevitable trend (Zhu *et al.* 2022). In contrast to glass, steel, and other traditional home building materials, wood is a natural carbon storage material (Zhang *et al.* 2023a). The production process requires relatively little energy consumption and a low carbon emission level, which result in obvious energy savings and carbon reduction advantages (Zhang *et al.* 2023b). However, as a large wood consumer, China has a limited share of forest resources. Coupled with the expansion of the scale of the timber industry, the supply of these limited wood resources is facing increasing pressure. It is proposed that color improvement with photonic crystal structure color is a clean and pollution-free ecological biomimetic coloring technology (Hu *et al.* 2020).

Reconstituted decorative thin wood belongs to one of the morphological classifications of reconstituted decorative lumber. Reconstituted decorative lumber, the trade name of which is technological wood, mainly uses rotary cut (or planed) veneer from plantation forests or common species of wood as raw material. It is manufactured through veneer toning, lamination, molding, gluing molding, and other technologies (Qiu *et al.* 2021). Reconstituted decorative lumber has the texture, grain, color, and other characteristics of naturally rare species of wood, and it can also present artistic patterns, which is a new type of wood decorative material (Wang *et al.* 2019).

Compared to other countries, the Chinese wood processing industry is large in scale, has a great demand, and offers enormous potential for further growth. Fast growing plantation wood has greatly alleviated the supply-side pressure on China's wood resources while promoting the sustainable development of the industry and contributing favorably to the improvement of the ecological environment (Yang *et al.* 2024b). Due to the softwood and low density, the artificial fast-growing wood cannot be used directly as a wood product; modifications have to be done to improve material performance and increase material

stability (Anwar *et al.* 2024). Therefore, modification is essential. After improvement and optimization, the artificial wood has improved functional properties and has wide areas of application (Fu *et al.* 2023); therefore, the product value is very high (Papa 2024).

As a kind of green environmental protection and renewable material, the reconstituted decorative wood has become the consensus of international peers in the context of energy conservation and emission reduction, helping to address world climate change (Chang *et al.* 2024). The production of reconstituted decorative wood processes and modified artificial wood gives more visual possibilities to the wood substrate and improves and optimizes its performance. It can satisfy the large demand for wood resources in the Chinese market, as well as meeting the high requirements of environmental performance for household materials. Reconstituted decorative thin wood is therefore expected to face more market opportunities during the transformation and upgrading of the household industry (Zhu *et al.* 2022). This paper hopes to enhance the market competitiveness of reconstituted decorative thin wood through color theory and design practice verification.

COLOR THEORY

Color System

Colors are possibly divided into colored and colorless systems (Zhang *et al.* 2023). The colorless system contains white, black, and several gray shades and hence possesses only the color property of brightness, but not that of chromaticity and hue. The colored system possesses all three basic attributes of color: hue, lightness, and color. Color system (Color-Order System), that is, according to the different benchmarks, is based on certain color harmony theory and color in a certain order for systematic representation of the color system (Ramos *et al.* 2020). Most common color systems use specific codes and values, defined by their respective encoding systems, to represent colors. Countries have so far built color systems, such as the Munsell color system, the Ostwald color system, the International Commission on Illumination (CIE) $L^*a^*b^*$ color system, the Practical Color Coordinate System (PCCS) color system, and other color systems for researching color metrology.

CIE (1976) $L^*a^*b^*$ Standard Colorimetric System

In 1931, the International Commission on Illumination outlined the color characterization system XYZ based on a corresponding standard to carry out color metrology research (Cheng *et al.* 2018). CIE $L^*a^*b^*$ system to L^* , a^* , b^* the three indices of this color characterization, the meaning of the representative of the sequence: the brightness of the color (related to black and white), between the red and green colors in position, between the yellow and blue colors in position. These three indices can accurately describe all the colors perceived by the human eye. Among them, L^* can be subdivided into values in the range 0 to 100, and a^* and b^* values range from -100 to 100. The color system can help people intuitively and quickly select the matching color, and the application is more widespread.

