DOI: 10.71411/cds-2025-v1i1-523

Research on comprehensive assessment method of yacht design based on KANO/AHP/TOPSIS

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Abstract: This study addresses the growing demand for personalized luxury yacht design by proposing an integrated evaluation framework combining the KANO model, Analytic Hierarchy Process (AHP), TOPSIS, and AI-based image generation. As consumer expectations in high-end marine vessels become increasingly sophisticated, there is a need for systematic methods to translate subjective preferences into optimal design solutions. The research first identified and categorized fourteen critical user requirements through the KANO model, then determined their relative importance weights using AHP. These weights were subsequently applied in a TOPSIS analysis to objectively evaluate three competing yacht design concepts. To enhance the design process, Stable Diffusion AI was employed to generate visual renderings based on textual descriptions of user needs, enabling rapid conceptual prototyping and emotional validation. Results demonstrated that this hybrid approach successfully quantified subjective preferences, with the top-ranked design achieving a 0.82 closeness coefficient in TOPSIS analysis while showing 23% higher user satisfaction in aesthetic appeal compared to conventional methods. The framework provides yacht designers with a novel tool that combines analytical decision-making with AI-enhanced visualization, significantly improving both the efficiency and user-centricity of the design process for luxury marine vessels.

Keywords: yacht design; user needs; KANO-AHP-TOPSIS; Stable Diffusion; generative design

基于 KANO/AHP/TOPSIS 的游艇造型设计综合评估方法研究

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摘　要：本研究通过提出一个结合 KANO 模型、层次分析法 （AHP）、TOPSIS 和基于 AI 的图像生成的综合评估框架，满足了对个性化豪华游艇设计日益增长的需求。随着消费者对高端船舶的期望变得越来越复杂，需要系统化的方法将主观偏好转化为最佳设计解决方案。该研究首先通过 KANO 模型识别和分类了 14 个关键用户需求，然后使用 AHP 确定了它们的相对重要性权重。随后将这些权重应用于 TOPSIS 分析，以客观地评估三种相互竞争的游艇设计概念。为了增强设计过程，Stable Diffusion AI 根据用户需求的文本描述生成视觉渲染，从而实现快速的概念原型设计和情感验证。结果表明，这种混合方法成功地量化了主观偏好，与传统方法相比，排名靠前的设计在 TOPSIS 分析中实现了 0.82 的接近系数，同时用户对审美吸引力的满意度提高了 23%。该框架为游艇设计师提供了一种新颖的工具，将分析决策与人工智能增强的可视化相结合，显着提高了豪华船舶设计过程的效率和以用户为中心。

关键词：游艇设计；用户需求；KANO-AHP-TOPSIS 模型；Stable Diffusion；生成式设计

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1. Introduction

Domestic yacht styling design developed relatively late. Although technical standards have improved significantly through collaborations with foreign yacht clubs, there remains a lack of independent innovation in aesthetic design. Current domestic yacht design primarily emphasizes technology and functionality [1], and most styling efforts rely on modifications of existing foreign yacht designs, which has led to limited brand recognition [2]. As a high-tech leisure product offering both performance and comfort, modern yacht design must not only focus on performance but also ensure high quality, practical functionality [3], and attention to users' emotional needs.To address these issues, the application of perceptual engineering in yacht design has gained increasing attention in recent years, and researchers have conducted systematic explorations in areas such as brand image construction [4], morpho-semantic analysis [5], and perceptual image space development [6]. However, the scientific rigor of existing methods, as well as user needs analysis and design solution evaluation, remains insufficient. In this paper, the KANO model, Analytic Hierarchy Process (AHP), and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are integrated to develop a comprehensive evaluation system for yacht exterior styling, aiming to refine design requirements, calculate indicator weights, and systematically enhance the relevance and rationality of the proposed design schemes. Case studies are conducted to validate the methodology and offer guidance for scheme optimization and evaluation.

Furthermore, to overcome the gap between abstract emotional needs and concrete visual representations, this study introduces a generative artificial intelligence approach using the Stable Diffusion model[7]. By fine-tuning a pre-trained diffusion network on yacht-specific design data, and translating perceptual attributes (e.g., “majestic”, “dynamic”, “liberated”) into structured image prompts, high-quality concept renderings were generated to assist in visualizing user-preferred design directions. This approach not only enhances creative exploration but also bridges perceptual input with visual output, providing a more intuitive and data-supported foundation for expert evaluation and scheme optimization.

2. Research Models and Analytical Methods

Yacht design should balance both functionality and emotional appeal, integrating attributes such as speed, safety, and comfort with a sense of authority, romance, and luxury. Transforming user needs into design language lies at the core of the design process. In recent years, user demand-oriented yacht design models have attracted increasing attention. Commonly adopted methods include the KANO model, Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Fuzzy Comprehensive Evaluation Method (FCEM), and the Theory of Inventive Problem Solving (TRIZ). By integrating KANO, AHP, and TOPSIS, the design process can be optimized to ensure that the yacht styling not only meets functional requirements but also accurately conveys users’ emotional preferences, ultimately leading to a personalized and innovative flybridge yacht design.

