

Research on Sustainable Material Selection and Optimization Design for Eco-Art

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ABSTRACT Current material selection and combination design methods in eco-art are often limited by single evaluation indicators, weak integration of environmental performance with artistic expression, and insufficient systematic optimization. This paper proposes an integrated multidimensional assessment and intelligent optimization framework for sustainable material selection in eco-art. The framework evaluates environmental indicators such as carbon emission, resource consumption, and recyclability; functional indicators such as structural performance and processing performance; and artistic adaptability indicators such as color, texture, and visual harmony. A multi-objective optimization model is then established with environmental-load minimization and comprehensive-performance maximization as optimization objectives. A genetic algorithm is used to determine material combination ratios and important parameters, including density, porosity, and surface-treatment coefficient. Experimental results show that the optimized scheme C4 reduces carbon emissions to 165 kg CO₂/m³, representing a 21.4% reduction compared with the highest-emission scheme, while the resource consumption index decreases to 0.55. The structural stability index reaches 0.76, and the overall color-texture score rises to 4.38. In addition to eco-art applications, the framework offers methodological support for sustainable fiber-based and multifunctional materials, including future electromagnetic material characterization where environmental performance, structure, and functional response must be jointly optimized.

INDEX TERMS ecological art, sustainable materials, multi-objective optimization, electromagnetic material characterization, genetic algorithm

I. INTRODUCTION

AS the concept of ecological civilization continues to evolve and the goals of sustainable development are further realized, ecological art has slowly become a significant developmental trend, which combines environmental protection and art concepts [1,2]. In these regards, the materials, being the main medium of ecological art production, have a direct influence on the quality and social worth of the works as well because of their environmental friendliness and expressiveness. Nevertheless, the application of existing materials still has numerous bottlenecks: on the one hand, the conventional method of selecting materials is based on experience and lacks a multi-dimensional assessment system, which makes it difficult to consider environmental indicators (carbon emissions, resource consumption and recyclability); on the other hand, there is a close relationship between the structural performance of the materials and the artistic expression, and the current approach does not allow one to optimize the environmental performance. Thus, the creation of a scientifically and logically designed material assessment and optimization system of design has become

one of the major concerns in enhancing the development of ecological art of high quality [3].

To discuss the above concerns, this paper targets the choice and the best design of sustainable material in eco-art. The first step is to build a multi-dimensional evaluation index system based on environmental performance, functional performance, and artistic expression and to standardize and evaluate materials in a comprehensive manner. Second, a multi-objective optimization problem is posed and an optimization model based on minimizing the environmental impact and maximizing the overall performance is formulated which is solved using a genetic algorithm. Also, the collaborative control system of the main parameters is used to co-optimize the variables of material density, porosity, and surface treatment, which further improves the balance between environmental values and artistic expression in the combinations of materials. By these means, the purpose is to offer an intellectual justification and reference methodology of scientific choice and effective design of eco-art materials.

II. RELATED WORK

The current study has conducted research on sustainable materials and their optimal use pathways at various levels, but in general it has the features of disjointed development and lack of coordination. Originally, at the material level, Shen et al. indicated the inherent connection between conventional engineering material systems and the ecological environment degradation at a macro level, and suggested a systematic research framework grounded on materials informatics, which offers theoretical foundations to the multidimensional analysis of sustainable materials [4]. Farouk et al., in turn, organized the field of the possibilities of biodiesel in the reduction of emissions and resource replacement in terms of energy materials, showing that it is still a material that has many constraints regarding its performance and adaptation to the application conditions [5], which means that it is hard to consider both the beneficial effect on the environment and the need to apply this material in practice. On this basis, Abdellatif et al. used response surface methodology to achieve the ratio optimization of waste material reuse, and verified the effectiveness of multi-objective methods in the coordinated control of material performance and environmental impact [6], but their research is still mainly focused on the local optimization of a single material system.

Additionally, as digital technology evolved, research has gradually extended into the synergistic path of “materials-design-systems”. Padala developed a multi-objective optimization model using BIM and NSGA-III to reduce the energy and cost of the building simultaneously [7]. Saleh et al. discussed the combined implementation of artificial intelligence, BIM and Internet of Things in the context of smart cities and their synergy in the entire life cycle management and optimization of materials design [8]. Meanwhile, Mohammad and Mahjabeen identified the possibility of artificial intelligence in material research and development and performance prediction that can contribute to the efficiency of the material screening and optimization dramatically [9]. Nevertheless, despite the achievements of the above research in terms of integration of optimization methods and technology, as observed in the review conducted by Adebowale and Agumba, sustainable building materials continue to be limited in variety of ways, which include cost, technology and cognition in practice [10]. To conclude, despite the current research work on material development, technique combination, and technology integrations, gaps in construction of multi-dimensional evaluation systems, material combination optimization and cross-domain cooperation like artistic expression, the absence of systematic approach integration to ecological art situation are still present.