Ostwald Color System

The Ostwald color system was proposed by the German physical chemist Ostwald in 1916, respectively, representing colors by a three-dimensional system of the

isochromatic chart of the square triangle as the basis for the construction. The color system would be red, yellow, green, and blue, four colors placed in the circumference of the four equal parts, the formation of two pairs of complementary color pairs. Then at each of the two colors orange, yellow-green, blue-green, violet four colors, a total of 8 colors were added. Then each of the 8 color phases was made into 3 colors accordingly to form a 24-color hue ring, starting with the first being yellow, and ending with the 24th being yellow-green. Among them, the second color of each 3 colors is the positive color. The Ostwald color system has the advantages of simple color code, which is easy to understand and remember. The color phase grading is clearer and more regular with easy to match color and harmony. However, it has the shortcoming of excluding highly saturated colors from the system and the distribution of the color rank may cause the brightness and saturation of color to go wrong, so it cannot meet some industrial requirements that need a great quantity of bright color in actual use (Ouyang *et al.* 2020).

CNCSCOLOR Chinese Application Color System

The CNCSCOLOR Chinese application color system is being used by the China Textile Information Centre, the China Popular Color Association, and other research from various organizations. On November 1, 2008, it was officially approved. The color system was reconstructed with the grading criteria of hue, lightness, and chroma after a large number of visual uniformity experiments.

The fundamental colors are five primary colors and five intermediate colors (Kayo *et al.* 2019). The hue ring is made up of those 10 basic colors in an equidistant arrangement; it has 10 main intervals. According to the visual uniformity of intervals, it could be further subdivided into 20 colors, 40 colors, 80 colors, and 160 colors, and its numerical value range is 001~160. CNCSCOLOR's hue value and color of the corresponding relationship are presented in Table 1. The value of the brightness of the color system is a psychological measure that shows the degree of brightness of the color. It shows the degree of lightness or darkness of color and can be represented by the symbol V . Brightness will be represented by the symbol L defined according to the COLOR platform in the subsequent study (Wang *et al.* 2024). The ideal white color is 100, the ideal black color is 0, and there are 99 brightness levels from 01 to 99 in the middle. Chroma, in abbreviation, is represented by the symbol C . Starting with 01, according to the principle of isochromatic aberration, chroma values increase from small to the direction of the outer radial line. The maximum achievable saturated color is different according to different hues. Black or pure gray or pure white specimens, having no chromaticity use the 00 symbol (Huang 2024).

Table 1. Corresponding Relation between Hue Value and Color in CNCSCOLOR System

Hue Value	001-016	016-032	032-048	048-064
Colors	Red	Reddish yellow	Yellow	Yellowish green
Hue value	080-096	096-112	112-128	128-144
Color	Blue green	Blue	Bluish purple	Purple
Hue value	008	024	040	56
Color	Pure red	Pure red yellow	Pure yellow	Pure yellow green
Hue value	088	104	120	136
Color	Pure blue green	Pure blue	Pure bluish violet	Pure Purple
Hue value	064-080	144-160	72	152
Color	Green	Reddish purple	Pure green	Pure red purple

Color Extraction

There are several relatively mature technology methods for image color feature processing, such as color histogram, color aggregation vector technology, the FCM clustering algorithm, the K-Means clustering algorithm, *etc.*, all of which can quantitatively present color information. The K-Means clustering algorithm is more widely used in the computer image color extraction field. (Zheng *et al.* 2024). Using the K-Means algorithm as the basic technology, CorelDRAW software was used to write the plug-in programs for realizing the extraction of the color features of single or multiple images (Nakano *et al.* 2018). The color relation network model established in this paper has great value in application and practice in the related fields of color applications (Peng *et al.* 2018).