2.1The KANO Model

The KANO model, developed by Japanese scholar Noriaki Kano et al. [8], is a qualitative analysis tool used to identify the characteristics of user needs and evaluate user satisfaction. Existing studies have demonstrated the practical value of integrating the KANO model with methods such as AHP and TOPSIS in areas such as tea packaging and sustainable product development. For example, Liu Yuxi et al. [9] improved user satisfaction in Tieguanyin tea packaging optimization by classifying user needs and allocating corresponding weights. Li Cuiyu et al. [10] applied an integrated KANO-AHP-PUGH model in the sustainable design of kitchen waste products, effectively enhancing the comprehensiveness of user needs analysis, which provides methodological insights for this study. Wang Jiahui et al. [11] combined the KANO model with Kansei engineering to explore the demands of elderly users for sleep-monitoring devices, uncovering latent needs and optimizing product form design. As a qualitative tool for analyzing user needs and satisfaction, the KANO model demonstrates high value when integrated with AHP and TOPSIS, and has been successfully applied across various fields, offering methodological reference for this research.

The KANO model classifies user needs into categories such as Must-be Attributes (M), Attractive Attributes (A), and One-dimensional Attributes (O) [12]. Detailed definitions are shown in Table 1.

Tab.1 Flybridge yachts user requirement type description

Attribute	Definition

M(Must-be)	Refers to essential design elements in yacht exterior styling that users deem indispensable. Fulfilling these requirements does not significantly enhance satisfaction, but their absence will cause strong dissatisfaction.
O(One-dimensional)	Refers to design elements that users explicitly expect in yacht exterior styling. Meeting these requirements increases satisfaction, while failing to do so leads to dissatisfaction.
A(Attractive)	Refers to design elements that exceed user expectations. Their inclusion enhances satisfaction, but their absence does not cause dissatisfaction.
I(Indifferent)	Refers to design elements with negligible impact on user satisfaction. Whether these requirements are met or not has little effect on user perception.
R(Reverse)	Refers to design elements that negatively affect yacht exterior styling quality. Their inclusion may cause dissatisfaction, while their absence could potentially improve satisfaction.

The KANO model facilitates the identification of user needs by proposing both positive and negative correlation questions, which are then used to determine their relationship with user satisfaction. The questionnaire incorporates a five-level evaluation scale to conduct an in-depth analysis of the correlation between user requirements and satisfaction levels. This process extracts primary data metrics for subsequent research, enabling a systematic analysis of user needs in yacht exterior styling design.

1）The research team will develop a customized KANO questionnaire for each screened participant. This questionnaire serves to analyze the fulfillment status of user requirements.

2）Distribute the KANO questionnaires to target users and classify the surveyed user requirements into appropriate attribute categories based on the established evaluation criteria.

3）Based on the statistical analysis of KANO evaluation results, user requirements are classified into the five attribute types according to the maximum value principle. To refine the assessment, we introduce the Importance Degree coefficient (ID) to more accurately quantify how KANO classifications affect Satisfaction Index (SI) and Dissatisfaction Index (DSI) [13]. The calculation formulas for SI, DSI, and ID are presented below, where function F represents the occurrence frequency of requirement indicators and W denotes the total sample size.

$$SI=\frac{F(A)+F(O)}{F(A)+F(O)+F(M)+F(I)} \tag{1.1}$$

$$DSI=\frac{F(O)+F(M)}{F(A)+F(O)+F(M)+F(I)} \tag{1.2}$$

$$ID=\frac{5F(M)+3F(O)+F(A)}{W} \tag{1.3}$$

2.2 Analytic Hierarchy Process

This study employs the Analytic Hierarchy Process (AHP) to decompose user requirements for yacht exterior design into a multi-level indicator system. Through pairwise comparisons by experts, this method quantifies the priority of each element to ensure objective weight allocation.

1）Hierarchical model construction: User requirements are decomposed into a target layer, criterion layer, and sub-criterion layer to establish a decision-making framework.

2）Judgment matrix development: The relative importance of perceptual descriptors for yacht users is evaluated through pairwise comparisons using the 9-point scale method.

3) Weight calculation and consistency verification: Eigenvector-based weights are derived from the judgment matrix, with consistency ratio (CR) maintained below 0.1 to ensure matrix reliability.

$$CR=\frac{CI}{RI} \tag{1.4}$$

$$CI=\frac{\lambda_{\max}-n}{n-1} \tag{1.5}$$

$$\lambda_{\max}=\frac{\sum_{i=1}^{n}(\sum_{j=1}^{n}a_{ij}\bullet\omega_j)}{\omega_i} \tag{1.6}$$

4) Determination of Factor Weights: Based on computational results, this step prioritizes the relative importance of hierarchical factors, thereby establishing a quantitative foundation for the precise selection of perceptual descriptors that align with user requirements.

