

Article

A Multilevel Fuzzy AHP Model for Green Furniture Evaluation: Enhancing Resource Efficiency and Circular Design Through Lifecycle Integration

Wenxin Deng  and Mu Jiang * 

School of Art, Soochow University, Suzhou 215123, China; 20224005007@stu.suda.edu.cn

* Correspondence: jiangmu@suda.edu.cn

Abstract

This study addresses this gap by proposing a multilevel fuzzy evaluation model combined with an analytic hierarchy process (AHP) to quantify the greenness of furniture products across their entire lifecycle. Focusing on an office desk as a case study, we developed an indicator system encompassing environmental attributes, resource efficiency, energy consumption, economic costs, and quality performance. Weighting results revealed that environmental attributes (27.2%) and resource efficiency (27.2%) dominated the greenness evaluation, with material recycling rate (33.5%) and solid waste pollution (24.3%) as critical sub-indicators. The prototype achieved a moderate greenness score of 70.38/100, highlighting optimization potential in renewable material adoption (10% current rate) and modular design for disassembly. Mechanically recycled materials could reduce lifecycle emissions by 18–25% in key categories. The model demonstrates scalability for diverse furniture types and informs policy-making by prioritizing high-impact areas such as toxic material reduction and energy-efficient manufacturing, thus amplifying its global and interdisciplinary multiplier effects.

Keywords: green furniture; multilevel fuzzy comprehensive evaluation; lifecycle assessment; resource efficiency; circular economy



Received: 17 July 2025

Revised: 21 August 2025

Accepted: 22 August 2025

Published: 25 August 2025

Citation: Deng, W.; Jiang, M. A Multilevel Fuzzy AHP Model for Green Furniture Evaluation: Enhancing Resource Efficiency and Circular Design Through Lifecycle Integration. *Systems* **2025**, *13*, 734. <https://doi.org/10.3390/systems13090734>

Correction Statement: This article has been republished with a minor change. The change does not affect the scientific content of the article and further details are available within the backmatter of the website version of this article.

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Lifecycle design is a systems-based design approach that focuses on the protection of the environment and views the product as a lifecycle system, including the entire lifecycle from raw material collection to product manufacture and assembly, transportation and sales of products, consumer use, and end of life and disposal of the final product [1,2]. The goal of the design is to prevent pollution at the source by requiring that every step in the product's lifecycle, from the collection of raw materials to the final disposal and disposal, meet minimum environmental pollution and resource and energy use. As an industrial product, furniture inevitably causes environmental pollution during the production process. Furniture design requires products to minimize environmental pollution and to use lifecycle design thinking from the lifecycle of each stage to analyze and take into account the problem [3,4].

“Green Furniture” is one of the categories of “Green Products.” According to the definition of “green product” in the machinery industry, green product refers to green material, advanced green design and manufacturing methods, and green packaging production of energy-saving, pollution-free, environmental protection products [5,6]. The basic principles are the unity of science and practicality, completeness and operability, the unity of

qualitative and quantitative indicators, and ensuring that the product lifecycle or multiple lifecycles have the minimum impact on the lifecycles of the environment [7]. Unlike green products in the machinery industry, the concept of “green furniture” is often understood as the impact on human health during consumption, the pursuit of humanity during use, the environmentally friendly nature of structures, and the recyclability of products. However, while some products show good greenness in light of the above factors, they have a greater negative impact on the environment during the collection and processing of raw materials. Aluminum alloy furniture, for example, can be very green in terms of consumption and recycling, but it can cause substantial environmental pollution in the early stages of raw material production, and the materials are nonrenewable, so we cannot simply judge their greenness based on these factors [8].

Due to the characteristics of the furniture itself, it is necessary to consider its specific environmental characteristics and related environmental factors and to use appropriate evaluation methods to start evaluating its greenness [9]. Specifically, the environmental characteristics of furniture products throughout their lifecycle include the following: (1) Resource characteristics, including human resources (manual, mechanical, or automated production); equipment resources, that is, equipment utilization and advanced equipment utilization rate; and material resources, that is, related material utilization, recycling, toxic material utilization, and recycled material utilization. (2) Environmental characteristics, mainly dust, include small amounts of volatile organic compounds (VOCs) emitted from paint shops; water pollution, mainly from the initial evaporation of logs and their impact on water quality; water curtains released from paint lines after recycling; solid pollutants, wood debris, particulate matter, assembly workshops, paint, etc., from drilling; pollution from paint shop operations and metal slabs, saws, etc. It includes the product quality indicators: the product quality grade rate, product sale rate, product structure disassembly rate, product safety, product maintenance, and repair characteristics, and so on; the product function index mainly refers to the product function characteristics in use, form, taste, etc. (4) Energy characteristics of the product, that is, the type of energy used in the production of the product, the energy efficiency, the energy consumption rate in the product recycling process, etc. The investigation of product environmental characteristics is an important basis for the follow-up evaluation of the product lifecycle. In some cases, there is a lack of comparability of environmental impact factors across the lifecycle of furniture products. For example, while a furniture product may function well, it may not be ideal for material recycling, or the product may be very good in terms of the environmental characteristics of the material, but it may have a limited service life or functionality. Therefore, in the evaluation, according to the specific situation, different weight values are given by quantitative methods. For the factors that cannot be quantified by statistical methods, the weight distribution is carried out by the expert weight coefficient method. Finally, by comparison of importance, a comprehensive fuzzy evaluation is carried out to realize the greenness judgment.

Despite growing attention to green furniture, existing evaluation frameworks exhibit critical limitations: (1) fragmented lifecycle integration—most studies focus on isolated stages (e.g., material production or disposal), neglecting systemic interactions across the entire lifecycle; (2) over-reliance on static quantitative metrics—qualitative factors (e.g., user health impacts, structural recyclability) are often oversimplified, leading to biased greenness assessments; and (3) inadequate handling of uncertainties—traditional methods (e.g., AHP alone) struggle to reconcile conflicting criteria (e.g., economic viability vs. environmental costs). To address these gaps, this study proposes a multilevel fuzzy AHP model that synergizes lifecycle assessment with dynamic weighting mechanisms. In this paper, we adopt the method of “lifecycle evaluation” and “multilevel fuzzy evaluation” in the comprehensive evaluation of the greenness of furniture products and comprehensively categorize, summarize, count,

and evaluate various greenness indexes, which may make some features that are not easy to compare or only capable of being described qualitatively comparable [10,11]. This paper presents a comprehensive green evaluation of the furniture lifecycle using a multilevel fuzzy approach combined with the analytic hierarchy process (AHP) to determine index weights. This study establishes a green furniture evaluation index system by analyzing both domestic and international research on furniture lifecycles and green product evaluations. It highlights the importance of considering various environmental characteristics throughout the furniture's lifecycle, including resource utilization, environmental impact, energy efficiency, and product quality [12]. By employing a multilevel fuzzy comprehensive evaluation method, the research aims to provide a scientific and holistic assessment of furniture greenness, ultimately enriching the understanding of green furniture production and offering guidance for future green design practices. Against rising global green demands, this study innovatively integrates fuzzy AHP with full lifecycle assessment, offering a scalable tool to quantify furniture greenness and guide circular design globally.

2. Literature Review

2.1. Lifecycle Assessment

Lifecycle assessment is an analytical approach that focuses on the entire lifecycle of a product or service, through which resources and energy consumed by a product or service throughout its lifecycle can be effectively analyzed [13,14]. LCA not only quantifies the impact of a product or service on the current environment but also systematically evaluates and analyzes the environmental implications of a product or service throughout its lifecycle. The idea of lifecycle assessment has been widely used in sustainable design, product production, and management decisions. The International Society of Environmental Toxicology and Chemistry (ISETs) divides the technical framework for LCA into four interrelated parts: goal and scope definition, inventory analysis, impact assessment, and improvement assessment [15]. Jeswani Harish Kumar et al. (2010) expand the scope of the lifecycle assessment methodology by integrating different social, economic, and environmental concepts based on the current lifecycle assessment theory [16]. Carla Pieragostini et al. (2012) established a framework for LCA optimization techniques in the field of engineering based on the LCA inventory analysis method, based on the view of system boundaries, and used LCA software to implement optimization of the lifecycle evaluation of the construction process of engineering projects [17]. Kanghee Lee et al. (2009) [18] divided the lifecycle of construction projects into three stages, construction, operation, and demolition, based on a lifecycle assessment inventory analysis method and established an engineering lifecycle assessment optimization technical framework that optimizes the lifecycle assessment of the construction process using lifecycle assessment software. A new lifecycle evaluation method was presented by establishing an evaluation model in which energy consumption and greenhouse gas emissions are important evaluation indicators. Shih et al. (2014) [19] compared the impact of several basic data collection methods on evaluation results. The opinion makes it clear that data collection methods and evaluation findings echo each other and cannot be treated in isolation. Gian Andrea Blengini et al. (2010) analyzed and compared the results of inventory analysis for several types of buildings. Because of the important impact of each subsystem on the results of the lifecycle evaluation, it is recommended that they be considered at each stage of the lifecycle [20]. Francesco Di Maria et al. (2013) [21] used targeted designed experiments to collect first-hand data for LCA studies. Because data collection has been a difficult issue in LCA research, this will be a new direction for LCA research. Especially for those products in the development stage or processes that are not yet perfect, this approach is more meaningful. Therefore, lifecycle evaluation is an important product evaluation

method, and its application prospects and social value will expand and improve with the development and improvement of technology and methods.