The k-means algorithm is a clustering method that groups data by calculating the proximity of the distance relationship between them and using it as a similarity criterion. The basic principle is to randomly select the initial clustering center in the data set, where the number of center points is K. The next step is to calculate the Euclidean distance from each point in this data set to the initial clustering center and divide the points with similar distances into the class clusters that are close to their clustering centers. According to the similarity between the dataset and the clustering center, the above steps are continuously updated until the iteration is done to meet the predefined termination conditions (Yusi *et al.* 2024). The value of K in K-means clustering is expressed as the number of extracted colors, and after the submission of the corresponding value of K, the computer will select the appropriate clustering centers according to the predefined judgment function and finally output the extracted colors. The initial setting of the clustering center will have two modes, grayscale mode and hue mode. The color extraction results for the same image using different modes will have some differences. The purpose of the Hue mode is to select the initial clustering center by hue, the clustering center will fall on the hue ring, and along the hue from 0 to 360 according to the number of required K values and the average distribution, so the color order of the output results will be by the order of the hue ring. The grayscale mode means that the initial clustering center is selected by the grayscale value, and the initial clustering center will fall on the diagonal of the RGB color space to calculate, and the grayscale value is evenly distributed along the hue from 0 to 255 according to the number of required K values, so the color of the output results will be displayed in the order of the grayscale level (Xiong *et al.* 2023).

The color extraction of the restructured artistic styling thin wood involves the use of K-means clustering technique to extract the color of a single thin wood image by clustering the required number of colors. The color composition of thin wood is rich, the main color is clear, and the color elements are not single, so the RGB hue mode is selected for the color extraction of the restructured decorative thin wood images. In addition, due to the differences in the restructuring method, the color matching characteristics of thin wood will be different, so the selection of the initial clustering center will be adjusted according to the color matching effect and pixel composition characteristics of the restructured decorative thin wood, which will improve the accuracy of color extraction. That is, the K value follows the image pixel distribution. With the setting in hue mode, the color is read along the hue ring and the characteristic color is selected as the initial clustering center, as shown in Fig. 1.



Fig. 1. Color extraction and color network model construction of single veneer

Color Harmony

Color Harmony refers to the process or state of realizing the harmony of multiple colors by adjusting the interrelationships of the colors. In 1916, Oswald put forward the theory of Harmony = Order, which advocated that color harmony should follow a certain order. In 1944, the American color theorists P. Moon and D. E. Spencer defined a beauty coefficient that was based on the Munsell color system, using the Barkhoff (George David Barkhoff) beauty formula, as follows,

$$M = O / C \quad (1)$$

where M is measure, O is the order, and C is the complexity and diversity. According to French art educator Henry Pfeiffer, color harmony is a comfortable and consistent state between plural colors and their visual connections (Wang *et al.* 2022). Some scholars have pointed out that aesthetic judgment of color harmony will change with subjective judgments after comparing the above color harmony theories (Mao *et al.* 2022).

Many scholars have explored the principle of color harmony, which has promoted systematic color research up to the present day, as well as the research on the sensual aspects of product aesthetics (Chen *et al.* 2020). However, due to the influence of regional differences, history, culture, socioeconomic, and other factors. There has not been a color harmony theory that has universal characteristics and can be applied as an aesthetic standard in the measurement of the aesthetics of color matching in various industries. Moreover, due to the influence of various factors such as the number of colors, color area, and color attributes, each color harmony theory is mostly used for the evaluation of the aesthetics of two color harmony in practical use.

Figure 2 shows the presentation of the five color reconciliation methods proposed by Moon and Spencer on the CNCSCOLOR hue ring. Figure 3 shows the CNCS-COLOR color system based on the above reconciliation theory, the more complex color matching law is studied after the derivation of the summary of the seven color reconciliation methods. Based on rich visual experiments, the color mixing theory points out that colors with the same interval distance cause the same color difference degree of human feelings, and this is also true in the three dimensions of hue, lightness, and chroma. Table 2 shows the seven types of color harmony and their characteristics.