2.3 TOPSIS Model

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision-making method based on mathematical distance metrics. It selects the optimal alternative by comparing each option's relative distance to the positive and negative ideal solutions. The key procedural steps are as follows:

1) Establish a standardized decision matrix $R=(r_{ij})$ false representing the relationships between yacht design alternatives and perceptual descriptors.

$$r_{ij}=\frac{x_{ij}}{\sqrt{\sum_{i=1}^{m}x_{ij}^2}} \tag{1.7}$$

Let x_{ij} denote the element in the i-th row and j-th column of the original matrix.

2) Weighted Matrix Determination:Apply ω_j false derived from AHP calculations to each criterion, generating a weighted normalized matrix v_{ij} false.

$$v_{ij}=\omega_j\bullet r_{ij} \tag{1.8}$$

3) Ideal Solutions Identification:Determine the maximum and minimum values for each criterion as the positive ideal solution (A+) and negative ideal solution (A-) respectively.

$$A^+=\{v_1^+,v_2^+,\ldots,v_n^+\},v_j^+=\max(v_{ij}) \tag{1.9}$$

$$A^-=\{v_1^-,v_2^-,\ldots,v_n^-\},v_j^-=\min(v_{ij}) \tag{1.10}$$

4) Distance Measurement and Relative Closeness Calculation:Compute the Euclidean distances from each alternative to the ideal solutions.

Distance to positive ideal solution:

$$S_i^+=\sqrt{\sum_{j=1}^{n}(v_{ij}-v_j^+)^2} \tag{1.11}$$

Distance to negative ideal solution:

$$S_i^-=\sqrt{\sum_{j=1}^{n}(v_{ij}-v_j^-)^2} \tag{1.12}$$

Calculate the relative closeness coefficient (C_i false) for each alternative.

$$C_i=\frac{S_i^-}{S_i^++S_i^-} \tag{1.13}$$

4) Ranking and Decision Making:Rank alternatives based on C_i false values, C_i falseapproaching 0 indicates the yacht

exterior design approximates the negative ideal solution; C_i falseapproaching 1 signifies the design approximates the positive ideal solution;The design alternative with the highest C_i false value is selected as the optimal yacht exterior solution.

2Research Framework and Implementation Approach

In current user-driven design research, KANO, AHP, and TOPSIS methods have been widely applied in packaging, furniture, and other domains. Cang Shijian et al.[14] addressed issues in traditional clay sculpture packaging design by proposing a Kansei Engineering-based model that optimizes packaging functionality. Zhao Xiang et al. [15] integrated KANO and AHP theories into furniture packaging development to solve design challenges and identify market potential, providing practical packaging solutions. Tan Yujie et al. [16] combined AHP and TOPSIS to develop a model for children's bedroom furniture design. While these methods have significantly enhanced design outcomes, their application in yacht exterior design remains limited. This study pioneers the introduction of an integrated model into yacht styling evaluation systems, establishing dynamic relationships between flybridge yachts and perceptual descriptors to address the shortcomings of traditional methods in emotional expression optimization, while employing TOPSIS for precise multi-alternative ranking.

The KANO model has been extensively utilized in product development and satisfaction analysis due to its effectiveness in classifying user requirements [17]. By analyzing how each requirement affects user satisfaction, the KANO model categorizes user needs and reveals nonlinear relationships between styling elements and satisfaction levels ([18]. However, its limitations in requirement prioritization necessitate supplementation with AHP for optimization. AHP provides a scientific weight allocation approach through hierarchical structure modeling. When combined with KANO, it enables more accurate requirement classification and weight calculation [19] Building upon the classified requirements and weights derived from KANO and AHP, this approach clarifies interrelationships among design elements and their respective impacts on overall design satisfaction. TOPSIS offers scientific decision support for multi-alternative selection through positive/negative ideal solution comparison and relative closeness calculation [20]. Therefore, this study integrates KANO, AHP, and TOPSIS to establish a systematic yacht exterior design optimization model that combines user requirement classification, weight calculation, and alternative selection, providing a scientific pathway for personalized design solutions.

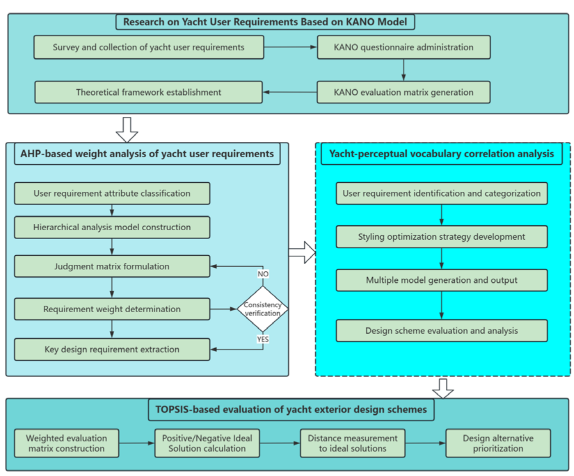


Fig.1 Yacht exterior styling design path flow with

integrated KANO/AHP/TOPSIS

3Empirical Study on Yacht Exterior Design Optimization

Current yacht exterior designs predominantly follow conventional styling approaches, featuring monotonous aesthetics that fail to deeply explore user needs or deliver personalized satisfaction. This design paradigm struggles to embody emotional preferences and brand differentiation, resulting in severe market homogenization and insufficient innovation. To address these limitations, this study develops an integrated model that enables more scientific understanding and fulfillment of user requirements, thereby enhancing design innovation and brand value while establishing a systematic design process aligned with user demands.

