

Research on the Design Method of High-Speed Rail Seat Shape Driven by Generative Artificial Intelligence

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Abstract: Moving beyond conventional paradigms, this study investigates the transformative integration of Generative Artificial Intelligence (GAI) within industrial design, proposing a novel framework specifically tailored for high-speed rail seat styling. The methodology commences with the extraction of consumer perceptual imagery regarding seating via user interviews and GPT-4o analysis. Subsequently, Midjourney is leveraged to translate these insights into a visual corpus of design alternatives. By defining target imagery and anchoring foundational geometries, candidate solutions are rigorously screened through a dual-track evaluation system. Furthermore, employing Rhino for geometric deconstruction and Stable Diffusion for rendering, the study executes a concrete recombination of design curves to yield innovative 3D prototypes. Empirical results substantiate that this GAI-augmented workflow not only reconciles aesthetic appeal with user perceptual expectations but also significantly catalyzes design efficiency and innovation, offering profound implications for the optimization of traditional design ecosystems.

Keywords: High-speed Rail Seats; Generative Artificial Intelligence; Industrial Design Process; Quantitative Evaluation.

1. Introduction

Generative AI (GAI) represents a frontier technology fundamentally altering established industrial design paradigms [1]. Utilizing large-scale data training and deep learning infrastructures, it enables the automated generation of multimodal content—spanning text, graphics, and 3D models—through natural language commands. This offers a disruptive solution for holistic optimization of the industrial design process [2].

The current academic landscape in this domain is defined by three converging trends in technological integration. Regarding conceptual design, Zhao Wenqiang's group utilized Peirce's semiotic theory to validate GAI's capacity for semantic interpretation [3]. Addressing methodological synthesis, Li Yuanfeng et al. proposed an AHP-GAI collaborative model for integrating user weighting analysis with concept generation [4], whereas Lu Peng's team constructed a GRA-GAI hybrid system targeting parameter optimization in detailed design [5]. In the sphere of requirements engineering, Du et al. established a GAI-driven pathway translating emotional demands into design elements through affective engineering [6], complemented by Wang's team who implemented morphological analysis and QFD to bridge conceptual proposals with engineering specifications [7]. Collectively, while these studies highlight the potential symbiosis of GAI with traditional design paradigms, they predominantly reside at the theoretical verification level, with a dearth of empirical evidence supporting holistic process application [8].

Focusing on the domain of high-speed rail seat styling, this study moves beyond isolated applications to systematically investigate the synergistic integration of text-to-text and text-to-image generative AI across the holistic design workflow [9]. To operationalize this integration, a robust validation framework is proposed, establishing a closed-loop GAI-driven ecosystem that seamlessly orchestrates requirement analysis, conceptual ideation, parametric refinement, and final visualization.

2. Methodological Framework

2.1. Proposal and Analysis of Design Issues for High-Speed Train Seating Configurations

High-speed rail seat design has always encountered two problems: to keep the brand image by means of distinctive features such as headrests and armrests, and to meet the ergonomic requirements and various aesthetic tastes [10]. In order to achieve a proper balance, this research applies GAI technology to establish an innovative procedure: firstly, by using ChatGPT to collect the emotional feedback from users and obtain relevant image-related words; secondly, using Midjourney to convert abstract needs into concrete designs; then, employing Rhino for structural division and reconstruction, together with Stable Diffusion to quickly produce three-dimensional renderings, thus reaching a dynamic coordination between brand recognition and users' emotional demands [11].

2.2. Implementation Steps for High-Speed Rail Seat Design Based on GAI

This segment delineates a structured GAI-integrated workflow for high-speed rail seat design, operationalized through four distinct phases: user requirement analysis, conceptual ideation, morphological reconstruction, and final visualization [12].

User Imagery Profiling: Grounded in the CRH400 seat as a benchmark, GPT-4o was deployed to synthesize emotional descriptors from user interviews and online forums. Subsequently, a refined set of eight candidate terms was evaluated by designers and users employing a 7-point Likert scale ($n=30$) [13]; the four highest-rated attributes—specifically 'technological' and 'lightweight'—were codified as primary design drivers.

Concept Synthesis: A specialized prompt library was engineered around these core descriptors, augmented by contextual modifiers (high-speed rail seat). Leveraging Midjourney's advanced semantic translation capabilities via

the /imaginecommand, a diverse array of seat design alternatives was batch-generated, thereby constructing a robust target imagery repository [14].