2.2. Green Furniture

Green furniture refers to the design, manufacture, and use of environmentally friendly furniture [22]. The concept of green furniture comes from the concept of sustainable development, emphasizing the balance and harmony between people and the natural environment. Against the background of the current shortage of resources and environmental pollution, the development of green furniture has attracted increasing attention. By promoting green furniture, the impact on the environment can be reduced, the sustainability of products and production processes can be improved, and the furniture industry can be promoted in a greener and more sustainable direction [23]. The concept of green furniture appeared from the 1980s to the present, although not for a long time, but it has been widely valued and developed relatively quickly [7]. From the initial pursuit of a single green material to the formation of a concept system, from a single concept to the development of a multisystem. Jegatheswaran Ratnasingam, through a questionnaire survey of wooden furniture manufacturers in Malaysia, found that the adoption of green production practices in the Malaysian wooden furniture industry is limited, mainly due to the lack of a premium for green furniture products and the high cost of adopting such practices. It was also suggested that most green production practices are now associated with the use of environmentally friendly materials [24]. Peng Wei et al. (2022) [25] focused on the use of environmentally friendly materials in the design of children's green furniture and combined fuzzy techniques with structured design techniques to establish a green furniture design system for children based on fuzzy techniques. The article also introduced two intelligent systems for children's furniture design, analyzed the structure of children's furniture through structured design, and produced an interactive system with user experience. The research results show that the children's furniture design system based on fuzzy technology has a good user experience and can play an important role in the application of environmentally friendly materials in children's green furniture design. Shengbo Ge et al. (2023) [26] proposed addressing the problem of untreated plastics causing significant damage to our world's ecosystems. Acrylonitrile–butadiene–styrene (ABS)/poplar composites with excellent properties were prepared by a novel one-step method. Ultimately, the great promise of synthetic wood–plastic composites to replace commercial plastics was experimentally demonstrated, with potentially extensive uses in furniture and construction. In short, green furniture research involves materials, production, EIA, and other fields and aspects. Green furniture is a new type of furniture that adapts to the changing needs of the times and people. Green furniture is not only good for environmental protection and resource conservation but also good for human health and social progress. Research on green furniture is comprehensive, interdisciplinary, and cross-cutting work that requires cooperation and support from all parties [27,28].

2.3. Multilevel Fuzzy Comprehensive Evaluation Method

The fuzzy comprehensive evaluation method is a kind of comprehensive evaluation method based on fuzzy mathematics that was founded in 1965 by American mathematics expert Eden. Based on the theory of affiliation in fuzzy mathematics, the qualitative evaluation of multifactor objects is transformed into a quantitative evaluation, and a comprehensive evaluation method is obtained. It has the characteristics of clear results, intuitiveness and an evaluation system, which can solve some uncertain and difficult-to-quantify fuzzy problems. Zuo Renguang et al. (2009) [29] applied these two combined methods to map porphyry copper prospects and porphyry copper prospects in the Gangdese region of

western China by combining multilevel fuzzy integrated evaluation with asymmetric fuzzy relationship analysis in the Tibetan region. The application of such methods can be used to guide the exploration of undiscovered research areas. Wang et al. (2022) [30] applied fuzzy comprehensive evaluation to the evaluation of mechanical product solution design. Several design solutions were evaluated in the schematic design phase of mechanical products to select the best design solution from them. The study combined the subjectivity of the hierarchical analysis method to determine the weights and the objectivity of the entropy method to determine the weights to calculate the weights of the evaluation indexes and established a combined assignment method to improve the reliability of the evaluation method. Finally, the best solution is selected by calculating the comprehensive evaluation value of each product design solution. A new method is provided for the evaluation and selection of other product design solutions. Pei He et al. (2022) [31] proposed a multilevel fuzzy evaluation model based on a multilevel fuzzy evaluation model for the reliability evaluation of integrated energy systems with comprehensive authorization. The fuzzy evaluation matrix is constructed from the membership degree of a single factor. The fuzzy evaluation matrix is constructed, which consists of single factors defined by the fuzzy integrated evaluation method, and the multilevel fuzzy evaluation results are obtained based on the single-level evaluation results. Five first-level indicators and twelve second-level indicators are proposed in the case study. Finally, the validity and advantages of the proposed model are analyzed, and this approach can be extended to other fields, such as the green evaluation of furniture. Overall, these papers demonstrate the usefulness of multilevel fuzzy comprehensive evaluation in various fields, such as sustainable development, regional innovation, environmental risk assessment, e-commerce performance evaluation, and power grid security assessment. The method can take into account multiple criteria and their interrelationships at different levels of the evaluation hierarchy, which makes it a powerful tool for decision-making [32,33].

3. Material

As a green product, the effect of green furniture meets the expected “green” requirements and environmental objectives, that is, from raw materials, production, sale (including packaging and transportation), use to disposal, and environmental and performance evaluation analysis of the entire lifecycle [34,35]. The evaluation of green furniture is a complex task involving multidisciplinary content and a great deal of process data. The greenness of furniture products often contains several aspects, such as environmental characteristics, resource characteristics, basic characteristics of the product itself, and energy characteristics of the product. Each has several evaluation elements. For example, the evaluation aspect of the basic characteristics of the product includes quality and functional indicators. Each evaluation factor has different evaluation factors, such as the quality factor, divided into the quality evaluation rate, safety, product sales rate, maintenance, structure disassembly, and other specific evaluation factors.

3.1. Principles of Evaluation

To achieve correct and objective scientific norms, operability, and a wide range of purposes, the following basic principles need to be followed in the process of establishing a green furniture evaluation system [36,37]:

(1) Comprehensive principles. The evaluation index system should start from technical, economic, and ecological aspects; reflect the comprehensive situation of the “green” degree of furniture products; use multidisciplinary, interdisciplinary comprehensive knowledge; and ensure the comprehensiveness and credibility of the comprehensive evaluation.

(2) Scientific principles. The evaluation index system should strive to objectively, truthfully, and accurately reflect the “green” attributes of the appraised furniture products. Some indicators may not yet have the necessary data but could be suggested as indicators as the larger relationship is evaluated.

(3) Systematic principle. The evaluation index system should have various indexes reflecting product resource attributes, energy attributes, environment attributes, quality attributes, and economic attributes, and master the main influencing factors; the evaluation index system should also have coordinated indexes reflecting these attributes.

(4) Combination of movement and movement. Furniture product indicators also need to keep changing according to market and user demand, along with the development of industry technology and society, not only to consider the existing situation but also to leave enough room for future development.

(5) The principle of quantitative and qualitative combination. The evaluation index system should be quantified as much as possible, and some indicators (such as environmental policy indicators, material characteristics indicators, etc.) can also be described using qualitative indicators when quantification is more difficult, so that scientific evaluation can be carried out from qualitative and quantitative perspectives.

(6) Practical and operability principles. Evaluation indicators should have a clear meaning and a realistic statistical basis to do so within one’s means. At the same time, under the premise of satisfying validity, the number of indicators should be appropriate, the content should be concise, and the evaluation operation should be as simple and easy to use as possible.

(7) The principle of independence and compatibility. The evaluation index of green furniture products has a wide range and should be concise, generalizable, and representative to avoid the repetition of variables with similar meanings.

(8) The focus and hierarchy principle of emphasizing and grading management. The evaluation index system of furniture products provides the basis for designers and management departments to develop design decisions, product inspection, and supervision; it also provides the basis for consumers’ consumer choice, and different indicators should be used for different levels of use. For example, in management, the overall indicators of the product need to be provided to meet this level of indicators and should focus on its integrity and comprehensiveness, while the designer needs to meet a certain level of specific requirements or functions when selecting, and the indicators should be more detailed, clear, and specific.