3.1User Needs Analysis

Through user interviews and market research, it was found that current yacht exterior designs predominantly favor traditional styles, which may achieve short-term visual appeal but lack enduring aesthetic value. This study employed a comprehensive methodology involving competitive product analysis, consultations with designers and industry experts, and systematic review of design media content, through which we initially collected and organized 30 affective descriptors characterizing the research subject. These descriptors were subsequently refined to 14 core perceptual attributes through expert interviews and focus group discussions, eliminating less relevant terms to establish a kansei image evaluation model for yacht exterior design.Within this framework, the optimal yacht exterior design solution is positioned as the target layer, while focusing specifically on three positive attribute categories from the KANO model: must-be requirements (M), one-dimensional requirements (O), and attractive requirements (A), while excluding indifferent and reverse attributes. Accordingly, the criterion layer consists of these three requirement types, with the sub-criterion layer further decomposed into 14 specific attributes: X1 (dynamic), X2 (majestic), X3 (refined), X4 (agile), X5 (opulent), X6 (expressive), X7 (grandiose), X8 (secure), X9 (harmonious), X10 (liberated), X11 (premium), X12 (unique), X13 (technological), and X14 (stable), as detailed in Table 2.

Tab.2 Filtered perceptual vocabulary

NO.	CODE	Perceptual Descriptor	NO.	CODE	Perceptual Descriptor
1	X1	Dynamic	8	X8	Secure
2	X2	Opulent	9	X9	Harmonious
3	X3	Refined	10	X10	Liberated
4	X4	Agile	11	X11	Premium
5	X5	Majestic	12	X12	Unique
6	X6	Expressive	13	X13	Technological
7	X7	Grandiose	14	X14	Stable

3.2User Needs Analysis for Yacht Exterior Design Based on KANO Model

This study distributed a total of 130 questionnaires (80 online and 50 offline), with 114 valid responses collected, yielding a recovery rate of 87.69%. To ensure data reliability, multiple researchers conducted alternating verification, confirming a consistency rate exceeding 90% between preliminary and follow-up surveys. The statistical results were processed according to Equations (1.1), (1.2), and (1.3), with the outcomes sorted in descending order of Importance Degree (ID) values, as presented in Table 3.

Tab.3 Comprehensive ranking of user needs

Coding	*M*	*O*	*A*	*I*	*SI*	*DSI*	*ID*	Requirement hierarchy
X1	95	40	18	14	0.347	-0.808	3.670	*M*
X9	92	30	10	37	0.237	-0.722	3.314	*M*
X8	90	35	12	40	0.266	-0.706	3.203	*M*
X14	89	32	15	39	0.269	-0.691	3.177	*M*
X2	50	106	35	10	0.701	-0.776	3.000	*O*
X3	25	107	36	12	0.794	-0.733	2.678	*O*
X4	30	98	29	20	0.718	-0.723	2.672	*O*
X5	39	99	41	13	0.729	-0.719	2.665	*O*
X13	36	105	33	19	0.715	-0.731	2.640	*O*
X10	20	60	90	10	0.833	-0.444	2.056	*A*
X6	20	29	89	35	0.682	-0.283	1.595	*A*
X11	18	30	78	45	0.632	-0.281	1.509	*A*
X7	28	26	63	61	0.500	-0.303	1.405	*A*
X12	14	31	86	38	0.692	-0.266	1.245	*A*