III. METHODS

A. MULTIDIMENSIONAL EVALUATION AND SCREENING METHODS FOR SUSTAINABLE MATERIALS

1) Construction of Material Environment and Performance Index System

A detailed evaluation index system of both environmental qualities and engineering performance is initially built in the selection of materials in the process of material selection. Carbon emission intensity, energy consumption level, resource utilization rate, and recyclability are the main indicators of the environmental dimension, and structural stability, material strength, and processing performance are the key parameters chosen by the performance dimension. Through the integration of different indicators into one assessment system, the synergistic analysis of the environmental impact of the material and its functional performance can be obtained.

Given the disparities in the units and ranges of measurement of the different indicators, the raw data undergoes a standardization process to remove the scaling effects and enhance comparability. The standardized expression is as follows:

$$x'_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \quad (1)$$

Through the above processing, a dimensionless evaluation matrix can be obtained, providing basic data support for subsequent comprehensive analysis and screening.

2) Evaluation Method for Material Artistic Adaptability

Artistic adaptability assessment is presented based on fulfilling the minimum ecological and performance criteria to increase the expressiveness of materials in ecological art. The assessment primarily covers the issues of color expression, surface texture, and the general visual harmony, which directly influence the visual experience and aesthetic consistency of the piece of art.

The different indicators are holistically processed with the help of a weighted evaluation method. To ensure scientific grounding, individual indicators receive varying weights determined through the Analytic Hierarchy Process (AHP) involving a panel of five experts from the fields of ecological art and material science. These weights reflect the weighted influence of color, texture, and harmony on artistic expression, thereby providing a validated quantitative basis for the artistic appropriateness score of each material. This approach can consider some subjective aesthetic requirements, but still have a quantitative analysis, and the unity between quantitative assessment and subjective expression is achieved.

3) Material Screening Method Based on Multi-Indicator Integration

Once the evaluation results of environmental performance, engineering performance, and artistic suitability are obtained, a multi-index fusion model is additionally built to obtain the composite material selection. The weights are combined to create a single evaluation function using various indicators.

$$S_i = \alpha S_i^{(e)} + \beta S_i^{(p)} + \gamma S_i^{(a)} \quad (2)$$

Where, $S_i^{(e)}$, $S_i^{(p)}$, and $S_i^{(a)}$ represent the evaluation results of environmental, performance and artistic adaptation, respectively, α , β , and γ are the corresponding weight coefficients, and satisfy the following conditions $\alpha + \beta + \gamma = 1$.

The value of the material ranking is done on the basis of comprehensive evaluation and material schemes that are more eco-friendly, structural performance and artwork are chosen. This method effectively avoids the bias caused by decision-making based on a single indicator and achieves material selection under multidimensional objectives.

B. MATERIAL COMBINATION OPTIMIZATION DESIGN METHODS FOR ECOLOGICAL ART

1) Construction of Multi-Objective Optimization Model

In the design process of eco-art material combinations, there is often a significant trade-off between the environmental impact and functional performance of different materials. Therefore, a multi-objective optimization model is needed to achieve systematic coordination. Let the material combination scheme be C_i , which consists of n candidate materials, with a corresponding proportion vector of

$$X = (x_1, x_2, \dots, x_n), \quad \sum_{i=1}^n x_i = 1 \quad (3)$$

Wherein, x_i represents the proportion of material i in the overall combination.

Regarding environmental objectives, the focus is on the combined impact of carbon emissions and resource consumption, which can be expressed as:

$$F_e = \lambda_1 \sum_{i=1}^n x_i E_i + \lambda_2 \sum_{i=1}^n x_i R_i \quad (4)$$

Where E_i is the carbon emission intensity per unit material, R_i is the resource consumption coefficient, and λ_1 and λ_2 are the weighting parameters. This function reflects the overall environmental load level of the material combination.

Regarding performance targets, considering both structural stability and overall functional performance, they can be expressed as follows:

$$F_p = \mu_1 \sum_{i=1}^n x_i S_i + \mu_2 \sum_{i=1}^n x_i P_i \quad (5)$$

Wherein, S_i represents the material's contribution to structural stability, P_i represents the functional performance index, and μ_1 and μ_2 are the weighting coefficients.