3.2. Element of Green Furniture Evaluation

According to the basic principle of establishing a green furniture evaluation index system and the requirement of green furniture product characteristics, under the guidance of the ISO14000 international environmental standards system, the framework of green furniture evaluation elements is shown in the figure below [38] (Figure 1).

(1) Environmental attributes refers to characteristics of furniture products that, in their entire lifecycle, do not damage the ecological environment, do not pollute the ecological environment or residential environment or cause pollution to minimize performance.

(2) Resource attributes refer to the property of whether furniture products economize on the use of all kinds of resources involved in the design and production process. By changing the unlimited exploitation and utilization, and extensive management methods, the maximum resource utilization rate of the products can be achieved.

(3) Energy attributes: the highest energy utilization rate; use of renewable and green energy sources.

(4) Economic attributes: production of green furniture products over the lifecycle at the lowest consumer cost.

(5) Quality attributes refer to the quality characteristic inherent in the furniture product and the degree to which it meets the requirements of use.

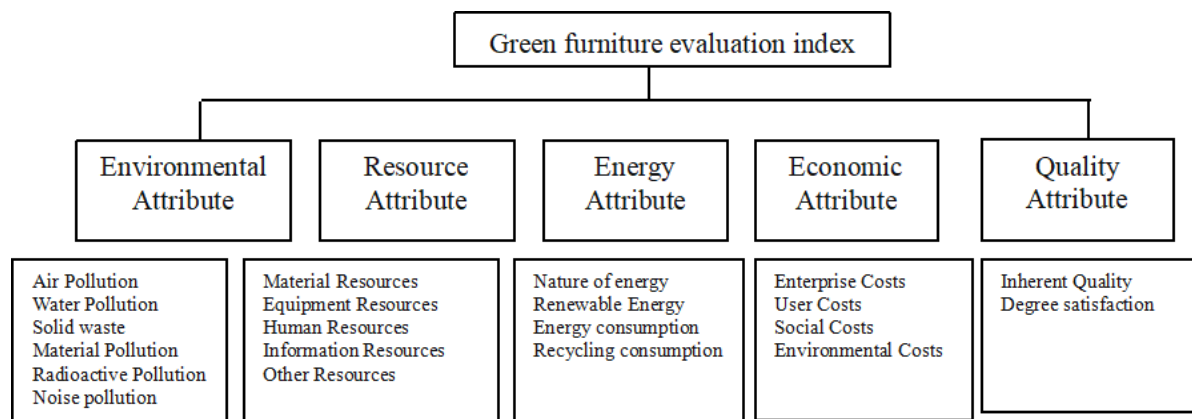


Figure 1. Composition framework of the green furniture evaluation system.

3.3. Content of Green Furniture Evaluation

(1) Environmental attribute indicators

It mainly refers to the entire lifecycle of furniture products caused by related environmental problems, divided into two levels of ecological damage and environmental pollution, reflecting one of the important characteristics of green furniture compared to other ordinary furniture.

(2) Resource attribute indicators

In the evaluation system, resources are broadly defined as the lifecycle of furniture products, and the various resources involved are the most basic conditions for the production of green furniture products, especially material resource indicators.

(3) Energy property indicators

Energy conservation and efficient utilization are other important characteristics of green furniture products. High energy utilization means less environmental pollution.

(4) Indicators of economic attributes

The green furniture economy is oriented toward the full lifecycle of the product, which is markedly different from the economic (cost) evaluation of traditional furniture products. In addition to the cost of production for the enterprise, consideration should be given to the following:

- ① Social costs due to resource destruction and environmental pollution caused by industrial production and economic activities;
- ② Additional medical costs due to toxic, harmful production processes or release of substances harmful to human health;
- ③ The lifecycle of the product for dismantling, recycling, and disposal costs. That is, we must consider the impact of various costs related to resources and the environment on the overall economy of the product [39].

(5) Quality attribute indicators

Products (including finished products, semi-finished products, and in-process products) are suitable for certain uses, meet various user needs, have different characteristics, and have the use value of products.

3.4. Criteria for the Evaluation of Green Furniture

Green furniture needs to be evaluated by general principles conducive to the environment. For example, the use of the product has the least impact on the environment; the use of the product can greatly improve the environment; and the treatment of the product

after use has the minimum impact on the environment. In addition, it includes additional criteria such as adequate pollution control measures at the production stage of the product, ease of handling of the product, low energy consumption of the product, compliance with quality and safety standards, and price of the product and similar products [40,41].

The establishment of evaluation criteria is an important part of the evaluation of green furniture. Due to the short time since the rise of green furniture and the variety of furniture products, all kinds of environmental problems have occurred. In addition, the current research on green furniture is not deep enough, and there are no specific, systematic green furniture evaluation criteria. There are many green product evaluation criteria, most of which do not have scientific, comprehensive evaluation criteria.

Green furniture evaluation criteria are based on existing environmental standards, product industry standards, and some local regulations, which are absolute standards, on the one hand, and existing products and related technologies, which identify reference products and evaluate the extent of green products through newly developed products and reference products, which are relative standards, on the other hand, according to market development and user demand [42].

The development of relevant standards requires the introduction of the concept of reference products. Reference products are generally divided into functional reference, i.e., existing equivalent products on the market, and technical reference, i.e., a collection of products representing the technical content of new products. In the evaluation of green furniture, the product can be used as a reference to formulate evaluation criteria [43].

4. Methods

4.1. Green Furniture Evaluation Methodology

The evaluation method is the core of the evaluation system. The evaluation method must be correct, simple, and operable. The evaluation of green furniture is a very complicated process involving multiple factors and objectives. The evaluation indicators, whether qualitative or quantitative, must adopt the comprehensive evaluation method. At present, the commonly used evaluation methods are economic analysis, expert consultation method, weighted average method, cost-efficiency method, value analysis method (functional cost analysis method), fuzzy evaluation method, and analytic hierarchy process (AHP). According to the characteristics of green furniture, the fuzzy analytic hierarchy process is more suitable. This multilevel fuzzy AHP model addresses limitations of single AHP and pure fuzzy methods, making it uniquely suited to quantify green furniture attributes across complex lifecycles.

On the one hand, the green attributes of furniture products have an obvious hierarchy; the green attribute indexes have both quantitative and qualitative components, and it is difficult to accurately describe the qualitative factors of green furniture by the analytic hierarchy process alone. In the fuzzy evaluation method, the concepts of affiliation function and affiliation degree are aimed at the qualitative factors, and the qualitative or uncertainty factors are described in precise mathematical language, which solves the problem of the uniformity of the quantitative outline of each index [44]. In general, each evaluation indicator should have a corresponding affiliation function. Green furniture, on the other hand, is green throughout the lifecycle of a product, not a process or phase, and evaluation methods must be able to reflect this.

The fuzzy hierarchy evaluation method based on the lifecycle of green furniture is based on the analysis of furniture products, considering the green properties of furniture products throughout the lifecycle and applying the analytic hierarchy judgment method to the products and the green properties, and the recursive hierarchy structure model of the appraised objects is established [45,46].

The process of fuzzy grading evaluation of green furniture generally includes [47] (1) establishing an evaluation hierarchy model; (2) determining relative importance; (3) calculating overall importance; (4) determining affiliation; (5) performing comprehensive evaluation calculation; and (6) comparing the comprehensive evaluation results of the products to be evaluated with the reference products, i.e., determining whether the furniture products to be evaluated meet the requirements of green furniture.

4.2. Multilevel Fuzzy Comprehensive Evaluation Theory and Methods

Through previous research, it is appropriate to choose fuzzy comprehensive evaluation methods. The basic idea is to conduct a comprehensive evaluation of the elements at the lowest level and then a step-by-step evaluation up to the highest level to arrive at the final evaluation results [30]. In other words, the fuzzy comprehensive evaluation method is a progressive evaluation method starting from the end. When using the fuzzy comprehensive evaluation method, we should first determine the evaluation index model, then determine each evaluation factor, index weight, and rubric affiliation degree according to relevant theory and data and finally combine the evaluation criteria to give the corresponding affiliation degree value through fuzzy transformation. Finish the fuzzy evaluation [48]. The specific methods are as follows: set up the evaluation index model and determine the weight of each evaluation indicator. After the evaluation index system is set up, the index hierarchy weight coefficients of each element in each layer are determined according to the order of the target layer, standard layer, and indicator layer, and the specific operation flow is as follows [49].