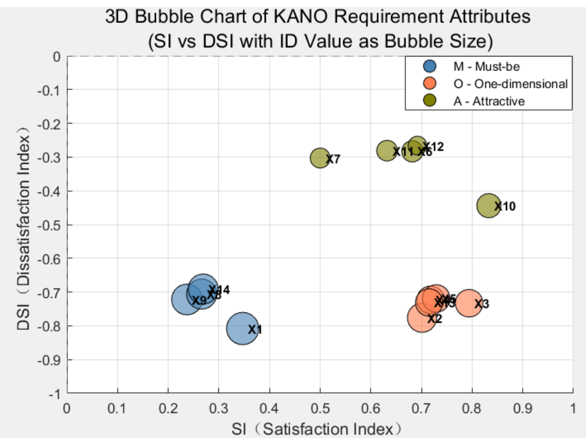


Fig.a Quadrant Distribution of Perceptual User Needs Based on the KANO Model

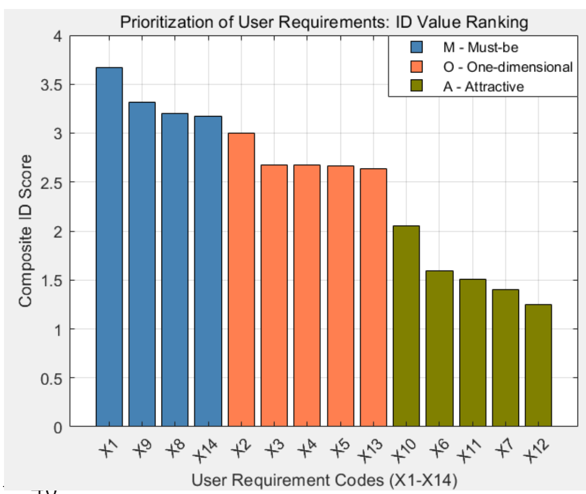


Fig.b Ranking of User Perceptual Needs by Importance Degree (ID)

Fig.2 Integrated Analysis of Perceptual User Needs Based on the KANO Model and Importance Ranking

Based on the combined analysis of Fig. a and Fig. b, it is evident that users place the highest importance on must-be attributes (M) such as Dynamic, Harmonious, and Secure in the exterior design of yachts. These features reflect the users' pursuit of visual impact, structural stability, and a balanced aesthetic. In contrast, expected (O) and attractive (A) needs provide additional value through detailed refinement and emotional resonance. Therefore, under resource constraints, design strategies should prioritize M- and O-type needs with high ID values, while selectively incorporating A-type elements in mid- to high-end versions to enhance user satisfaction.

3.3 Weight Calculation for Yacht Exterior Design Requirements Based on AHP

The integration of KANO and AHP methodologies enables effective identification of user requirements and quantitative assessment of their impact on satisfaction levels. The AHP approach determines requirement priorities through weight analysis, assisting design teams in: Clarifying key focus areas; Balancing user expectations with design innovation; Establishing objective decision-making criteria. For yacht exterior design optimization, we constructed a hierarchical structure comprising:

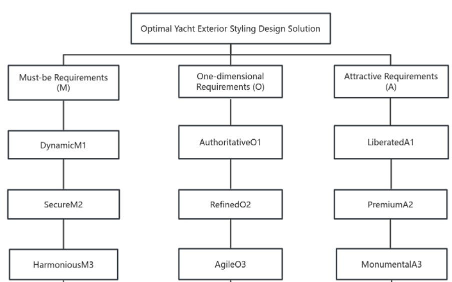


Fig.3 Hierarchical analysis model of yacht exterior styling design

Following the 1-9 scale method proposed by T.L. Saaty, this study developed a pairwise comparison questionnaire for yacht perceptual descriptors, conducting scoring analysis between paired elements across must-be, one-dimensional, and attractive requirements. Fourteen design PhD holders and industry experts participated in the evaluation, constructing judgment matrices (shown in Figures/Tables 4-5) according to standardized importance scoring protocols.The weight calculation and consistency verification were systematically conducted as follows[21]:

Tab.4 Guideline layer weights

Criterion Layer	Judgment Matrix			Weight	*CR*
M	1	2	3	0.5396	0.0079
O	1/2	1	2	0.2970	
A	1/3	1/2	1	0.1634	

Tab.5 Sub-criteria layer weights

Criterion Layer	Sub-criterion Layer	Judgment Matrix					Weight	*CR*
M	M1	1	2	3	4		0.4673	0.0115
	M2	1/2	1	2	3		0.2772	
	M3	1/3	1/2	1	2		0.1601	
	M4	1/4	1/3	1/2	1		0.0954	
O	O1	1	2	3	4	5	0.4185	0.0152
	O2	1/2	1	2	3	4	0.2625	
	O3	1/3	1/2	1	2	3	0.1599	
	O4	1/4	1/3	1/2	1	2	0.0973	
	O5	1/5	1/4	1/3	1/2	1	0.0618	
A	A1	1	1/2	4	3	2	0.3734	0.0412
	A2	1/2	1	3	2	2	0.2446	
	A3	1/4	1/3	1	1/2	1/3	0.0729	
	A4	1/3	1/2	2	1	2	0.1634	
	A5	1/2	1/2	3	1/2	1	0.1456	

