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Innovative Data-Driven CMF Design for Age-Friendly Furniture

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Abstract. This study presents an innovative data-driven approach to CMF (Color, Material, Finishing) design for age-friendly furniture. By integrating K-means clustering, decision tree model, and AHP-SD evaluation method, with age-friendly consideration from data source, professional evaluation and user selection, this study aimed to identify optimal CMF schemes tailored to the preferences and needs of older adults. The result reveals that orange Hue, D5(mid Saturation and mid Value) colors are predominantly preferred, and M3F5 (linen) emerged as the top choice. The data-driven method demonstrates high efficiency and scientific objectivity in providing design recommendations compared to traditional methods. These findings underscore the potential of data-driven CMF design to create aesthetically pleasing, and age-friendly furniture, ultimately improving the quality of life for older adults and offering valuable insights for designers and manufacturers in the furniture industry.

Keywords. CMF, AHP-SD, data-driven design, age-friendly, decision tree model

1. Introduction

China has been an aging society for over 20 years, and as the senior population grows older, their physical functions gradually deteriorate [1]. These changes, such as reduced sensory perception, directly impact how they perceive furniture in terms of color, material, and texture [2]. However, current research on age-friendly furniture design primarily focuses on physiological needs, with limited attention to aesthetics, and lacks a standardized design system. To efficiently meet the quality requirements of seniors, while ensuring innovation in furniture design with minimal changes to basic functions, and lower production costs, this study introduces CMF design theory, emphasizing Color, Material, and Finishing elements in product design.

Moreover, user-centered design method targeting older adults face challenges, such as difficulties in clearly expressing their actual needs, and the subjective biases of designers [3]. Therefore, this research proposes a data-driven approach, taking the living room sofa as an example, to explore innovations and standardized developments in CMF design. By enriching the research content and direction of age-friendly furniture, this study aims to provide designers and furniture companies with innovative design process through a comprehensive and diversified perspective on CMF design.

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2. Related Work

Research on age-friendly design not only enhances the quality of life for older adults but also promotes societal inclusivity and sustainable development [4]. It could prolong independent living for older adults by providing more comfortable environments and products for them. Current research on age-friendly furniture primarily focuses on the physiological needs of older adults. Color studies in this context often examining the functional and psychological impacts on users. However, market surveys reveal that most furniture offers a limited color palette and seldom considers CMF.

Within CMF design, C and M can often be customized by users, M and F are inseparable. CMF design can address physiological, psychological, and personalized needs from the perspective of older adults. This approach aids designers in controlling product details and quality, fostering innovation, and strengthening the emotional connections. It also helps enterprises precisely target and categorize their markets, achieving commercialization and mass production while addressing issues of product homogenization. Despite these advancements, there is a notable gap in the aesthetic and emotional needs of seniors.

In consideration of design efficiency, data-driven design leverages large datasets and advanced analytics to optimize design decisions [5]. This approach has gained traction across various domains, including architecture, product design, and user experience design. Machine learning can predict design outcomes based on historical data, enabling more efficient and effective design processes. These models can facilitate the creation of personalized experiences tailored to individual user needs and preferences. However, data-driven design faces challenges related to data privacy and ethical considerations. Addressing these challenges requires robust frameworks that balance data utility with user rights and ethical standards.

3. Method

3.1 Data-driven Innovative CMF Design Process

Traditional furniture design process typically includes steps such as product positioning, design refinement, manufacturing, and feedback [6], and CMF design can add values in the second stage. This study proposes a data-driven innovative CMF design process that mainly involves Data Collection, Trend and Scheme Development, Evaluation and Archive, which is shown in the Figure 1.

In the Data Collection phase, foundational information on user preferences, market and industry trends can be gathered through literature, images, and product manuals. Based on this collected data, tools such as expert scoring method and decision tree models are employed to conduct trend research and develop CMF schemes. To obtain user feedback, evaluations of CMF schemes are necessary to determine their suitability and to provide recommendations for further design development. Finally, CMF design schemes that meet the required criteria are archived for future reference.