4.2.1. Establishment of Various Types of Indicator Sets in Evaluations

(1) Identification of each evaluation aspect, element, and element set U

Factor sets are a combination of factors affecting the subject of evaluation, as follows [50]:

$$U = \{U_1, U_2, \dots, U_i, \dots, U_m\} \text{ (set of evaluation aspects)} \quad (1)$$

$$U_i = \{\mu_1, \mu_2, \dots, \mu_j, \dots, \mu_N\} \text{ (set of elements of evaluation aspect } U_i) \quad (2)$$

$$U_{ij} = \{\mu_1, \mu_2, \dots, \mu_k, \dots, \mu_P\} \text{ (set of elements of evaluation aspect } U_{ij}, \text{ i.e., the } j\text{th rank of the } i\text{-th factor)} \quad (3)$$

(2) Establish the evaluation set V

The evaluation set may have N results; then, the evaluation set composed of them is

$$V = \{v_1, v_2, \dots, v_n\} \quad (4)$$

as follows: v_i ($i = 1, \dots, N$) are excellent, good, average, poor, and terrible.

(3) Establish the fuzzy matrix R_{IJ}

The fuzzy matrix R_{IJ} of the I th aspect, the J th element, is as follows:

$$B_{IJ} = \begin{pmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \dots & \dots & \dots & \dots \\ r_{p1} & r_{p2} & \dots & r_{pn} \end{pmatrix}_{IJ} \quad (5)$$

In Equation (5), each row of R_{IJ} , $(R_i)_{IJ} = (r_{i1} \ r_{i2} \ \dots \ r_{in})_{IJ}$, is the evaluation result of the i th factor, and r_{ij} is the affiliation degree of the i th evaluation factor to the j th evaluation level, which reflects the fuzzy relationship between each evaluation factor and the evaluation level expressed by the affiliation degree [51].

(4) Establish the weight coefficient matrix A

The weight coefficient is the affiliation degree coefficient of the lower evaluation index to the upper evaluation index, and it is a fuzzy subset of the factor set. It includes three coefficients of evaluation aspect weights, evaluation factors, and evaluation factors [52].

Weighting coefficients of evaluation aspects

$$A = \{\alpha_1 \alpha_2 \dots \alpha_i \dots \alpha_M\}, \text{ and satisfy. } 0 < \alpha_i \leq 1, \sum_{i=1}^n \alpha_i = 1 \quad (6)$$

Evaluation element weight coefficients

$$A = \{\alpha_1 \alpha_2 \dots \alpha_j \dots \alpha_N\}I \text{ and satisfies } 0 < \alpha_{jI} \leq 1, \sum_{j=1}^n \alpha_{jI} = 1 \quad (7)$$

Evaluation factor weight coefficients

$$A_{IJ} = \{\alpha_1 \alpha_2 \dots \alpha_k \dots \alpha_P\}IJ \text{ and satisfies. } 0 < \alpha_{kIJ} \leq 1, \sum_{k=1}^n \alpha_{kIJ} = 1 \quad (8)$$

(5) Determine the affiliation of the evaluation object to the factor level. Single-factor comprehensive evaluation matrix B_{IJ}

The I th aspect, the J th factor's comprehensive evaluation, is calculated by the formula

$$B_{IJ} = A_{11}R_{11} = \begin{bmatrix} a_1 & a_2 & \dots & a_p \end{bmatrix}_{IJ} \begin{pmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \dots & \dots & \dots & \dots \\ r_{p1} & r_{p2} & \dots & r_{pn} \end{pmatrix}_{IJ} = \begin{bmatrix} b_1 & b_2 & \dots & b_j & \dots & b_n \end{bmatrix}_{IJ} \quad (9)$$

In Equation (9): $b_{iIJ} = \sum_{i=1}^p a_{iIJ} R_{ijIJ}, (i = 1, 2, \dots, n)$

4.2.2. Multilevel Comprehensive Fuzzy Evaluation

A multilevel fuzzy comprehensive evaluation is judged from low-level to high-level layer by layer. First, each factor of low level is evaluated comprehensively; then, each factor of high level is evaluated, and so on. Finally, the highest level is evaluated [53]. The fuzzy evaluation results of each single factor B_{IJ} ($J = 1, 2, \dots, N$) are combined to form the evaluation matrix R_I of the higher level, and the same method is used to combine R_I with the weight coefficient matrix A_I to find the comprehensive evaluation result B_I ($I = 1, 2, \dots, M$) of the I th factor, and the matrix R of the higher level is formed by B_I . Finally, the comprehensive evaluation matrix B is found, and the result of matrix B is the final result of the comprehensive evaluation. The specific calculation formula:

$$B = AR = \begin{bmatrix} \alpha_1 & \alpha_2 & \dots & \alpha_M \end{bmatrix} \begin{bmatrix} A_1 R_1 \\ \dots \\ A_I R_I \\ \dots \\ A_M R_M \end{bmatrix} = \begin{bmatrix} b_1 & b_2 & \dots & b_k & \dots & b_n \end{bmatrix} \quad (10)$$

The results of the comprehensive evaluation can be expressed as a total score value. The method is to take the set of evaluation criteria affiliation $\mu = \{\mu_1 \mu_2 \dots \mu_k \dots \mu_n\}$ and apply Equation (12) to calculate the specific score S of the comprehensive evaluation.

$$S = 100B\mu = \left(\sum_{k=1}^n b_k \mu_k \right) \times 100 \quad (11)$$

4.3. Constructing a Comprehensive FAHP Evaluation Model for Green Furniture

4.3.1. Green Furniture Evaluation FAHP Hierarchy Model

The model divides the criteria affecting the goal of “degree of green furniture” into five aspects: “environmental attributes”, “resource attributes”, “energy attributes”, “economic attributes”, and “quality attributes”. The model divides the criteria affecting the goal of “green furniture degree” into five aspects: “environmental attributes”, “resource attributes”, “energy attributes”, “economic attributes”, and “quality attributes”. Then, the connotation of green furniture requirements is used to determine the set of indicators under each criterion, in which the “environmental attributes” criterion contains indicators “air pollution”, “water pollution”, “solid waste pollution”, “microorganisms pollution”, and “noise pollution”; “resource attributes” includes “material resources”, “equipment resources”, “human resources”, “information resources”, and “Other Resources”; “Energy Attributes” includes “Energy Type”, “Renewable Energy”, “Energy Consumption”, and “Energy Recovery and Disposal”; “Economic Attributes” includes “Business Costs”, “User Costs”, “Energy Consumption”, and “Energy Recovery and Disposal”; “Economic Attributes” includes “Business Costs”, “User Costs”, “Social Costs”, and “Environmental Costs”; and “Quality Attributes” include “inherent quality characteristics” and “degree of satisfaction of requirements”. The hierarchical framework of the final markup is shown in Figure 2.

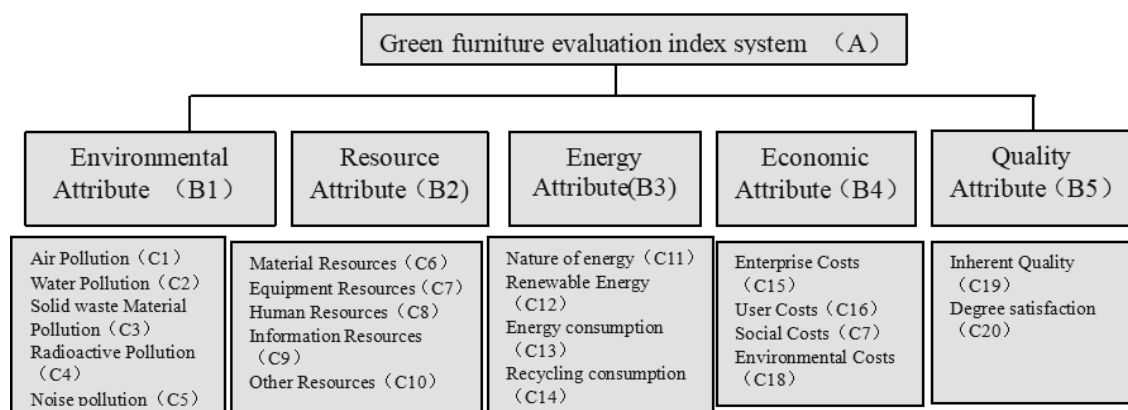


Figure 2. Green furniture evaluation FAHP hierarchy framework.

4.3.2. Fuzzy Judgment Matrix and Weights of the Criterion Layer

The two-by-two judgment results of the importance of the criterion layer relative to the total objective layer are shown in Table 1.

Table 1. Fuzzy judgment matrix of target layer A-B.