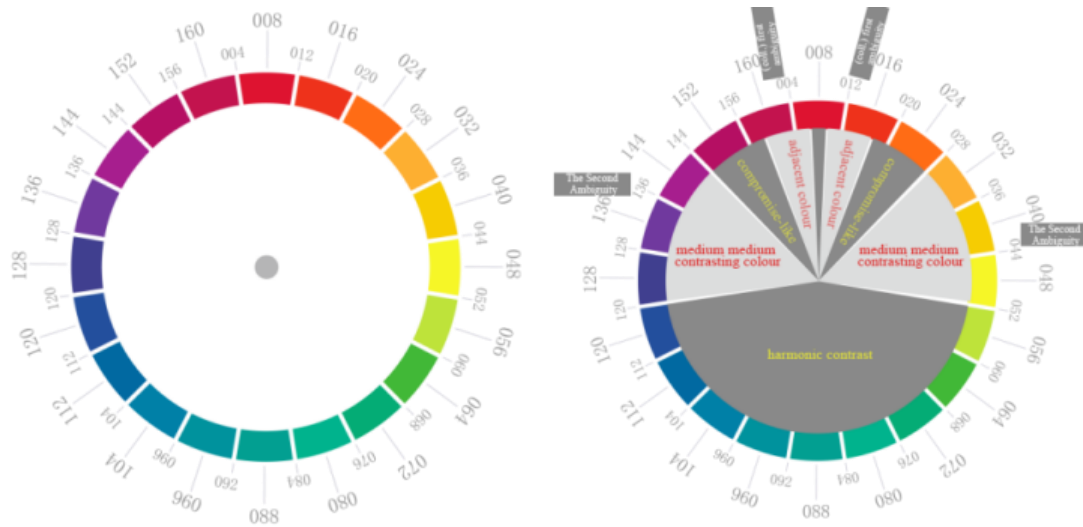


Fig. 2. CNCSCOLOR hue ring and color harmonic relation

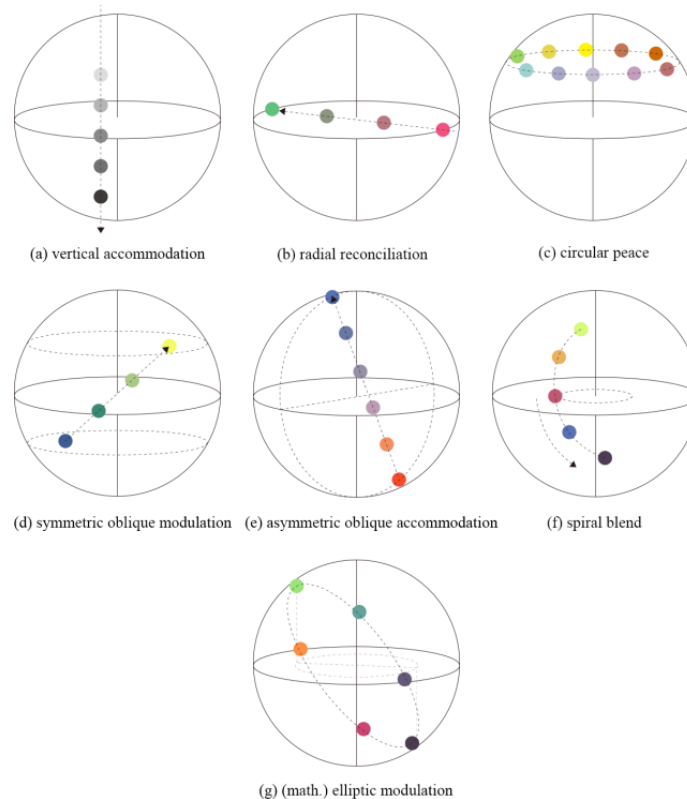


Fig. 3. Embodiment of seven color harmony methods in color three-dimensional space

Previous research (Ramos *et al.* 2020) on the restructuring of decorative thin wood products found that some of the products present many colors and distinctive features. In the face of multi-color matching and reconciliation, CNCSCOLOR is based on the color arrangement law of the Munsell color system. It is also based on the visual isochromatic principle of the multi-color reconciliation theory, which is more suitable for this study on the color reconciliation of restructured artistic modeling of thin wood.