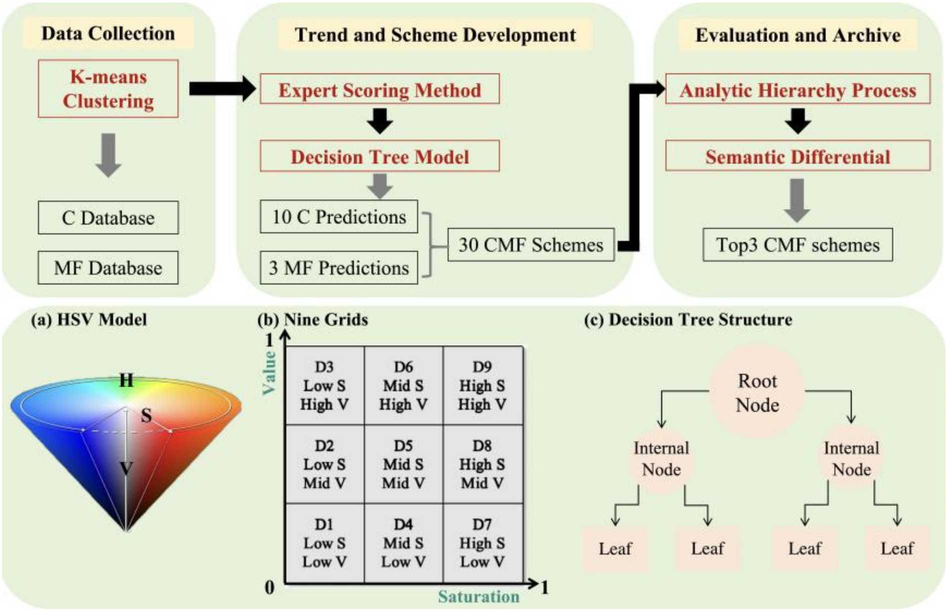

Figure 1. Innovative data-driven CMF design process, (a)HSV model, (b)Nine Grids, (c)Structure of DT.

3.2 Data Collection

3.2.1 Material and Finishing

The design and selection of MF are critical steps in enhancing product performance and quality [7]. Different MF possesses unique characteristics and emotional values. For instance, linen, is breathable, soft, comfortable and durable. A rough appearance conveys a sense of simplicity and closeness. Generally, smooth textures can enhance the fashion and technological feel but might create a sense of distance for users. In contrast, coarser surfaces tend to convey warmth and intimacy.

MF is heavily dependent on available technologies, requiring a high level of expertise. Even "customizable" options are provided to users only after rigorous selection by professionals. This study by categorizing the collected data on age-friendly living room sofas, analyze the M and F used. Examples of materials include M1 (wood), M2 (leather), M3 (textile), M4 (rattan), and M5 (metal). Finishing include F1 (glossy), F2 (matte), F3 (brushed), F4 (baked), and F5 (linen). By systematically analyzing these combinations, the study aims to identify optimal MF options that enhance the comfort and aesthetic appeal of age-friendly furniture. This step ensures a comprehensive understanding of how different MF combinations can meet the needs and preferences of seniors, thereby improving their overall living environment.

3.2.2 Color K-means Clustering

Color is one of the most prominent features in design. HSV (Hue, Saturation, Value) model is commonly used in image processing, computer vision, and computer graphics [8], shown in Figure1. (a). Hue(H) represents the category of color, Saturation(S) indicates the vividness and Value(V) represents the brightness or lightness of the color. Based on S and V, colors can be categorized into nine grids, which is shown in Figure1.

(b). Each grid possesses unique stylistic attributes. For instance, D1 colors are often perceived as dark, muted, calm, mysterious, and serene, while D2 colors are seen as soft, warm, earthy, restrained, neutral, and stable.

In this stage, image data were collected from databases such as Unsplash, Flickr, Pinterest, and product manuals. And the color database was sourced from 3 types of images: A1. indoor living rooms of seniors, A2. age-friendly furniture products, and A3. theme inspiration, totaling 211 images. The collected images were processed using the K-means clustering method to extract RGB data. To be specific, K-means is a widely used clustering algorithm that divides data points into distinct clusters [9]. It operates by iteratively assigning data points to the nearest cluster center and updating the cluster centers to minimize the sum of squared distances within clusters. All color data was saved with the top 5 dominant RGB, and then were converted to HSV for easier classification. All data were stored in an Excel file for subsequent use.

3.3 Trend and Scheme Development

3.3.1 Expert Scoring Method

Before using the decision tree model, it is essential to refine and score the labels for each data point. Therefore, expert scoring method was introduced in this research. Combining conclusions from age-friendly research, we invited 10 experts from gerontology, healthcare, material science, manufacturing and design to establish evaluation criteria for C and MF respectively. Colors were categorized based on: Source, Hue Range, and Nine Grids. Experts evaluated these categories based on their professions, scoring them on their friendliness to older adults and the compatibility. For MF, the focus was on comfort and safety. This method ensures that physiological and psychological factors relevant to older adults are scientifically considered.

3.3.2 Decision Tree Model

Decision trees are fundamental methods for classification and prediction which work by recursively splitting data into binary partitions, selecting the best feature for each split, and creating a tree structure [10], which is shown in the Figure1. (c). The scores for C and MF, calculated through expert scoring, were then fed into the model. The process for both C and MF decision trees follows a similar approach by Python. First, data are loaded with features and labels separated. For instance, the features for C include R, G, B, H, S, V, and scores. The label is the color trend, categorized as high, relatively high, medium, relatively low, or low. The data were split into training and testing sets. The trained model was then used to predict the color trends in the testing set, yielding the top 10 predicted results. Finally, a 3D scatter plot was created, where the x, y, and z axes represent the R, G, and B channel of the colors, respectively. At the end of this section, 10 Colors and 3 MF combinations were collected.