A	B1	B2	B3	B4	B5
B1	0.5	0.5	0.7	0.9	0.5
B2	0.5	0.5	0.7	0.9	0.7
B3	0.3	0.3	0.5	0.7	0.1
B4	0.1	0.1	0.3	0.5	0.3
B5	0.5	0.3	0.9	0.7	0.5

According to the previous formula, the weight of each criterion B relative to the target layer A can be calculated to obtain the weight vector: $W_{A-B} = (0.2721, 0.2721, 0.1902, 0.0959, 0.1697)$.

4.3.3. Fuzzy Judgment Matrix and Weights of the Indicator Layer

(1) The results of a two-by-two judgment of the importance of the indicator layer about the criterion of “environmental attributes” are shown in Table 2.

Table 2. Fuzzy judgment matrix of environmental attribute criteria B1-C.

B1	C1	C2	C3	C4	C5
C1	0.5	0.9	0.7	0.6	0.5
C2	0.1	0.5	0.3	0.2	0.9
C3	0.3	0.7	0.5	0.4	0.7
C4	0.4	0.8	0.6	0.5	0.8
C5	0.5	0.1	0.3	0.2	0.5

According to the previous formula, the consistency test is passed, the weights of the indicators under the “environmental attributes” criterion layer can be calculated, and the weight vector is obtained as follows: $WB1-C = (0.3112, 0.1012, 0.2014, 0.2431, 0.1431)$.

(2) The results of the two-by-two judgment of the importance of the indicator layer relative to the criterion of “resource attributes” are shown in Table 3.

Table 3. Fuzzy judgment matrix for resource attribute criteria B2-C.

B2	C6	C7	C8	C9	C10
C6	0.5	0.9	0.7	0.6	0.5
C7	0.1	0.5	0.3	0.2	0.9
C8	0.3	0.7	0.5	0.4	0.7
C9	0.4	0.8	0.6	0.5	0.8
C10	0.5	0.1	0.3	0.2	0.5

According to the previous formula, the consistency test is passed, the weights of the indicators under the “Resource Attributes” guideline layer can be calculated, and the weight vector is obtained: $WB1-C = (0.3353, 0.1362, 0.2012, 0.1235, 0.2038)$.

(3) The results of the two-way judgment of the importance of the indicator layer about the criterion of “energy attributes” are shown in Table 4.

Table 4. Fuzzy judgment matrix of energy attribute criteria B3-C.

B3	C11	C12	C13	C14
C11	0.5	0.8	0.6	0.7
C12	0.2	0.5	0.3	0.4
C13	0.4	0.7	0.5	0.6
C14	0.3	0.6	0.4	0.5

According to the previous formula, the consistency test is passed, and the weights of the indicators under the “Resource Attributes” criterion layer can be calculated, obtaining the weight vector $WB3-C = (0.3291, 0.1709, 0.2765, 0.2236)$.

(4) The results of the two-way judgment of the importance of the indicator layer about the “economic attributes” criterion are shown in Table 5.

Table 5. Fuzzy judgment matrix of economic attribute criteria B4-C.

B4	C15	C16	C17	C18
C15	0.5	0.9	0.7	0.6
C16	0.1	0.5	0.3	0.2
C17	0.3	0.7	0.5	0.4
C18	0.4	0.8	0.6	0.5

According to the previous formula, the consistency test is passed, from which the weights of the indicators under the “economic attributes” criterion layer can be calculated, obtaining the weight vector $WB4-C = (0.3453, 0.1275, 0.2364, 0.2908)$.

(5) The results of the two-by-two judgment of the importance of the indicator layer relative to the “quality attribute” criterion are shown in Table 6.

Table 6. Fuzzy judgment matrix of quality attribute criteria B5-C.

B5	C19	C20
C19	0.5	0.7
C20	0.3	0.5

According to the previous formula, the consistency test is passed, and the weights of the indicators under the “quality attributes” criterion layer can be calculated, and the weight vector WB5-C = (0.6042, 0.3958).

According to the importance level of each sub-indicator, all sub-indicators can be categorized into five levels of importance, i.e., as Table 7 shows. Of course, all of the above are evaluation indicators of the degree of green furniture, only their respective degrees of importance are different, in the process of green furniture design, we should focus on the above indicators of greater importance, while reasonably taking into account the importance of lesser indicators, to promote the comprehensive green degree of green furniture (Table 7).

Table 7. Importance level of each sub-indicator.

Level of Importance	Corresponding Indicator
The first level of importance	C1, C6, C11, C15, C19, C20
The second level of importance	C4, C17, C18, C13
The third level of importance	C3, C8, C10, C14
The fourth level of importance	C5, C7, C12
The fifth level of importance	C2, C9, C16

The FAHP green furniture comprehensive evaluation model established in this paper contains two parts: one is to construct a systematic FAHP hierarchical model, determine the content of specific evaluation indicators, and evaluate and calculate the weights of each criterion and indicator, which is also a part of the model, and is the basis for the assessment of the actual program; the other is to calculate each sub-indicator of the bottom layer based on the weights of each layer, to calculate the degree of importance to the total goal, and thus to derive the primary and secondary of each indicator in the indicator system of the degree of green furniture, and to classify the indicators into five grades according to importance, as a theoretical reference for green furniture design.

5. Result and Discussion

5.1. Valuation of Each Evaluation Index

The evaluation model constructed with different weight ratios for each indicator, due to its different importance levels in the evaluation model, can be assigned according to the importance of each indicator to the evaluation target [54]. In this study, an office desk designed by the author’s team was selected as the evaluation prototype. The solution uses wood–plastic composite plywood (comprising 60% recycled polypropylene and 40% wood fibers) and metal materials in terms of materials; modular disassembly and assembly in terms of structure, increasing the connection of the structure can facilitate disassembly and assembly; in terms of function to meet the requirements of home and office systems, the material, color, and shape have a strong sense of modernity and aesthetics, and enhance the storage function of the desk. The prototype desk incorporated design-for-disassembly principles, utilizing three primary joint typologies: quick-release fasteners for major structural connections, threaded inserts for panel attachments, and slot-and-tab connectors for non-structural components.

These joints were selected to ensure high reliability across multiple disassembly cycles, with quick-release fasteners and threaded inserts demonstrating robust performance and minimal wear in qualitative testing, thereby supporting the product’s circularity goals.

The determination of the AHP weights was conducted by a panel of 15 experts, each bringing diverse expertise in sustainable design, furniture manufacturing, and environmental engineering. The selection criteria for these experts included a minimum of five years of experience in green product evaluation or furniture lifecycle analysis, as well as holding senior positions in academia—such as professors in industrial design—or industry, such as chief sustainability officers in furniture enterprises. To ensure a comprehensive perspective, the panel included 60% of experts from China, reflecting the industrial context of the case study, and 40% from Europe and North America, thereby enhancing the global applicability of the findings. The composition of the panel consisted of eight academic researchers specializing in lifecycle assessment (LCA) and circular economy, five industry practitioners from leading furniture manufacturers, and two policy advisors involved in green product certification standards. Their collective insights were synthesized through three rounds of Delphi surveys, aimed at minimizing individual bias and reaching a consensus on the weight assignments.

In this study, expert users and furniture designers from different backgrounds were recruited to score the four evaluation factors of the office desk (Figure 2) to ensure the comprehensiveness and objectivity of the weight value determination process [55]. The evaluation of the greenness of furniture products can be achieved by statistically deriving the total scores of each factor from the experts and by deriving the weight coefficients of each indicator factor in the standard layer through the ratio of the total scores obtained to the total scores of all factors, respectively, and the results are shown in Table 8.

Table 8. A multilevel fuzzy comprehensive evaluation of furniture product greenness.