Table 2. Types and Characteristics of Color Harmony

Types of Color Harmony	Features
Radial harmony	Lightness level is rich, hue is uniform
Hue value	Rich in color, consistent in brightness, and contrasting in hue
Circular harmony	The brightness and chroma are the same, but the hue is different
Symmetrical oblique harmony	Brightness, hue symmetry contrast, rich color
Asymmetrical oblique harmony	Brightness, hue contrast, rich color
Spiral harmony	Color consistency, lightness, hue gradient
Elliptic harmony	Color consistency, brightness, hue periodic gradient

Application

Most of the restructured decorative lamellas in the domestic market are used as finishes in customized home furnishing products such as closets, wooden doors, background walls and kitchen cabinets, and are rarely used in finished furniture products. As the largest share of the customized home furnishing industry, the customized closet will bring the user's personalized needs into the closet consumption field. Thus, the restructuring of decorative thin wood application design has huge potential in the market space(Zhou *et al.* 2023).

A questionnaire was employed to explore the preference of new-age urban youth for the pattern design and application of closet solutions using restructured decorative lamellas, aiming to establish the data relationship between users' perceived preference for the design solutions and their actual willingness to buy. This study evaluated the design solutions of restructured decorative lamellas based on the color harmony theory of CNCSCOLOR and validated the market value of these products. The research was mainly divided into basic information research and preference evaluation. The effectiveness of the color scheme based on the color harmony theory was verified by setting up a sample control group. As shown in Fig. 4, the yellow tone (Y) and blue tone (L) were selected as the basic color tone for this experimental sample.

**Fig. 4.** Graphical examples of verification samples

The evaluation questionnaire was mainly distributed on an online platform, with 98 questionnaires collected and 96 valid questionnaires obtained, including 41 men and 55 women. This study targets urban youth (aged 18-35) in economically developed regions as the primary research demographic for customized closets. This group is characterized by their higher aesthetic appreciation, demand for personalization, and consumption habits regarding home products. Accordingly, this participant type was selected as the research

user for this paper. The age distribution was 18 to 35 years old. The respondents were required to have normal eyesight, without color weakness, color blindness, or other visual special conditions. At the same time, based on the identity background as the basis for division, design professionals and non-design professionals were differentiated, in order to set up a control population. The basic information of the research population is shown in Table 3.

Table 3. Basic Information of Survey Population

Form	Options	Frequency	Percentage (%)	Form	Options	Frequency	Percentage (%)
Sexes	Female	55	57.3	age	18 to 25 years old	62	64.6
	Male	41	42.7		26 to 35 years old	34	35.4
Back-ground	Design Professionals	53	55.2		35 to 45 years old	0	0
	Non-design professionals	43	44.8		45 and over	0	0
Total						96	100

The respondents determined their score for the degree of conformity with their personal preferences based on the psychological feelings they received from the overall effect in the illustrated sample and checked the appropriate scoring options. A Likert scale was used to quantify consumer perceptions of the program, categorizing and scoring preferences and purchase intentions. In the preference dimension, participants chose between the following responses: very much like (5 points), like (4 points), average (3 points), do not like (2 points), very much dislike (1 point). In the dimension of willingness to buy, the specific is very willing to buy (5 points), willing to buy (4 points), indifferent (3 points), unwilling to buy (2 points), and very unwilling to buy (1 point).