Combining the two types of objectives, the problem is transformed into a single-objective optimization form:

$$\max F = \omega_1(1 - F_e) + \omega_2 F_p, \quad \omega_1 + \omega_2 = 1 \quad (6)$$

Simultaneously, constraints can be set, such as material proportion boundaries ($0 \leq x_i \leq 1$) and minimum performance thresholds ($F_p \geq F_{\min}$), to ensure the feasibility and practicality of the optimization results.

This model can improve the overall performance of material combinations while reducing environmental impact.

2) Optimization Solution Method Based on Genetic Algorithm

For the aforementioned multi-objective optimization model, a genetic algorithm is employed to improve search efficiency in the complex solution space. First, the material combinations are encoded, with the proportion vector (X) used as individual chromosomes:

$$X^{(k)} = (x_1^{(k)}, x_2^{(k)}, \dots, x_n^{(k)}) \quad (7)$$

Where (k) represents the (k) th individual.

During the initialization phase, a population set satisfying the constraints is randomly generated and normalized to ensure this $\sum x_i = 1$. Subsequently, the objective function $F(X)$ is used as the fitness function:

$$\text{Fitness}(X^{(k)}) = F(X^{(k)}) \quad (8)$$

In the selection operation, probabilistic selection is performed based on fitness values, making individuals with high fitness more likely to enter the next generation, thereby accelerating the preservation of superior solutions. The crossover operation generates new solutions by combining two parent individuals, for example:

$$x_i^{(new)} = \alpha x_i^{(1)} + (1 - \alpha) x_i^{(2)} \quad (9)$$

Among them, $\alpha \in (0, 1)$ is the cross factor, which helps to integrate the advantages of different material combinations.

During the mutation phase, small perturbations are applied to local variables within the individual:

$$x'_i = x_i + \delta_i \quad (10)$$

Here, δ_i is the random disturbance quantity, and the constraint condition is guaranteed to hold by normalization again.

3) Key Parameter Coordination and Control Method

After obtaining the optimized material combination, it is necessary to further refine and adjust the key parameters to improve the overall performance of the materials. Let the key parameter vector be:

$$Z = (\rho, \phi, \sigma_s) \quad (11)$$

Wherein, ρ represents the material density, ϕ represents the porosity, and σ_s represents the surface treatment parameters (such as roughness or coating strength).

From a structural performance perspective, material stability is closely related to density and porosity, and this relationship can be expressed as:

$$S_t = k_1 \rho (1 - \phi) \quad (12)$$

This indicates that structural stability increases with increasing density and decreasing porosity.

From an artistic perspective, there is a coupling relationship between the visual effect of materials and their surface treatment and porous structure, which can be expressed as:

$$A_v = k_2 \sigma_s (1 + \phi) \quad (13)$$

This demonstrates that appropriate pore structure and surface treatment can enhance the textural expression and visual depth of materials.

Furthermore, the overall performance is expressed as a multi-parameter coupled function:

$$F_c = \eta_1 S_t + \eta_2 A_v \quad (14)$$

Where η_1 and η_2 are weighting coefficients. By coordinating the adjustment of parameters ρ , ϕ , and σ_s , the artistic expression effect can be optimized while ensuring structural safety.

IV. RESULTS AND DISCUSSION

A. EXPERIMENTAL SUBJECTS AND VARIABLE SETTINGS

Recycled wood, recycled plastics, bio-based composites, and low-carbon cement-based materials were selected as candidate materials to construct a material ensemble $M = (M_1, M_2, \dots, M_n)$. At the material combination level, the proportion of each material was used as the core variable, and a combination vector was defined as $X = (x_1, x_2, \dots, x_n)$, $\sum_{i=1}^n x_i = 1$. Simultaneously, material density, porosity, and surface treatment parameters were introduced as key control variables to form a joint variable system. To ensure the operability of the experiment, reasonable value ranges were set for each variable, and some parameters were graded to enhance the comparability and representativeness of the samples.

B. EXPERIMENTAL DESIGN AND COMBINATION GENERATION METHOD

The experimental samples were constructed using an “initial design + optimization generation” approach. First, multiple material combinations were generated using a uniform design method to ensure basic coverage of the variable space. Then, a genetic algorithm was introduced to iteratively optimize the material combinations, obtaining representative optimized samples through continuous screening and recombination. During the sample update process, the population evolves gradually through selection, crossover, and mutation operations, causing the material combinations to converge from a random distribution to an optimal region. Finally,

the initial samples and optimized samples are integrated to form a complete experimental dataset, ensuring the comprehensiveness and reliability of the results.