		Evaluation Elements			Evaluation Factors			Evaluation Level V					
No. ui	Level of importance	No.j	Uji	Level aji	No.k	ukij	Level akij	V ₁	V ₂	V ₃	V ₄	V ₅	
								Fuzzy matrix					
								None	Few	Some	Many	Numerous	
1	Environmental Attribute Index	0.20	1	Atmospheric pollutants	0.10	1 2	Exhaust gas Particulate matter	0.25 0.75	0.10 0.10	0.30 0.20	0.40 0.40	0.20 0.20	0.00 0.10
			2	Water pollutants	0.35	1 2	Water toxicity Water quality	0.65 0.35	0.20 0.20	0.20 0.20	0.40 0.25	0.10 0.35	0.10 0.00
			3	Solid waste pollutants	0.35	1 2	Organic pollutants Inorganic pollutants	0.60 0.40	0.15 0.20	0.25 0.30	0.30 0.30	0.20 0.20	0.10 0.00
			4	Noise pollutants	0.20	1	Production noise	1.00	0.20	0.20	0.30	0.20	0.10
2	μ Basic Attribute Indicators	0.40	1	Quality indicators	0.55	1	Quality grade rate	0.25	0.30	0.40	0.20	0.10	0.00
						2	Structure disassembly	0.25	0.05	0.15	0.45	0.25	0.10
			3	Product sales rate	0.10	0.20	0.30	0.35	0.15	0.00			
					4	Safety and health	0.15	0.10	0.30	0.35	0.15	0.10	
			5	Maintenance and repairability	0.25	0.15	0.20	0.30	0.20	0.15			
					2	Functional indicators	0.45	1 2 3	Function of use Form function Taste function	0.50 0.30 0.20	0.30 0.25 0.25	0.35 0.35 0.40	0.20 0.25 0.25
3	Resource Attributes Indicators	0.30	1	Human resources	0.15	1	The proportion of professional staff	0.60	0.35	0.40	0.20	0.05	0.00
						2	Green knowledge penetration rate	0.40	0.10	0.25	0.35	0.20	0.10
			2	Equipment resources	0.25	1	The utilization rate of equipment resources	0.65	0.20	0.35	0.35	0.10	0.00
						2	The utilization rate of advanced equipment	0.35	0.10	0.30	0.40	0.20	0.00
			3	Material resources	0.60	1	Material utilization rate	0.40	0.20	0.35	0.35	0.10	0.00
						2	Material recycling rate	0.30	0.10	0.30	0.45	0.15	0.00
						3	Toxic material ratio	0.20	0.05	0.15	0.40	0.30	0.10
						4	Renewable material ratio	0.10	0.10	0.20	0.30	0.25	0.15

Table 8. Cont.

			Evaluation Elements			Evaluation Factors			Evaluation Level V				
4	Energy Attribute Indicators	0.10	1	Energy utilization	0.10	1	Energy type	0.40	Excellent	Good	Average	Poor	Terrible
						2	Energy utilization	0.60	0.20	0.30	0.30	0.20	0.20

5.2. Discussion of Results

According to the above table, the greenness of the evaluation desk is calculated comprehensively. The fuzzy matrix (evaluation level data) is obtained by the professional test method combined with the expert survey method, and the data of “material utilization rate” in the “resource element” of the material are expressed by the degree of affiliation. For example, in the case of man-made panels, the material utilization rate can be calculated according to the opening scheme. In the case of solid wood, the data are obtained by combining the existing specifications of the enterprise, the actual dimensions of the product parts, and the expert evaluation data. When applying the expert weighting coefficient method, the weighting information of “functional elements” should be examined for specific product categories because the importance of “function” varies for different categories of products [56]. For example, the “use function” of the chair is the most important, accounting for a larger weight, while if it is a decorative cabinet, the “taste function” is relatively important.

(1) First, establish the evaluation elements, such as functional indicators of the set of elements U_{22} .

$$U_{22} = \{\text{use function } (\mu_1) \text{ form function } (\mu_2) \text{ grade function } (\mu_3)\}_{22} \quad (12)$$

(2) Then, establish the fuzzy evaluation matrix R_{22} of the “functional index” evaluation elements.

$$R_{22} = \begin{bmatrix} 0.30 & 0.35 & 0.20 & 0.15 & 0.00 \\ 0.25 & 0.35 & 0.25 & 0.15 & 0.00 \\ 0.25 & 0.40 & 0.25 & 0.10 & 0.00 \end{bmatrix} \quad (13)$$

The fuzzy matrix of the functional evaluation element is R_{22} , and the weight coefficient matrix is A_{22} . Then, the comprehensive evaluation matrix of this element is B_{22} .

$$B_{22} = A_{22}R_{22} = \begin{bmatrix} 0.50 & 0.30 & 0.20 \end{bmatrix}_{22} \begin{bmatrix} 0.30 & 0.35 & 0.20 & 0.15 & 0.00 \\ 0.25 & 0.35 & 0.25 & 0.15 & 0.00 \\ 0.25 & 0.40 & 0.25 & 0.10 & 0.00 \end{bmatrix} = \begin{bmatrix} 0.28 & 0.36 & 0.22 & 0.14 & 0.00 \end{bmatrix} \quad (14)$$

The same method can be used to obtain the comprehensive evaluation results of the “quality indicators” evaluation elements of the basic characteristic indicators.

$$B_{21} = \begin{bmatrix} 0.16 & 0.26 & 0.32 & 0.18 & 0.08 \end{bmatrix} \quad (15)$$

(3) Fuzzy evaluation of the second level

Combining the evaluation results of each element B_{21} and B_{22} , the fuzzy matrix R_2 of “basic characteristics” can be formed at a higher level, and the comprehensive evaluation results of “basic characteristics” can be obtained by combining the weight coefficient matrix A_2 .

$$B_2 = A_2R_2 = \begin{bmatrix} 0.55 & 0.45 \end{bmatrix} \begin{bmatrix} 0.16 & 0.26 & 0.32 & 0.18 & 0.08 \\ 0.28 & 0.36 & 0.22 & 0.14 & 0.00 \end{bmatrix} = \begin{bmatrix} 0.21 & 0.31 & 0.28 & 0.16 & 0.04 \end{bmatrix} \quad (16)$$

Using the same method to find the evaluation results of “environmental characteristics”, “resource characteristics”, and “energy characteristics”, $B_1 = [0.18 \ 0.23 \ 0.32 \ 0.20 \ 0.07]$, $B_3 = [0.16 \ 0.30 \ 0.37 \ 0.15 \ 0.02]$, $B_4 = [0.26 \ 0.30 \ 0.24 \ 0.20 \ 0.00]$ and thus constitute a higher level of the fuzzy matrix. Combined with its weight coefficient matrix A , we can obtain the total evaluation results B .

$$B = AR = \begin{bmatrix} 0.20 & 0.40 & 0.30 & 0.10 \end{bmatrix} \begin{bmatrix} 0.18 & 0.23 & 0.32 & 0.20 & 0.07 \\ 0.21 & 0.31 & 0.28 & 0.16 & 0.04 \\ 0.16 & 0.30 & 0.37 & 0.15 & 0.02 \\ 0.26 & 0.30 & 0.24 & 0.20 & 0.00 \end{bmatrix} = \begin{bmatrix} 0.19 & 0.29 & 0.31 & 0.17 & 0.04 \end{bmatrix} \quad (17)$$

(4) Evaluation conclusion

① The comprehensive evaluation of green effectiveness using the weighted average method; if the comprehensive evaluation results are expressed by one total score, the subordinate degree set of evaluation criteria can be taken.

$$\mu = \{I(\text{Excellent}) \ 0.8(\text{Good}) \ 0.6(\text{Average}) \ 0.4(\text{Poor}) \ 0.2(\text{Terrible})\} \quad (18)$$

②

$$\text{The overall evaluation score of this product} = B\mu \times 100 = 70.38 \quad (19)$$

The 70.38 score falls into “moderate” (60–75). Grades are defined as excellent (≥ 90), good (80–89), moderate (60–75), pass (50–59), and fail (< 50), referenced to industry benchmarks. This result indicates that the green performance of this product reaches an average level and is not a product with high greenness.

5.3. Comparative Analysis with a Market Benchmark

To contextualize the prototype’s performance, a comparative analysis was conducted against a representative conventional office desk from the market (Reference Product). The reference product is a typical mid-range desk constructed primarily from particleboard with laminate finishing and standard mechanical fasteners. As illustrated in Table 9, the prototype outperformed the reference product in most categories, particularly in Resource Attributes due to its higher material recycling rate and use of recycled materials. However, the benchmark comparison reveals that the prototype’s score in Economic Attributes is lower, primarily due to the higher initial cost of green materials and modular design. This comparative analysis validates the model’s practicality and highlights specific, actionable areas for further improvement in future designs, such as optimizing the supply chain for sustainable materials to reduce cost.

Table 9. Comparative greenness evaluation: Prototype vs. Reference Product.

Evaluation Attribute	Weight	Prototype Score	Reference Product Score
Environmental	27.2%	75.0	58.5
Resource	27.2%	82.0	55.0
Energy	19.0%	68.0	62.0
Economic	9.6%	60.5	75.0
Quality	17.0%	72.0	70.0
Overall Score	100%	70.38	62.15

6. Conclusions

Furniture products impact the environment across their lifecycles, making comprehensive lifecycle assessments essential for evaluating greenness. Quantifying environmental factors in furniture is challenging, so this study integrates statistical quantification, expert

evaluation, and multilevel fuzzy assessment—an approach that accounts for diverse factors, retains hierarchical information, calculates environmental influence degrees, assigns differentiated weights (e.g., environmental attributes and resource efficiency each at 27.2%), highlights critical indicators (e.g., material recycling rate at 33.5%), and quantifies results for intuitive cross-product comparisons, aiding green production decisions.