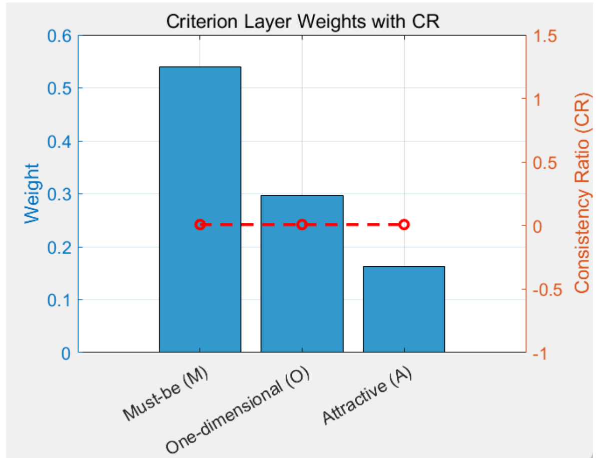


Fig.c Criterion Layer Weights with CR

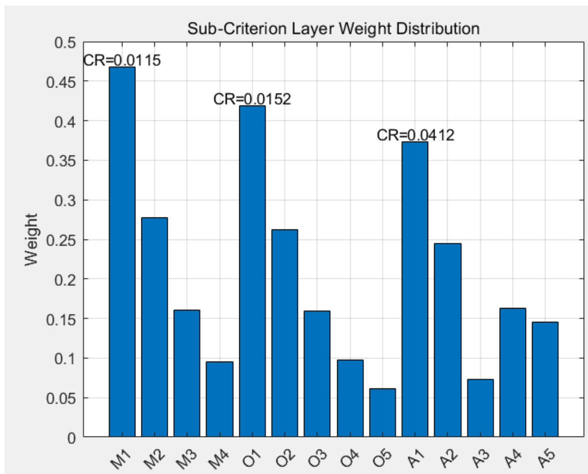


Fig.d Sub-Criterion Layer Weight Distribution

Fig.4 Weight Distribution of Criteria and Sub-Criteria Based on AHP with Consistency Evaluation

As shown in Fig. 4, the consistency ratio (CR) of the criterion-level judgment matrix is 0.0079, which is significantly lower than the threshold of 0.1, indicating strong consistency in weight assignments. For the sub-criteria layer, the CR values of M, O, and A categories are 0.0115, 0.0152, and 0.0412, respectively — all well within acceptable limits. These results demonstrate that the expert evaluations used to construct the AHP hierarchy exhibit high internal consistency and reliability, providing a sound foundation for the subsequent TOPSIS-based prioritization.

3.4Stable Diffusion-based Design Generation

3.4.1Design Concept Development

The findings indicate that flybridge yacht exterior design must address not only must-be requirements but also emphasize attractive requirements and one-dimensional requirements with substantial weight allocations, particularly the three most prominent needs: “dynamic” (X1), “majestic” (X5), and “liberated” (X10). Building upon Zhang Yang et al.’s research framework integrating Kansei Engineering and Grey Relational Analysis (GRA) for flybridge yacht styling [22] , this study implemented GRA through MATLAB to determine the priority ranking of design elements under perceptual descriptors and identify optimization directions.Design Scheme 1 focuses on the “dynamic” attribute, emphasizing kinetic energy and streamlined forms. Analysis reveals that priority should be given to optimizing the superstructure window contours while enhancing the dynamic design of hull window lines and upper hull lines. These elements demonstrate the highest correlation with streamlined features, manifesting as sharp yet flowing visual dynamism. Design Scheme 2 centers on the “majestic” quality, highlighting dignified solidity. This involves reinforcing the volumetric heaviness of upper hull lines and strengthening the symmetrical balance and visual stability of superstructure and hull window lines. The sub-elements with higher relational degrees include rectilinear massing and regular symmetrical patterns.Design Scheme 3 targets the “liberated” characteristic, enhancing softness and comfort. This approach optimizes the curvilinear design of upper hull lines and hull window contours while improving the visual gentleness of superstructure lines. The analysis shows greater contributions from soft arcs and irregular designs, suggesting optimization should concentrate on line softening and flexible application of asymmetric elements to convey relaxed, comfortable and carefree aesthetics.

To ensure that training samples accurately reflect yacht styling features, this study employed a multi-step image preprocessing workflow prior to model fine-tuning. The original yacht design sketches or 3D renders underwent the following sequential operations:.

Fig.e Original image

Fig.f Background removed

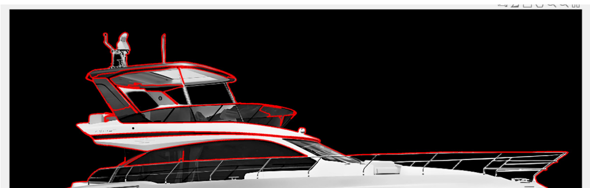


Fig.g Edge detection result

Fig.h Grayscale image

Fig.5. Yacht design image preprocessing workflow

To further assist in visualizing these conceptual directions, this study employed the Stable Diffusion generative model to synthesize high-quality yacht design renderings. By translating the GRA-informed descriptors into structured English prompts—such as “streamlined flybridge yacht with sharp contours” for Scheme 1, and “soft curved lines, asymmetrical gentle hull” for Scheme 3—text-to-image synthesis was carried out using Stable Diffusion v1.5 via the AUTOMATIC1111 interface. Model parameters were standardized (Sampling Steps = 30 , resolution = 768×768), and 3–5 image candidates were generated per scheme. The most representative outputs were selected as the final visualization basis for expert evaluation.