Table 4 shows the results of the cross-tabulation analysis of the respondents' preference for the color and texture of the customized closet, and it can be concluded that more than 60% of the respondents preferred the customized closet with natural wood effect, totaling 65 people.

Table 4. Cross-analysis of Respondents' Preference for Color and Texture of Customized Wardrobe

Typology	Natural wood	Geometric textures	Grain leather with cloth pattern	3D effect textures	Organic Morphological	Total
warm color	33 (80.5%)	4 (9.8%)	1 (2.4%)	2 (4.9%)	1 (2.4%)	41
cool color	8 (66.7%)	2 (16.7%)	0 (0.0%)	2 (16.7%)	0 (0.0%)	12
neutral color	24 (55.8%)	9 (20.9%)	2 (4.6%)	2 (4.6%)	6 (14.0%)	43
Total	65	15	3	6	7	96

Among them, the number of people who preferred warm color (natural wood grain) was the largest, totaling 33 people; followed by neutral color (natural wood grain), totaling 24 people; and finally, cool color (natural wood grain), totaling 8 people. In addition, the

number of people who chose the Geometric Texture type as a decorative effect for their custom closets ranked higher, totaling 15 people, with the highest number of people choosing Neutral Colors (Geometric Texture), totaling 9 people.

As can be seen in Fig. 5, male respondents preferred warm tones for the color of the custom closet, while female respondents preferred neutral tones, and both showed less interest in the use of cold tones in the custom closet. In terms of texture, both male and female respondents preferred natural wood grains, with a small number of female respondents choosing organic textures for their customized closets.

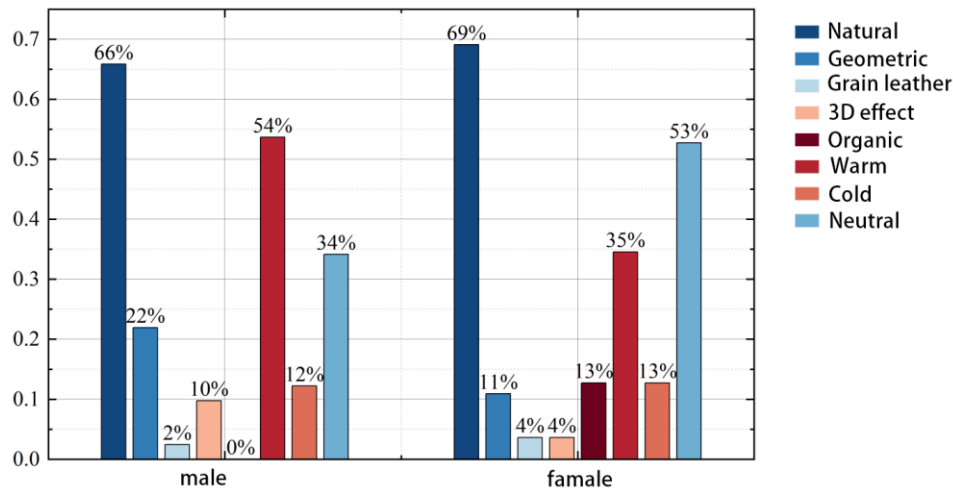


Fig. 5. Different genders' preference for color and texture of customized wardrobe

As can be seen from Fig. 6, for the choice of custom closet hue and texture, most of the respondents with design professional experience and non-design professional respondents tended to choose custom closets with natural wood grain effect, and they tended to choose warm and neutral colors in terms of color.