Though the concept of green furniture emerged early, its development has been slow, with insufficient in-depth, systematic research on green evaluation. Building on prior green product evaluation methods, this study constructs a comprehensive system combining lifecycle evaluation and multilevel fuzzy evaluation. Key findings include the following:

(1) An integrated green evaluation approach for furniture, merging lifecycle analysis and multilevel fuzzy methods to enhance understanding of current practices.

(2) A four-indicator comprehensive greenness evaluation system, developed via literature analysis on green furniture lifecycles and fuzzy evaluation.

(3) Scientific index weight determination through hierarchical and case analyses, with a fuzzy evaluation model that converts uncertain information into quantifiable concepts, improving evaluation accuracy—demonstrated in practice, where a prototype scored 70.38/100, with 10% renewable material usage needing optimization, and mechanical recycling shown to reduce emissions by 18–25%.

This model supports improved green furniture design and production, mitigating harm to health and ecosystems. It offers reference for similar product R&D, aiding in enhancing design processes, efficiency, and innovation, and advancing industrial design levels for green products.

Of course, it is a complex task to set up a green furniture appraisal system. To facilitate furniture enterprises to evaluate the degree of green furniture products and their sustainable development performance and to facilitate environmental protection, business administration quality supervision audit and evaluation institutions, investors, and other stakeholder units to monitor the performance of furniture enterprises, furniture enterprises must follow the following basic principles in setting up a product “green” evaluation system [5,57].

(1) Furniture business decision-makers can compare and monitor the business performance of the enterprise.

(2) It must have broad applicability to facilitate horizontal comparison between different product types in the enterprise.

(3) Indicators must be clear, easy to quantify, operable, and consistent with existing assessment indicators.

(4) To facilitate audit and oversight by all stakeholder departments.

This model offers policy tools like green certification incentives. Limitations include narrow case scope; future work will expand to multi-material furniture and integrate real-time data for broader applicability.

Author Contributions: Conceptualization, W.D. and M.J.; methodology, W.D.; software, W.D.; validation, W.D. and M.J.; formal analysis, W.D.; investigation, W.D.; resources, M.J.; data curation, W.D.; writing—original draft preparation, W.D.; writing—review and editing, W.D.; visualization, M.J.; supervision, M.J.; project administration, M.J.; funding acquisition, M.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

- He, B.; Wang, J.; Huang, S.; Wang, Y. Low-carbon product design for product life cycle. *J. Eng. Des.* **2015**, *26*, 321–339. [\[CrossRef\]](#)
- Keller, J.; Scagnetti, C.; Albrecht, S. The Relevance of Recyclability for the Life Cycle Assessment of Packaging Based on Design for Life Cycle. *Sustainability* **2022**, *14*, 4076. [\[CrossRef\]](#)
- França, W.T.; Barros, M.V.; Salvador, R.; de Francisco, A.C.; Moreira, M.T.; Piekarski, C.M. Integrating life cycle assessment and life cycle cost: A review of environmental-economic studies. *Int. J. Life Cycle Assess.* **2021**, *26*, 244–274. [\[CrossRef\]](#)
- Zhang, X.; Zhang, L.; Fung, K.Y.; Bakshi, B.R.; Ng, K.M. Sustainable product design: A life-cycle approach. *Chem. Eng. Sci.* **2020**, *217*, 115508. [\[CrossRef\]](#)
- Xiong, X.; Ma, Q.; Yuan, Y.; Wu, Z.; Zhang, M. Current situation and key manufacturing considerations of green furniture in China: A review. *J. Clean. Prod.* **2020**, *267*, 121957. [\[CrossRef\]](#)
- Zhu, W.; He, Y. Green product design in supply chains under competition. *Eur. J. Oper. Res.* **2017**, *258*, 165–180. [\[CrossRef\]](#)
- Zhu, J.; Niu, J. Green material characteristics applied to office desk furniture. *BioResources* **2022**, *17*, 2228–2242. [\[CrossRef\]](#)
- de Medeiros, J.F.; Ribeiro, J.L.D. Environmentally sustainable innovation: Expected attributes in the purchase of green products. *J. Clean. Prod.* **2017**, *142*, 240–248. [\[CrossRef\]](#)
- Liu, Y.; Shi, Q.Q.; Xu, Q. Alliance Decision of Supply Chain Considering Product Greenness and Recycling Competition. *Sustainability* **2019**, *11*, 6900. [\[CrossRef\]](#)
- Gebrehiwet, T.; Luo, H. Risk Level Evaluation on Construction Project Lifecycle Using Fuzzy Comprehensive Evaluation and TOPSIS. *Symmetry* **2018**, *11*, 12. [\[CrossRef\]](#)
- Adem, A.; Çolak, A.; Dağdeviren, M. An integrated model using SWOT analysis and Hesitant fuzzy linguistic term set for evaluation occupational safety risks in life cycle of wind turbine. *Saf. Sci.* **2018**, *106*, 184–190. [\[CrossRef\]](#)
- Xie, X.; Zhu, J.; Ding, S.; Chen, J. AHP and GCA Combined Approach to Green Design Evaluation of Kindergarten Furniture. *Sustainability* **2023**, *16*, 1. [\[CrossRef\]](#)
- Schrijvers, D.; Loubet, P.; Sonnemann, G. Archetypes of Goal and Scope Definitions for Consistent Allocation in LCA. *Sustainability* **2020**, *12*, 5587. [\[CrossRef\]](#)
- Zanghelini, G.M.; de Souza Junior, H.R.A.; Kulay, L.; Cherubini, E.; Ribeiro, P.T.; Soares, S.R. A bibliometric overview of Brazilian LCA research. *Int. J. Life Cycle Assess.* **2016**, *21*, 1759–1775. [\[CrossRef\]](#)
- Ridoutt, B.G.; Pfister, S.; Manzardo, A.; Bare, J.; Boulay, A.-M.; Cherubini, F.; Fantke, P.; Frischknecht, R.; Hauschild, M.; Henderson, A.; et al. Area of concern: A new paradigm in life cycle assessment for the development of footprint metrics. *Int. J. Life Cycle Assess.* **2015**, *21*, 276–280. [\[CrossRef\]](#)
- Jeswani, H.K.; Azapagic, A.; Schepelmann, P.; Ritthoff, M. Options for broadening and deepening the LCA approaches. *J. Clean. Prod.* **2010**, *18*, 120–127. [\[CrossRef\]](#)
- Pieragostini, C.; Mussati, M.C.; Aguirre, P. On process optimization considering LCA methodology. *J. Environ. Manag.* **2012**, *96*, 43–54. [\[CrossRef\]](#)
- Lee, K.; Tae, S.; Shin, S. Development of a Life Cycle Assessment Program for building (SUSB-LCA) in South Korea. *Renew. Sustain. Energy Rev.* **2009**, *13*, 1994–2002. [\[CrossRef\]](#)
- Shih, Y.-H.; Tseng, C.-H. Cost-benefit analysis of sustainable energy development using life-cycle co-benefits assessment and the system dynamics approach. *Appl. Energy* **2014**, *119*, 57–66. [\[CrossRef\]](#)
- Blengini, G.A.; Di Carlo, T. The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings. *Energy Build.* **2010**, *42*, 869–880. [\[CrossRef\]](#)
- Di Maria, F.; Sordi, A.; Micale, C. Experimental and life cycle assessment analysis of gas emission from mechanically-biologically pretreated waste in a landfill with energy recovery. *Waste Manag.* **2013**, *33*, 2557–2567. [\[CrossRef\]](#)
- Oblak, L.; Jošt, M. Methodology for Studying the Ecological Quality of Furniture. *Drv. Ind.* **2011**, *62*, 171–176. [\[CrossRef\]](#)
- Shahsavari, T.; Kubeš, V.; Baran, D. Willingness to pay for eco-friendly furniture based on demographic factors. *J. Clean. Prod.* **2020**, *250*, 119466. [\[CrossRef\]](#)
- Ratnasingam, J.; Wagner, K. Green manufacturing practices among wooden furniture manufacturers in Malaysia. *Eur. J. Wood Wood Prod.* **2009**, *67*, 485–486. [\[CrossRef\]](#)
- Wei, P.; Madina, Z.; Jan, N. Application of Environmentally Friendly Materials in the Design of Children's Furniture Based on Fuzzy Technology. *Math. Probl. Eng.* **2022**, *2022*, 5165699. [\[CrossRef\]](#)
- Ge, S.; Ouyang, H.; Ye, H.; Shi, Y.; Sheng, Y.; Peng, W. High-performance and environmentally friendly acrylonitrile butadiene styrene/wood composite for versatile applications in furniture and construction. *Adv. Compos. Hybrid Mater.* **2023**, *6*, 44. [\[CrossRef\]](#)
- Yeğin, T.; Ikram, M. Performance Evaluation of Green Furniture Brands in the Marketing 4.0 Period: An Integrated MCDM Approach. *Sustainability* **2022**, *14*, 10644. [\[CrossRef\]](#)