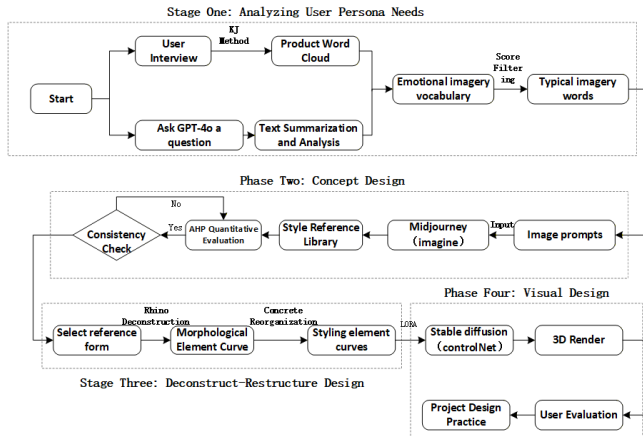


Figure 1. Design Flowchart

Morphological Reconfiguration: Utilizing the CRH400BF seat as the foundational prototype, morphological analysis was applied to deconstruct the design into five constituent elements: backrest, cushion, armrests, tray table, and headrest [15]. In Rhino, Bézier curves were employed to precisely redraw these components from both baseline and reference models. Through figurative recombination, these elements were synthesized to harmonize

cultural heritage with contemporary aesthetics, yielding viable candidate schemes.

Photorealistic Rendering: The finalized line drawings were imported into Stable Diffusion, utilizing ControlNet and LoRA models within an 'img2img' pipeline to produce high-fidelity 3D prototypes, thereby actualizing the design implementation.

3. Case Study

Based on the previous implementation procedures, this part will describe the particular procedure of the GAI-based seating design method in high-speed train applications.

3.1. Analysis of User Image Requirements

GPT-4o was instructed to extract user-oriented imagery adjectives by using a segmented questioning method. Firstly, it classified the descriptive words from the positive reviews of high-speed rail websites. Secondly, it found the important design features (backrest, cushion and armrests) related to these words. At last, it produced a list of 50 imagery adjectives which reflected the passengers' perceptual requirements.

Subsequent evaluation of the CRH400 seat was operationalized through a 7-point Likert instrument grounded in eight candidate descriptors. Based on 30 valid responses, the mean scores for each term were calculated, with results presented in Table 1.

Table 1. Average score for the subjective evaluation of seat quality on high-speed trains

Sample	Vocabulary of emotional imagery	Quantitative Score							average
	futuristic	-3	-2	-1	0	1	2	3	2.12
	smooth	-3	-2	-1	0	1	2	3	2.02
	safe	-3	-2	-1	0	1	2	3	1.87
	comfortable	-3	-2	-1	0	1	2	3	1.54
	elegant	-3	-2	-1	0	1	2	3	1.32
	conventional	-3	-2	-1	0	1	2	3	1.21
	distinctive	-3	-2	-1	0	1	2	3	0.18
	luxuriant	-3	-2	-1	0	1	2	3	0.02

3.2. Concept Design

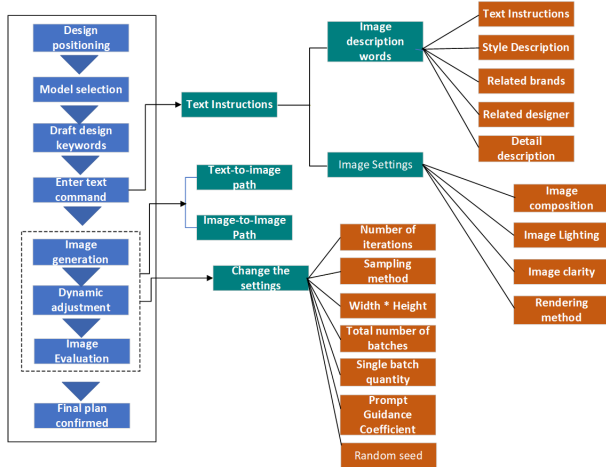


Figure 2. Design workflow for AIGC image generation

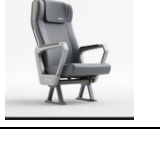
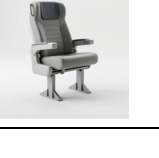
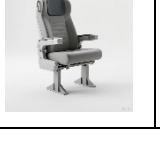
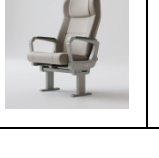
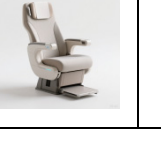
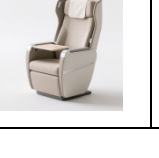
Identify four representative imagery adjectives as key cue phrases for Midjourney, and designate "high-speed rail," "seat design," "industrial design," "3D," "C4D," "white background [16]," and "high quality" as essential cue phrases. The raw image processing workflow is illustrated in Figure2.