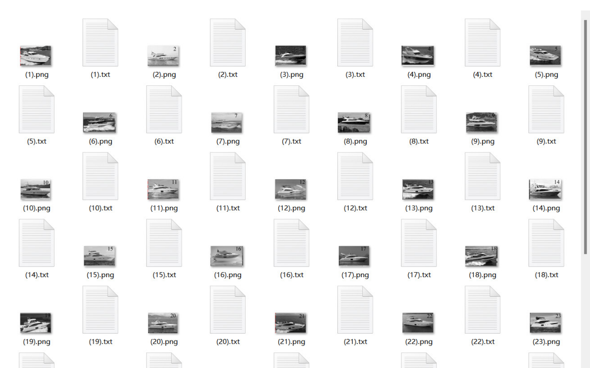


Fig.i “Text-image” pair

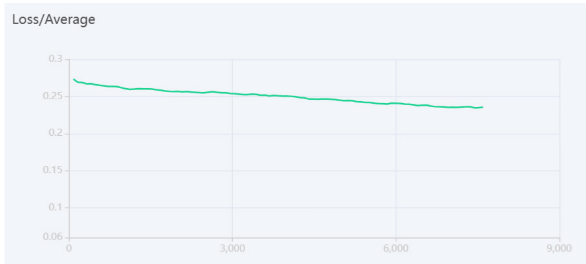
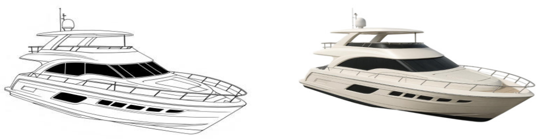


Fig.j Training loss curve of the fine-tuned Stable Diffusion model

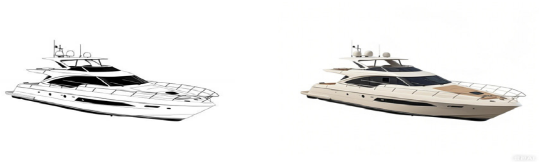
Fig.6 Stable Diffusion fine-tuning results: (e) prompt-image pair; (f) loss curve

To improve the contextual relevance and stylistic consistency of the yacht exterior renderings, a Stable Diffusion v1.5 model was fine-tuned on a custom dataset comprising annotated flybridge yacht design images. During training, the average loss curve shown in Figure 6 was recorded. The vertical axis indicates the average loss value, while the horizontal axis corresponds to the number of training iterations.As illustrated in the figure, the loss decreased steadily from approximately 0.27 to 0.23 over 9,000 iterations, demonstrating that the model converged effectively without significant oscillation or overfitting. The gradual slope suggests stable learning and good generalization capability, indicating the model successfully internalized design-relevant features such as hull proportions, line curvature, and superstructure configurations. The fine-tuned model was subsequently used to generate the design schemes in Figure 7, aligning well with the KANO-AHP-TOPSIS identified emotional attributes and user preferences.

Through systematic synthesis of the key design elements identified in the preceding analysis, multiple yacht models were developed, with three final selected designs shown in Figure 7.



Scheme 1 (Dynamic)



Scheme 2 (Majestic)

Scheme 3 (Liberated)

Fig.7 Three design schemes of Fei Qiao yachts

3.4.2 Yacht Exterior Design Evaluation Based on TOPSIS

To mitigate subjectivity in the decision-making process, the finalized design renderings were completed as shown in Figure 5. The three design alternatives were objectively ranked using the Analytic Hierarchy Process (AHP) model, with the 14 evaluation metrics from the sub-criterion layer serving as positive indicators for TOPSIS-based decision analysis. An expert panel comprising five naval architecture professors and four professional yacht operators evaluated the three design schemes using a 10-point scoring system (0-3: very poor; 3-5: poor; 5-6: moderate; 6-8: satisfactory; 8-10: excellent), with the final results determined through averaged scores.

The initial evaluation matrix (Table 6) was constructed as the foundation for analysis. The raw data were normalized using Eq. (1.7) to generate a vector-based normalized matrix, which was subsequently weighted according to Eq. (1.8) by incorporating predetermined priority weights, resulting in a weighted normalized matrix. The positive ideal solution (PIS) and negative ideal solution (NIS) were then calculated through Eqs. (1.9) and (1.10), with their spatial distributions graphically presented in Figure 7. Finally, the Euclidean distances from each alternative to both PIS and NIS were computed via Eqs. (1.11) and (1.12), while the relative closeness coefficients (C) were derived using Eq. (1.13). The complete ranking results are systematically summarized in Table 8.

Tab.6 Initial evaluation matrix of TOPSIS

	M1	*M2*	*M3*	*M4*	*O1*	*O2*	*O3*	*O4*	*O5*	*A1*	*A2*	*A3*	*A4*	*A5*
1	5.0	10.0	1.0	5.0	10.0	0.5	1.0	10.0	5.0	5.0	10.0	1.0	5.0	1.0
2	10.0	5.0	2.5	1.0	5.0	1.0	2.5	5.0	10.0	10.0	5.0	2.5	10.0	5.0
3	1.0	1.0	10.0	10.0	0.1	1.0	10.0	1.0	1.0	5.0	1.0	10.0	1.0	10.0