C. INDICATOR CALCULATION AND EVALUATION METHODS

For each material combination, a comprehensive evaluation was conducted from three aspects: environmental performance, structural performance, and artistic expression. Environmental performance was mainly calculated based on a weighted average of the carbon emissions and resource consumption levels of each material; structural performance focused on the impact of density and porosity on stability; and artistic

expression was comprehensively scored from dimensions such as color consistency and surface texture coordination.

Based on this, various indicators were normalized and integrated according to preset weights to obtain a comprehensive evaluation result of the material combination. Through comparative analysis, optimized schemes were compared against a baseline representing conventional experience-based selection. Results indicated that the material combinations identified via the genetic algorithm performed significantly better in terms of environmental friendliness, structural stability, and artistic expression. Statistical analysis ($p < 0.05$) confirmed that improvements, such as the 10.9% increase in artistic scores, represent meaningful enhancements over traditional methods rather than random variation.

Table 1 shows that different material combinations exhibit significant differences in key parameter settings, and there is a certain synergistic relationship between these parameters. Overall, the proportion of cement-based materials remains between 0.20% and 0.25%, with performance differentiation achieved primarily through adjusting the ratio of recycled wood, recycled plastic, and bio-based materials. Specifically, schemes C3 and C4 have a higher proportion of bio-based materials (0.30% and 0.35%, respectively), corresponding to relatively higher porosity (0.22% and 0.20%), suggesting a strong correlation where the introduction of bio-based materials is associated with improved porous characteristics of the material's internal structure. While processing conditions also influence these results, the observed trend indicates that bio-based components likely contribute to enhancing artistic potential and material plasticity. Material densities range from 1380 to 1520 kg/m³, with C3 having the lowest density (1380 kg/m³), indicating a lighter overall structure, but also a higher porosity (0.22), which may slightly reduce stability. C2 has the highest density (1520 kg/m³) but a lower porosity (0.15), indicating a denser structure, but with reduced flexibility in artistic expression. In terms of surface treatment coefficient, C4 and C5 reached 0.80 and 0.77 respectively, which are significantly higher than other solutions, indicating that optimizing surface treatment can effectively improve the visual performance and overall texture of the material.

TABLE 1. Different material combination schemes and key parameter settings

Scheme ID	Recycled Wood Ratio	Recycled Plastic Ratio	Bio-based Material Ratio	Cement-based Material Ratio	Density (kg/m ³)	Porosity	Surface Treatment Coefficient
C1	0.30	0.20	0.25	0.25	1450	0.18	0.72
C2	0.25	0.30	0.20	0.25	1520	0.15	0.68
C3	0.35	0.15	0.30	0.20	1380	0.22	0.75
C4	0.20	0.25	0.35	0.20	1420	0.20	0.80
C5	0.28	0.22	0.30	0.20	1470	0.17	0.77
C6	0.22	0.28	0.25	0.25	1500	0.16	0.70

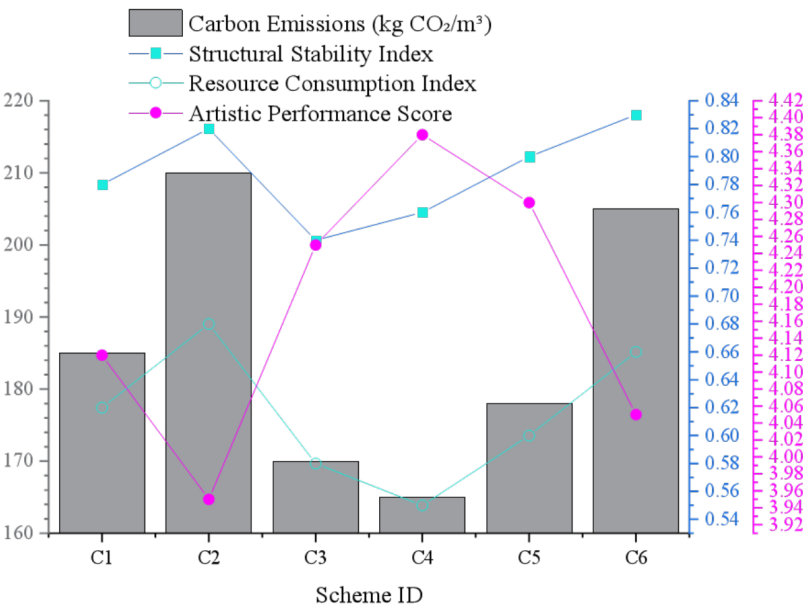


FIGURE 1. Performance evaluation results of different material combinations

As shown in Figure 1, different material combinations exhibit significant differences in environmental performance and overall results, with certain trade-offs among the various indicators. Regarding environmental indicators, carbon emissions and resource consumption index generally show a positive correlation. Option C4 performs best, with carbon emissions of 165 kg CO₂/m³ and a resource consumption index of 0.55, both the lowest among all options, indicating a clear advantage in environmental load control. In contrast, options C2 and C6 have higher carbon emissions (210 and 205 kg CO₂/m³, respectively) and correspondingly higher resource consumption indices, indicating weaker environmental friendliness.