Testing confirmed that the complete prompt sequence and its internal phrases were determined as: "high-speed rail seat design, futuristic/fluent/safe/comfortable, high-speed rail, industrial design, white background, 3D, C4D, high quality." Subsequently, these four key phrase combinations were sequentially input into Midjourney's "/imagine" command; each combination generated eight high-speed rail seat designs after two runs [17]. Together, the four key phrases produced $4 \times 8 = 32$ front-end designs, forming a reference library of seat designs as shown in Table 2.

3.3. Separation Structure – Concrete Reorganization Design

The Fenghuo CR400BF-Z is China's next-generation intelligent high-speed train, featuring a biomimetic streamlined front end optimized for aerodynamics, which significantly reduces both operational drag and noise levels. This study adopts the train's seating configuration as its foundational design element (Figure3) and, aligning with the brand's positioning of "future-oriented innovation," identifies "comfort" as the core conceptual focus [18].

Table 2. High-Speed Rail Seat Reference Library

futuristic				futuristic			
							
							
safe				comfortable			
							
							

To select the reference design, the study combined consumer perceptual evaluations with AHP expert assessments to evaluate eight candidate options (Com1–Com8). Consumer perception (n=49) gauged alignment with the 'comfort' construct via a 0–1 metric, while expert appraisal (n=12) utilized a 1–9 scale to evaluate 'sportiness' through

pairwise comparison matrices. As delineated in Table 3, the convergent validity of these evaluations was statistically substantiated, revealing a pronounced positive correlation ($r=0.954$, $p<0.01$). Consequently, the highest-ranked scheme, Com1, was designated as the definitive reference design.

Table 3. Quantitative evaluation results based on AHP and consumers' subjective evaluations

Expert evaluation												User review	
	Com1	Com2	Com3	Com4	Com5	Com6	Com7	Com8	Mean value	Weight	rank	score	rank
Com1	1	1.11	1.43	4.23	1.33	1.82	3.36	2.37	1.84	0.20	1	0.81	1
Com2	0.90	1	1.29	3.60	1.20	1.64	2.77	1.80	1.59	0.18	2	0.79	2
Com3	0.70	0.78	1	2.81	0.93	1.26	2.22	1.42	1.23	0.13	4	0.78	3
Com4	0.24	0.28	0.36	1	0.31	0.45	0.73	0.52	0.45	0.06	8	0.65	7
Com5	0.75	0.83	1.07	3.25	1	1.36	2.43	1.53	1.36	0.16	3	0.74	4
Com6	0.55	0.61	0.79	2.20	0.73	1	1.56	1.10	0.96	0.12	5	0.72	5
Com7	0.30	0.36	0.45	1.43	0.42	0.64	1	0.70	0.58	0.07	7	0.63	8
Com8	0.42	0.56	0.71	2.00	0.68	0.90	1.42	1	0.86	0.10	6	0.67	6
Pearson correlation coefficient (i) = 0.954, $p < 0.01 \Rightarrow$ The correlation is significant													

In Rhino, cubic B-spline curves were applied to outline the main contour features of both the standard model and the base model (backrests, seat cushions, armrests, small tables and

headrests), and then normalization was carried out to guarantee accurate and efficient integration in the subsequent modeling process.

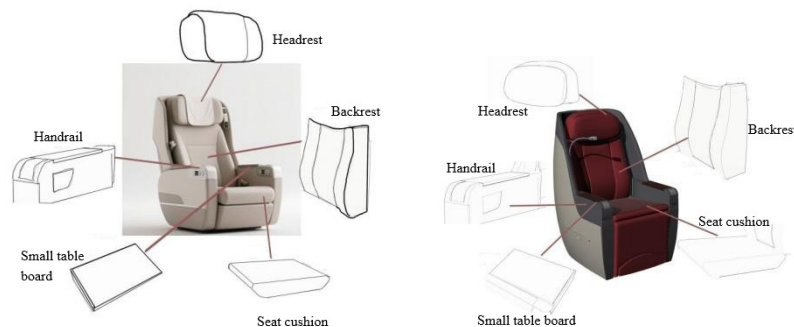


Figure 3. Separation and Deconstruction Processing

Both the baseline and reference designs were subjected to morphological decomposition, isolating five discrete components: headrest, armrests, tray table, backrest, and seat cushion. The creative transformation was actualized through the extraction of characteristic curvilinear geometries, which were subsequently reorganized according to visual syntax to achieve a state of 'disconnected forms with interconnected essence' (Figure 3). Crucially, this process transcended mere segmentation; it strategically employed integration, stratification, and exaggeration to construct a seating schema that balances cultural identity and formal aesthetics with enhanced rhythmic cadence [19].