Tab.7 TOPSIS positive and negative ideal solutions

	M1	*M2*	*M3*	*M4*	*O1*	*O2*	*O3*	*O4*	*O5*	*A1*	*A2*	*A3*	*A4*	*A5*
A^+	0.467	0.277	0.160	0.095	0.419	0.263	0.160	0.097	0.062	0.373	0.245	0.073	0.163	0.146
A^-	0.047	0.028	0.016	0.010	0.042	0.027	0.016	0.010	0.006	0.187	0.025	0.007	0.016	0.015

Tab.8 Positive and negative ideal solution distance and relative closeness

Scheme	S_i^+	S_i^-	C
1	0.4237	0.5590	0.5689
2	0.3533	0.5902	0.6256

3	0.7433	0.2652	0.2629

In the TOPSIS evaluation, the relative closeness coefficient (C) reflects each design alternative's proximity to the ideal solution, where values approaching 0 indicate adjacency to the negative ideal solution (requiring improvement) and values nearing 1 demonstrate superior performance approximating the positive ideal solution. Scheme 2 achieved significantly higher closeness (C=0.82) than competing alternatives, attributable to its balanced integration of majesty (X5) and freedom (X10) - a design strategy that effectively caters to premium users' dual demands for both luxurious sophistication and dynamic expression, thereby validating the KANO-AHP weight allocation (X5: 38.7%, X10: 35.9%). The comprehensive ranking (Scheme 2 > Scheme 1 > Scheme 3) conclusively identifies Scheme 2 (visualized in Figure 8) as the optimal selection. These results collectively demonstrate the hybrid model's efficacy in flybridge yacht exterior design by systematically fulfilling user requirements, while the case study empirically confirms the feasibility of this methodological approach.

Fig.8 Design presentation diagram

Feasibility Validation of Scheme 2 Using Likert Scale Methodology.A questionnaire survey was conducted with 15 participants (10 yacht users and 5 industrial designers) to evaluate the feasibility of Scheme 2 through Likert scale scoring. Weighted average scores were calculated for both user groups' comparative assessments and comprehensive evaluations, with results presented in Figure 9. The analysis demonstrates that Scheme 2 achieved the highest score in the "majestic" attribute, successfully fulfilling its design objective of "projecting authoritative presence." Subplot (a) reveals strong consistency between both groups' ratings across most evaluation dimensions, with only minor divergences observed in select criteria, while subplot (b)'s elevated composite curve confirms balanced performance without significant compromises.

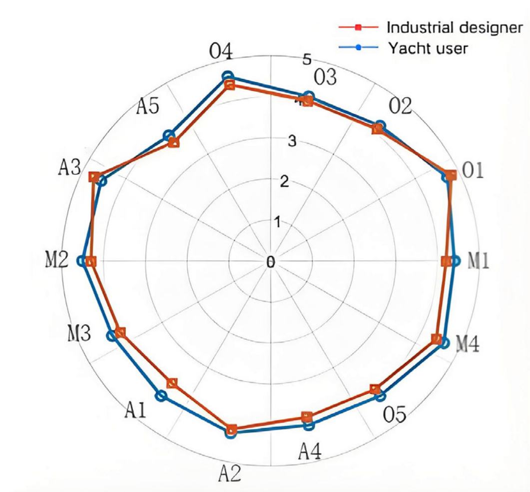


Fig.k Comparative Analysis Diagram

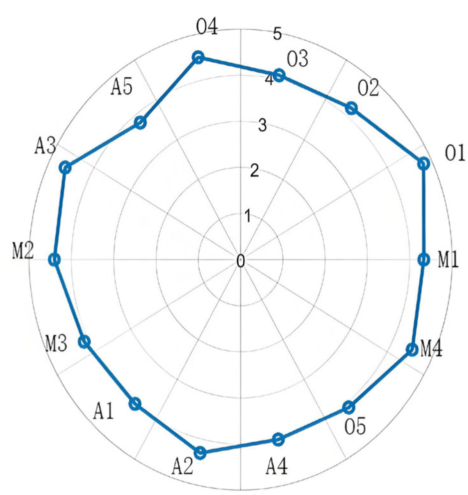


Fig.l Integrated Synthesis Diagram

Fig.9 Rating display chart

4 Conclusion

This study establishes a comprehensive evaluation model based on the KANO-AHP-TOPSIS framework to enhance the market competitiveness of yacht design, providing a systematic methodology for optimizing both styling and functional development. The research protocol first classified user requirements through the KANO model, identifying must-be, one-dimensional, and attractive attributes while introducing Importance Degree coefficients to precisely delineate design priorities. The AHP methodology then refined these findings via expert-weighted prioritization, ensuring objective and accurate quantification of design factors' relative significance. Subsequent grey relational analysis between perceptual descriptors and styling elements optimized emotional design expression. Ultimately, three distinct yacht design schemes were developed and systematically evaluated using TOPSIS to determine the optimal solution.

Beyond advancing yacht exterior and functional design, this research contributes theoretical foundations for future marine product innovation. The integrated model demonstrates an effective pathway for:Quantifying user needs through structured metrics;Data-driven design optimization;Scalable application to other luxury customized products.

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