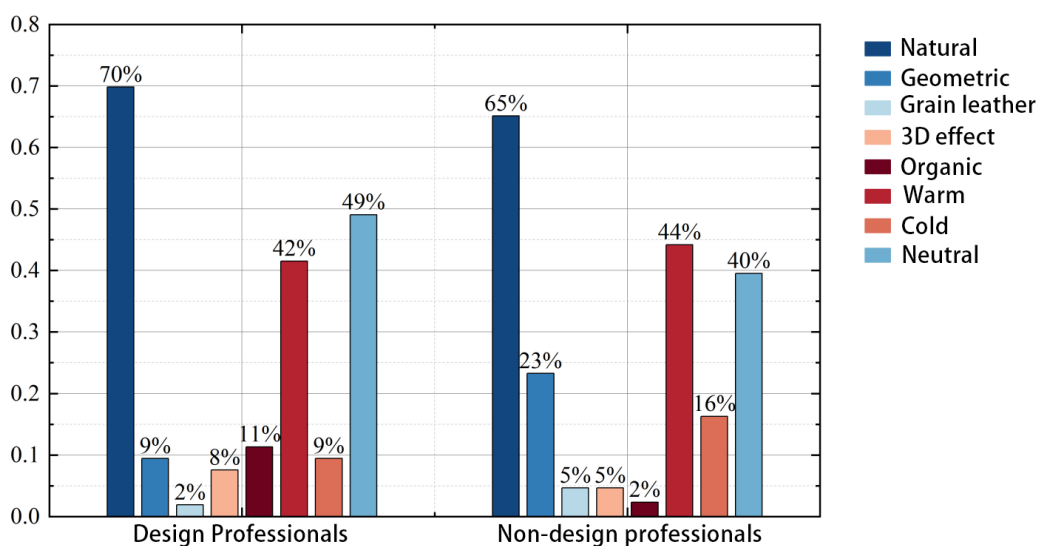


Fig. 6. Choice preference of color and texture of customized wardrobe from different professional backgrounds

It is noteworthy that 23.3% of non-design professionals chose geometric texture for their choice of custom closet texture, in contrast to 9.4% of respondents in the design professional group who chose this option. In addition, 11.3% of design professionals on the other hand showed more interest in organic form textures, while only 2.3% of non-design professionals chose this option. This result shows the difference in the choice of texture and color of customized closets between the consumer group with design professional background and the general consumer group, which reflects the possibility of designing more texture effects such as geometric shapes and organic shapes when designing customized closets with color texture for a wider range of consumer groups.

CONCLUSIONS

1. Integration with color theory enhances design possibilities. The combination of reconstituted decorative thin wood and color theory offers innovative opportunities for interior design. By leveraging color relationships (*e.g.*, primary and complementary colors) and extracting inspiration from the wood's natural textures, designers can create unique, harmonious color schemes. This enhances visual appeal, emotional resonance, and spatial functionality, providing a pleasant psychological experience.
2. Reconstituted decorative thin wood is an ecofriendly material that reduces log consumption, minimizes wood waste, and utilizes low-volatile organic compound (VOC) adhesives, aligning with sustainable development. Its market is expanding, particularly in interior decoration and furniture design, due to its aesthetic appeal and physical properties. Increasing consumer demand for green products is driving its adoption and industrial growth.
3. Through the results of the questionnaire data, it is concluded that compared with artificial color matching, the restructured decorative thin-wood color matching design scheme derived from the theory of color blending was preferred by the respondents.
4. The overall preference of the respondents for the reconstituted decorative thin wood design scheme and its application to customized closet design was higher than the overall degree of willingness to buy, which reflects the fact that when the respondents are shopping for reconstituted decorative thin wood and customized closet products, in addition to the influence of the color and texture factors, there are also other factors affecting the user's purchase of the products.
5. In the two color matching groups with yellow (*Y*) as the tonal base color and blue (*L*) as the tonal base color, the samples with yellow (*Y*) as the tonal base color for vertical toning were rated higher, and the samples with blue (*L*) as the tonal base color for asymmetric diagonal toning were rated higher, which is a side-effect of the result that the users' concern on the way of color toning is affected by the tonal base color to a certain extent.
6. A significant preference gap exists: nearly a quarter of non-designers prefer geometric textures, whereas designers favor organic forms. This highlights the need for diverse texture options in closet design to cater to varying tastes.

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