3.4 AHP-SD Evaluation

30 CMF schemes were derived by combining predicted C and MF. Then, the same 10 experts were invited to establish the evaluation criteria using the Analytic Hierarchy Process (AHP). The process addresses complex decision-making problems by emphasizing hierarchical structuring, breaking down the problem into multiple levels from the overall goal to specific alternatives, which shown in the Table1.

Table 1. Criterion and sub-criterion level and descriptions with the SD adjective pairs defined by experts.

Criterion Level	Sub-criterion Level	Description	SD Adjective Pair
J1.Visual Quality	K1.Color Durability	The longevity and stability	Outdated - Attractive
	K2.Texture Quality	The quality of overall texture	Poor - Excellent
	K3. Compatibility	The compatibility of environment	Jarring - Harmonious
J2.Age-Friendliness	K4.C Friendliness	Color friendliness to seniors	Unfriendly - Friendly
	K5.MF Friendliness	The friendliness of MF to seniors	Unfriendly - Friendly
	K6.Cleaning	The ease of cleaning	Difficult - Easy
J3.Implementation	K7.Efficiency	The efficiency of manufacturing	Low - High
	K8.Cost	The cost of manufacturing	Low - High
	K9.Sustainability	The environmental sustainability	Fatal - Sustainable

The evaluation model construction involves 4 steps. First, decompose the complex decision problem into hierarchical levels and establish the structure. Next, compare different factors at each level to determine relative importance, creating pairwise comparison matrices. Third, weight calculation, to use mathematical calculations to derive the weights for each factor. Next, consistency verification, which need to apply the weights to evaluate the alternatives. After that, 10 experts assessed the criteria layer (J) and sub-criteria layer (K) based on their professional judgment, using a nine-point scale for scoring. The weights were calculated by geometric mean method, where each column of the matrix was normalized, and were summed by row, and the results were further normalized to obtain the final weights [11].

The Semantic Differential (SD) method was employed to quantify the subjective attitudes and perceptions of users toward specific objects [12]. Based on the AHP evaluation structure, pairs of adjective factors were established, which is shown in Table 1 as well. A questionnaire was distributed to 120 older users, and the final scores for each CMF scheme were obtained by multiplying the weights derived from the AHP evaluation by the corresponding scheme layer scores. This combined approach ensured a comprehensive evaluation, integrating expert judgment with user perceptions to identify the most age-friendly CMF scheme for living room sofas.

4. Results

4.1 Results of Data Collection and CMF Prediction

In the Data Collection section, an overall 869 RGB data was extracted by K-means clustering and 16 MF were collected. Next, in the Trend and Scheme Development section where decision tree model was applied, resulted in top 10 color predictions, the distribution and RGB values are shown in Figure2.

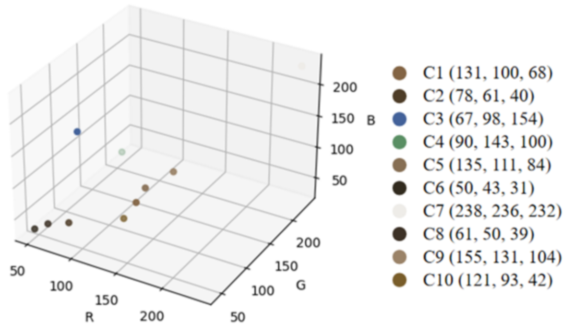

Figure 2. The 3D scatter plot of top 10 color predictions by decision tree model.

Among these 10 color predictions, orange hues account for 80%, with 60% of the colors from D5(mid S and mid V). Moreover, top 3 MF combinations were predicted through decision tree model as well: M2F1(glossy finish leather), M2F2(matte finish leather) and M3F5(linen).

4.2 Results of AHP-SD Evaluation

In the Evaluation section, experts were invited to establish criteria and sub-criteria for the best age-friendly living room sofa CMF schemes. The criteria were divided into 3 levels, with each criterion level further subdivided into 3 sub-criterion levels. The weights were calculated, and the results are shown in Table 2. The analysis revealed that the criterion J2. Age-friendliness was the most important, accounting for 55.5% of the total weight. This was followed by J3. Implementation at 33.7%, and J1. Visual Quality at 10.8%. Within the sub-criteria, K5. MF Friendliness was deemed more important than both K6. Cleaning and K4. C Friendliness. And K8. Cost was considered more important than K9. Sustainability and K7. Efficiency. This structured evaluation highlights the primary importance of age-friendliness in the design of living room sofas for older adults, with particular emphasis on the material and finishing aspects, followed by considerations of craft implementation and visual texture.