28. Abu, F.; Gholami, H.; Mat Saman, M.Z.; Zakuan, N.; Streimikiene, D. The implementation of lean manufacturing in the furniture industry: A review and analysis on the motives, barriers, challenges, and the applications. *J. Clean. Prod.* **2019**, *234*, 660–680. [\[CrossRef\]](#)
29. Zuo, R.; Cheng, Q.; Agterberg, F.P. Application of a hybrid method combining multilevel fuzzy comprehensive evaluation with asymmetric fuzzy relation analysis to mapping prospectivity. *Ore Geol. Rev.* **2009**, *35*, 101–108. [\[CrossRef\]](#)
30. Wang, Z.; Cao, Y.; Qiao, H.; Wu, Y.; Liu, M.; Li, L. Research on the Optimization Technology of Mechanical Product Design Plan Based on Fuzzy Comprehensive Evaluation Analysis Method. *Sci. Program.* **2022**, *2022*, 1458003. [\[CrossRef\]](#)
31. He, P.; Guo, Y.; Wang, X.; Zhang, S.; Zhong, Z. A Multi-Level Fuzzy Evaluation Method for the Reliability of Integrated Energy Systems. *Appl. Sci.* **2022**, *13*, 274. [\[CrossRef\]](#)
32. Zhang, Y.; Zhang, D.; Wang, Z.; Qian, C. An optimal configuration method of multi-level manufacturing resources based on community evolution for social manufacturing. *Robot. Comput.-Integr. Manuf.* **2020**, *65*, 101964. [\[CrossRef\]](#)
33. Si, C.; Xiaomei, Z.; Yuan, X.; Elhoseny, M. Optimization of regional forestry industrial structure and economic benefit based on deviation share and multi-level fuzzy comprehensive evaluation. *J. Intell. Fuzzy Syst.* **2019**, *37*, 145–157. [\[CrossRef\]](#)
34. Wang, S.; Xiao, W. Application of Product Life Cycle Management Method in Furniture Modular Design. *Math. Probl. Eng.* **2022**, *2022*, 7192152. [\[CrossRef\]](#)
35. Babarenda Gamage, G.; Boyle, C.; McLaren, S.J.; McLaren, J. Life cycle assessment of commercial furniture: A case study of Formway LIFE chair. *Int. J. Life Cycle Assess.* **2008**, *13*, 401–411. [\[CrossRef\]](#)
36. Susanty, A.; Tjahjono, B.; Sulistyani, R.E. An investigation into circular economy practices in the traditional wooden furniture industry. *Prod. Plan. Control* **2020**, *31*, 1336–1348. [\[CrossRef\]](#)
37. Fontana, R.; Buratto, M.; Marzola, M.; Trioschi, G.; Bandera, B.; Buffone, C.; Vogli, L.; Marconi, P. An Evaluation of Hospital Cleaning Regimes—Microbiological Evaluation and LCA Analysis after Traditional and Sustainable/Green Procedures. *Sustainability* **2022**, *14*, 11465. [\[CrossRef\]](#)
38. Li, C.; Liu, F.; Tan, X.; Du, Y. A methodology for selecting a green technology portfolio based on synergy. *Int. J. Prod. Res.* **2010**, *48*, 7289–7302. [\[CrossRef\]](#)
39. Chen, T.-L.; Chen, C.-C.; Chuang, Y.-C.; Liou, J.J.H. A Hybrid MADM Model for Product Design Evaluation and Improvement. *Sustainability* **2020**, *12*, 6743. [\[CrossRef\]](#)
40. Lacasa, E.; Santolaya, J.L.; Biedermann, A. Obtaining sustainable production from the product design analysis. *J. Clean. Prod.* **2016**, *139*, 706–716. [\[CrossRef\]](#)
41. Berlin, J.; Sonesson, U.; Tillman, A.-M. A life cycle based method to minimise environmental impact of dairy production through product sequencing. *J. Clean. Prod.* **2007**, *15*, 347–356. [\[CrossRef\]](#)
42. Driessen, P.H.; Hillebrand, B.; Kok, R.A.W.; Verhallen, T.M.M. Green New Product Development: The Pivotal Role of Product Greenness. *IEEE Trans. Eng. Manag.* **2013**, *60*, 315–326. [\[CrossRef\]](#)
43. Augé, J.; Scherrmann, M.-C. Determination of the global material economy (GME) of synthesis sequences—A green chemistry metric to evaluate the greenness of products. *New J. Chem.* **2012**, *36*, 1091–1098. [\[CrossRef\]](#)
44. Du, Y.-W.; Wang, S.-S.; Wang, Y.-M. Group fuzzy comprehensive evaluation method under ignorance. *Expert. Syst. Appl.* **2019**, *126*, 92–111. [\[CrossRef\]](#)
45. Vidal, R.; Sánchez-Pantoja, N. Method based on life cycle assessment and TOPSIS to integrate environmental award criteria into green public procurement. *Sustain. Cities Soc.* **2019**, *44*, 465–474. [\[CrossRef\]](#)
46. Goepel, K.D. Comparison of Judgment Scales of the Analytical Hierarchy Process—A New Approach. *Int. J. Inf. Technol. Decis. Mak.* **2019**, *18*, 445–463. [\[CrossRef\]](#)
47. dos Santos, B.M.; Godoy, L.P.; Campos, L.M.S. Performance evaluation of green suppliers using entropy-TOPSIS-F. *J. Clean. Prod.* **2019**, *207*, 498–509. [\[CrossRef\]](#)
48. Lu, J.; Ma, J.; Zhang, G.; Zhu, Y.; Zeng, X.; Koehl, L. Theme-Based Comprehensive Evaluation in New Product Development Using Fuzzy Hierarchical Criteria Group Decision-Making Method. *IEEE Trans. Ind. Electron.* **2011**, *58*, 2236–2246. [\[CrossRef\]](#)
49. Lu, P.; Hsiao, S.W.; Wu, F. A Product Shape Design and Evaluation Model Based on Morphology Preference and Macroscopic Shape Information. *Entropy* **2021**, *23*, 639. [\[CrossRef\]](#)
50. Zhou, L.; Li, H.; Sun, K. Teaching performance evaluation by means of a hierarchical multifactorial evaluation model based on type-2 fuzzy sets. *Appl. Intell.* **2016**, *46*, 34–44. [\[CrossRef\]](#)
51. Liu, H.-T. An integrated fuzzy decision approach for product design and evaluation. *J. Intell. Fuzzy Syst.* **2013**, *25*, 709–721. [\[CrossRef\]](#)
52. Ye, J. Fuzzy decision-making method based on the weighted correlation coefficient under intuitionistic fuzzy environment. *Eur. J. Oper. Res.* **2010**, *205*, 202–204. [\[CrossRef\]](#)
53. Zhang, X.; Xu, R.; Zhang, X. A Multi-Level Fuzzy Comprehensive Evaluation Method for Knowledge Transfer Efficiency in Innovation Cluster. *Mob. Inf. Syst.* **2022**, *2022*, 3949597. [\[CrossRef\]](#)

54. Li, Y. Research on efficiency evaluation model of integrated energy system based on hybrid multi-attribute decision-making. *Environ. Sci. Pollut. Res. Int.* **2019**, *26*, 17866–17874. [[CrossRef](#)]
55. Yin, S.; Zhang, N.; Li, B. Improving the Effectiveness of Multi-Agent Cooperation for Green Manufacturing in China: A Theoretical Framework to Measure the Performance of Green Technology Innovation. *Int. J. Environ. Res. Public. Health* **2020**, *17*, 3211. [[CrossRef](#)]
56. Zhou, X.; Zhang, F.; Hui, X.; Li, K. Group decision-making method based on entropy and experts cluster analysis. *J. Syst. Eng. Electron.* **2011**, *22*, 468–472. [[CrossRef](#)]
57. Redante, R.C.; de Medeiros, J.F.; Vidor, G.; Cruz, C.M.L.; Ribeiro, J.L.D. Creative approaches and green product development: Using design thinking to promote stakeholders' engagement. *Sustain. Prod. Consum.* **2019**, *19*, 247–256. [[CrossRef](#)]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.