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An Exploration of the Application of Bionic Design Methods in the Design of Miniaturized Personal Vehicles

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Abstract: With the acceleration of urbanization and the deepening of the concept of sustainable development, miniaturized personal transportation vehicles have become a key carrier for solving the "last mile" travel demand. However, current market products generally face the dilemma of homogenized styling and a lack of emotional value. Meanwhile, biomimetic design, as an interdisciplinary innovation method, provides a new perspective for breaking through this bottleneck. This study aims to systematically explore the application value and practical path of biomimetic design methods in the styling of miniaturized personal transportation vehicles. Through literature review, case analysis, and morphological deconstruction, it deeply analyzes the internal logic and manifestations of three application modes: morphological biomimetic, functional biomimetic, and imagery biomimetic. The study finds that biomimetic design can endow products with natural beauty and vitality through organic forms, optimize aerodynamic performance and lightweight structure with biological prototypes, and evoke emotional resonance in users through abstract imagery. The study further proposes an integrated strategy of "form-function-emotion," emphasizing that the selection of biological prototypes should be deeply aligned with user cognition and usage scenarios. Despite the challenges of engineering implementation and over-mimicry, biomimetic design combining intelligent interaction and sustainable technologies will become an important evolutionary direction for future personalized mobility experiences. This study provides a theoretical basis and practical inspiration for constructing miniaturized transportation vehicles that combine aesthetic value, functional rationality, and emotional warmth.

Keywords: Bionic design; Miniaturized personal transportation; Styling design; Biomimetic form; Biomimetic function

1 INTRODUCTION

With the continuous acceleration of global urbanization, population growth and the surge in the number of motor vehicles have led to a series of serious urban problems such as traffic congestion, environmental pollution and energy shortage. Against this backdrop, miniaturized personal transportation tools, represented by electric scooters, balance bikes and folding electric bicycles, are rapidly transforming from marginal leisure products into key solutions for urban "last mile" travel due to their advantages of flexibility, convenience and environmental friendliness, and have ushered in unprecedented market opportunities and development waves [1]. At the same time, the field of industrial design is undergoing a profound paradigm shift. Bionic design, as an innovative methodology that crosses biology and design, is no longer limited to the simple imitation of natural forms but is increasingly delving into the reference and learning at the functional, structural and even system levels, providing an endless source of inspiration for creating efficient, harmonious and sustainable man-made objects [2]. Therefore, at the intersection of these two trends, exploring how to systematically apply biomimetic design methods to the styling of miniaturized personal vehicles is not only valuable in enhancing the aesthetic appeal of the product, but also in optimizing its aerodynamic performance, achieving structural lightweighting, enhancing the emotional connection with users, and ultimately promoting its deeper level of sustainable development. This has significant theoretical and practical value.

At the academic research and industrial practice levels, the combination of biomimetic design and transportation has shown broad prospects. Internationally, from university research institutions to well-known enterprises, many cutting-edge explorations have been carried out. Such as the Mercedes-Benz biomimetic concept car draws inspiration from the skeletal structure of the boxfish, achieving low wind resistance while obtaining extremely high structural strength, while some high-end bicycle brands abroad have long studied the aerodynamic characteristics of bird feathers to optimize the frame styling [3]. In contrast, domestic research and practice are also steadily advancing. The academic community is increasingly exploring theoretical models of biomimetic design, and the industry has also seen the emergence of electric scooter products that borrow from biological forms in some aspects of their styling. However, a comprehensive review of existing research reveals that foreign studies are mostly focused on high-performance automobiles or aerospace, while domestic studies tend to focus more on macroscopic theories or home product applications. Systematic and in-depth research on biomimetic design specifically targeting the category of "miniaturized personal vehicles" is still relatively weak [4]. Existing research either emphasizes morphological appearance or is limited to single functions, failing to form a complete methodological system from biological prototype selection to styling language transformation and user experience verification. This leaves clear room for the development of this research.

Based on the above background and current situation, this study aims to systematically construct a set of biomimetic design methods applicable to miniaturize personal vehicles. This paper will first clarify the core ideas and hierarchical divisions of biomimetic design and define the styling characteristics and design challenges of miniaturized personal vehicles. Then, it will focus on analyzing the specific application paths and expression techniques of different modes such as morphological biomimetic, functional biomimetic, and imagery biomimetic in the styling design of this type of product. To verify the feasibility of the theory, this paper will also select representative design cases from home and abroad for in-depth analysis, explaining their biomimetic logic and design gains and losses [5]. Ultimately, this study aims to extract guiding design strategies and envision their future integration with intelligent and sustainable concepts. To achieve these research objectives, this paper will primarily employ literature review to clarify the theoretical foundation, case study analysis to interpret practical examples, and morphological analysis to compare and deconstruct biological characteristics and design elements, thus forming a clear research technical route from theory to practice, and from analysis to synthesis.