On the basis of this foundation, we used a minimalist design language to modify the forms, and incorporated the obtained curved parts into a new scheme which blends cultural uniqueness with modern visual attractiveness (Figures 4 and 5).

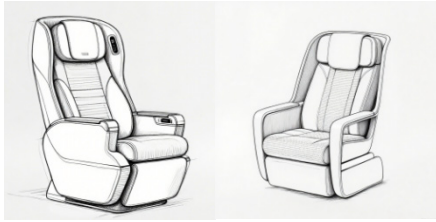


Figure 4. Alternative reference design (post-recombination)

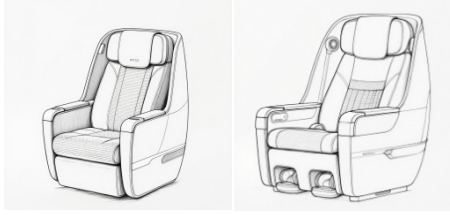


Figure 5. Alternative basic modeling scheme (after recombination)

3.4. Visualization Design

To more accurately represent the design alternatives, this study employed the ControlNet image preprocessing plugin from Stable Diffusion [20] in conjunction with CivitAI's publicly available LoRA model "car design" (unique identifier Hash value: 6037C05A) to transform the shape curves of two alternative designs into three-dimensional prototypes. As shown in Figure 6, these 3D renderings not only achieve realistic visual effects but also demonstrate excellent fidelity in reproducing the shape curves.



Figure 6. The first set of visualization schemes



Figure 7. The second set of visualization schemes

4. Design Evaluation

To verify the feasibility of the design results, participants were invited to evaluate two alternative options (see Figures 6 and 7). This study employed AHP for quantitative evaluation of the alternatives and collected participants' qualitative assessments through paired comparison questionnaires. The specific evaluation criterion was: "Compared to Alternative A, how much more active is Alternative B?" with a scoring scale of {1, 3, 5, 7, 9}. A total of 50 questionnaires were distributed for both groups, with 45 valid responses collected (25 males and 20 females, aged 26–49 years). Statistical results for the four alternatives in Group 1 are presented in Table 4, while those for Group 2 are shown in Table 5.

Table 4. AHP evaluation results for the first group of alternative options

	Solution 1	Solution 2	Solution 3	Solution 4	mean	weight	sort
Solution 1	1	1.15	2.83	5.42	2.05	0.42	1
Solution 2	0.88	1	2.05	4.37	1.67	0.32	2
Solution 3	0.35	0.52	1	2.12	0.76	0.15	3
Solution 4	0.17	0.23	0.39	1	0.39	0.08	4

Table 5. AHP evaluation results for the second group of alternative options

	Solution 5	Solution 6	Solution 7	Solution 8	mean	weight	sort
Solution 5	1	1.14	1.53	2.75	1.47	0.34	1
Solution 6	0.90	1.04	1.23	2.63	1.35	0.30	2
Solution 7	0.45	0.59	1	2.12	0.90	0.23	3
Solution 8	0.32	0.34	0.65	1	0.50	0.12	4

Statistical data indicate that the exercise intensity priorities for the two alternative schemes are as follows: Group 1 (Scheme 1 > 2 > 3 > 4), Group 2 (Scheme 5 > 6 > 7 > 8). As shown in Figure 7, a higher proportion of reference shape

curves aligns better with the "comfort" objective; conversely, a greater emphasis on the base shape curve enhances brand family identity. Compared to a single combination approach, the two curve integration strategies proposed in this study

enable precise balancing of users' emotional needs and brand recognition through flexible adjustment of blending ratios, thereby achieving diverse design outcomes.

5. Conclusion

The GAI-driven high-speed rail seat design methodology revolutionizes the entire process—from imagery requirement analysis to conceptual design, detailed design, and visualization design—by integrating ChatGPT, Midjourney, and Stable Diffusion. ChatGPT identifies and refines passengers' comfort requirements and functional preferences during the imagery analysis phase, providing guidance for ergonomic design; Midjourney transforms subjective needs into design references for seat morphology, materials, and interaction interfaces during the conceptual phase, complementing parametric ergonomic modeling to balance brand identity with user experience innovation; Stable Diffusion leveraging ControlNet and LoRA rapidly generates multi-angle 3D renderings during visualization, significantly enhancing design iteration efficiency while reducing prototyping costs. Furthermore, combining GPT-4o with traditional passenger behavior observation enhances the contextual depth and cultural adaptability of user requirement analysis. Cross-verifying Midjourney-generated seat designs with finite element analysis and human-computer interaction simulations minimizes design deviations and ensures seats meet engineering standards in terms of safety, durability, and riding comfort.

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