Table 2. AHP results of criterion and sub-criterion weights, calculated by geometric mean method.

Criterion Level	Criterion Weight(%)	Sub-criterion Level	Sub-criterion Weight(%)
J1.Visual Quality	10.8	K1.Color Durability	15.2
		K2.Texture Quality	44.6
		K3. Compatibility	40.2
J2.Age-Friendliness	55.5	K4.C Friendliness	14.5
		K5.MF Friendliness	52.8
		K6.Cleaning	32.7
J3.Implementation	33.7	K7.Efficiency	23.5
		K8.Cost	50.3
		K9.Sustainability	26.2

After determining the AHP weights, 120 older users were invited to rate the 30 CMF schemes using the SD method through questionnaire. By integrating the AHP weights and the scores, each CMF scheme were calculated, and the top 3 schemes were identified as C5M2F2, C9M2F2, and C10M2F2. In addition to identifying the best overall CMF schemes, the scoring data provided valuable insights. The best-performing RGB colors were C5 (135, 111, 84), C9 (155, 131, 104), and C10 (121, 93, 42). These colors, all from the orange hue family and of medium saturation and medium value, originated from indoor settings, products, and inspirational themes, respectively. Regarding materials and surface treatments, M2F2 (matte finish leather) scored highest in surface texture and cleaning capability, while M3F5 (linen) excelled in friendliness, process efficiency, implementation cost, and sustainability.

5. Discussion

The focus of CMF design is not about changing the shape but on achieving product renewal through changes in color, material, and finishing. By using a data-driven approach, CMF schemes can be efficiently selected and applied to various sofa designs and living room settings. An example of the application of C5M2F2 scheme is archived in the Figure3. This inherently makes CMF design a highly easy but systematic method for product updates. Compared to traditional design methods, a data-driven approach is more efficient due to the scientific and reliable data sources, typically derived from research, production, and trend. This method quickly provides recommended combinations of colors, materials, and finishing using objective data and allows for database updates in response to new trends or materials within standards and criteria.

Figure 3. Archive of C5M2F2 scheme and is applied in different living rooms settings and sofa shapes.

The innovative CMF design process, centered on data-driven methods, includes data collection, K-means clustering for color extraction, decision tree models for predicting color, material and finishing combinations, and AHP-SD scoring to derive the best-performing CMF schemes. Through this standardized process evaluation weights can be adjusted based on different users and scenarios. In this study, the main objective is to rapidly develop CMF schemes for age-friendly furniture. Therefore, from the beginning, the data sources were centered around "age-friendliness," with data being highly relevant to older users and age-friendly products. Additionally, when inviting experts to establish criteria and scores, the needs of older adults were fully considered from a professional perspective. Furthermore, older adults were also invited to participate in the simple scheme evaluation and selection process. Thus, this study is data-driven and age-friendly focused, considering "age-friendliness" from data sources, professional evaluation, and user perspectives. Consequently, compared to user-centered design methods, the data-driven CMF design method reduces subjectivity and mitigates the challenges faced by older adults in express their needs and preferences, as well as the designers' subjective preferences.

However, the use of data for rapid CMF design has potential issues, such as incomplete data extraction from images, discrepancies between extracted digital colors and real-world scenarios and data privacy. Future work could involve more comprehensive color databases from material suppliers, or the development of new CMF samples based on color trend models. Additionally, there is a need to continuously enrich the database with seniors' color preferences, trend colors, and new materials to achieve more accurate CMF predictions.

6. Conclusion

The data-driven CMF design allows for rapid and systematic innovation in furniture, focusing on color, material, and finishing, to provide users with fresh visual and tactile experiences. In order to select the best age-friendly CMF design schemes for living room sofas, this research proposes a standardized innovative process involving data collection, trend and scheme development, evaluation, and archiving. Within the process, K-means clustering, expert scoring method, decision tree model, and AHP-SD evaluation were applied. From data sources, professional evaluation to scheme selection, "age-friendliness" is fully considered throughout the process. Key findings revealed a preference for orange Hue, with colors in the D5 (mid Saturation, mid Value) being particularly popular. Thus, Designers are encouraged to consider these color characteristics in future designs. Although C5M2F2, C9M2F2, and C10M2F2 scored the highest in the AHP-SD evaluation, M3F5 (linen) also performed well in terms of friendliness, process efficiency, implementation cost, and sustainability, making it a recommended option for future use.

This innovative data-driven CMF design method, compared to user-centered design approaches, enables the scientific, efficient, and systematic updating of product CMF. It reduces designer subjectivity and mitigating the challenges of faced by older adults in expressing their needs. In the future, researchers, designers, and manufacturers can utilize this standardized design process to collaboratively update and sustainably use the CMF database.

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