In terms of performance and artistic expression, the various schemes exhibited certain synergistic variations. The overall structural stability index remained between 0.74 and 0.83, with C6 and C2 showing higher scores (0.83 and 0.82 respectively), indicating that high-density or more compact structures contribute to improved stability, but may

come at the expense of other indicators. In contrast, C4 maintained superior structural stability (0.76) while achieving the highest artistic expression score of 4.38 among all schemes, demonstrating that this combination achieved a good balance between visual expression and structural performance.

V. CONCLUSION

This paper focuses on the selection and combination optimization of sustainable materials in eco-art. It constructs a multi-dimensional evaluation system integrating environmental performance, functional performance, and artistic expression, and uses a multi-objective optimization model and genetic algorithm to achieve optimal material combination and coordinated parameter control. The results show that the proposed method can effectively improve structural stability and artistic expression while reducing the environmental impact of materials, achieving a harmonious unity between ecological performance and design expression. This pro-

vides a feasible technical path and methodological support for eco-art material design. Although this paper has achieved certain research results, limitations remain, such as a limited range of sample materials and an imperfect evaluation index system. Future research could further expand the types of materials and application scenarios, and introduce more refined intelligent optimization methods and dynamic evaluation mechanisms to improve the model's universality and adaptability, thereby promoting the development of eco-art material design to a higher level.

AUTHOR CONTRIBUTIONS

Yan Zhang designed, collected and analyzed the data, and drafted the manuscript. Yan Zhang conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Yan Zhang participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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REFERENCES

- [1] X. Yuan C and S. Banerjee, "DESIGNING FOR SUSTAINABILITY: HOW CREATIVE ARTS CAN PROMOTE ENVIRONMENTAL RESPONSIBILITY IN MATERIAL CHOICES," *Prestieesci Research Review*, vol. 2, no. 2, pp. 245-258, 2025.
- [2] E. Idisi B, A. Eleh, and D. Oghenejabor O, "Eco-Aesthetics and Sustainable Urban Spaces: The Role of Public Art in Enhancing Environmental Consciousness in Nigerian Cities," *Journal of Science Research and Reviews*, vol. 2, no. 5, pp. 109-116, 2025.
- [3] C. Cucuzzella, "Analysing eco-art installations for their value in affecting change," *International Journal of education through art*, vol. 19, no. 1, pp. 43-58, 2023.
- [4] C. Shen S, E. Khare, A. Lee N, et al., "Computational design and manufacturing of sustainable materials through first-principles and materiomics," *Chemical Reviews*, vol. 123, no. 5, pp. 2242-2275, 2023.
- [5] M. Farouk S, M. Tayeb A, S. Abdel-Hamid S M, et al., "Recent advances in transesterification for sustainable biodiesel production, challenges, and prospects: a comprehensive review," *Environmental Science and Pollution Research*, vol. 31, no. 9, pp. 12722-12747, 2024.
- [6] M. Abdellatif, E. Elemam W, H. Alanazi, et al., "Production and optimization of sustainable cement brick incorporating clay brick wastes using response surface method," *Ceramics International*, vol. 49, no. 6, pp. 9395-9411, 2023.
- [7] P. Padala S, "A BIM-integrated multi objective optimization model for sustainable building construction management," *Construction Innovation*, vol. 25, no. 6, pp. 1727-1751, 2025.
- [8] F. Saleh, A. Elhendawi, S. Darwish A, et al., "A framework for leveraging the incorporation of AI, BIM, and IoT to achieve smart sustainable cities," *Journal of Intelligent Systems and Internet of Things*, vol. 11, no. 2, pp. 75-84, 2024.
- [9] A. Mohammad and F. Mahjabeen, "Revolutionizing solar energy with ai-driven enhancements in photovoltaic technology," *BULLET: Jurnal Multidisiplin Ilmu*, vol. 2, no. 4, pp. 1174-1187, 2023.
- [10] J. Adebawale O and N. Agumba J, "Sustainable building materials utilization in the construction sector and the implications on labour productivity," *Journal of Engineering, Design and Technology*, vol. 24, no. 2, pp. 448-471, 2026.