2 RELEVANT THEORETICAL FOUNDATIONS AND CONCEPTUAL DEFINITIONS

Bionics is an ancient yet young discipline. Its origins can be traced back to early human imitation of nature, but as an independent interdisciplinary field, it formally emerged in the mid-20th century. Its name derives from the Greek words "bios" (life) and "mimesis" (imitation), aiming to draw inspiration from the structure, function, processes, and systems of organisms to solve technological challenges. This concept gradually permeated the field of design, forming biomimetic design. It transcends early, simple, and representational copying of forms; its core idea lies in exploring and learning the "successful strategies" optimized by nature over millions of years of evolution, thereby achieving a sublimation from "formal resemblance" to "spiritual resemblance." Specifically, biomimetic design can be divided into several interconnected levels: the most basic form biomimetic focuses on the outline, lines, and texture of the organism's exterior; functional and structural biomimetic delves into the internal mechanisms by which organisms achieve specific functions, such as drag reduction, load bearing, or reversal; color and texture biomimetic learns from the organism's camouflage, warning, or communication mechanisms; and the highest level, imagery biomimetic, extracts the spiritual temperament and emotional characteristics inherent in the organism and expresses them in an abstract artistic way [6]. To achieve this multi-level design transformation, a systematic process is crucial, usually starting with clear "biological identification" and problem definition, followed by "principal analysis and feature extraction" of the selected biological prototype, and finally, through artistic techniques such as abstraction, simplification, and exaggeration, completing the "design transformation and integration" into the man-made object.

After clarifying the methodology, we must focus on the specific object of this study-miniaturized personal transportation vehicles. These products usually refer to compact vehicles owned and used by individuals, primarily powered by electricity or human power, designed to provide convenient and flexible mobility solutions for short-distance travel. Its scope broadly encompasses various forms such as electric scooters, balance bikes, electric bicycles, folding mobility scooters, and emerging electric unicycles [7]. Compared to traditional cars or motorcycles, their physical scale is significantly reduced, which directly shapes their unique styling language and user experience. In terms of styling, they need to integrate power, control, and load-bearing units within extremely limited space, which makes their form often highly integrated and structurally exposed, with the layout of components directly defining the overall outline. In terms of user experience, the interaction between users and products is more intimate and direct, with the posture shifting from "riding" to "standing" or "riding," and the operation method is more intuitive and dynamic. Therefore, the styling design must closely serve the comfort of human-computer interaction, the intuitiveness of operation, and the convenience of carrying and storing.

Although the market is flooded with products, the current styling design of miniaturized personal transportation vehicles is facing homogenization and innovation bottlenecks. Many products have fallen into a cycle of "micro-innovation" of a few successful models, or are constrained by the inherent engineering architecture, resulting in a conservative and similar overall design language, mainly consisting of simple geometric blocks and tubular structures, lacking distinct brand recognition and emotional appeal. This bottleneck stems from compromises in cost control and manufacturing processes on the one hand and reflects an overemphasis on the "transportation" attribute in design thinking, while ignoring its fashion attributes and emotional value as a personal technology consumer product [8]. When users face a bunch of similar looking "metal skeletons", it is difficult to generate a deep emotional resonance and identity. Therefore, how to break through the existing design paradigm and inject new vitality into such products has become an urgent problem to be solved. This is precisely the area where bionic design methods can play a significant role, providing a set of solutions that are derived from nature, time-tested, and full of aesthetic appeal.

3 ANALYSIS OF THE APPLICATION PATTERNS OF BIONIC DESIGN IN TRANSPORTATION VEHICLE DESIGN

Integrating biomimicry into the design of miniaturized personal vehicles is not a singular operation, but rather a multi-layered and multi-dimensional application mode based on different design goals. The most intuitive of these is morphological biomimicry, which directly affects the visual aesthetics of the product. It aims to capture and transform the external morphological characteristics of organisms in nature, giving the product an organic sense of life and visual appeal. This imitation can be a grasp of the overall outline of an organism. Such as the smooth back curve of a cheetah when it runs or the agile body of a dolphin when it swims can be transformed into the main frame lines of an electric scooter or electric bicycle, so that it contains dynamic tension even when it is static [9]. At the same time, morphological biomimicry is also exquisitely reflected in the depiction of local details. Such as the headlights are designed to mimic the sharp pupils of felines, which not only creates a unique visual identity, but also optimizes the lighting beam effect in terms of function; or the foot pedals are inspired by the shape of a leaf with distinct veins, which adds a natural aesthetic interest while satisfying the pedaling function. This kind of figurative or semi-figurative form borrowing can quickly establish an emotional connection between users and nature, reducing the sense of alienation from cold machinery.

However, excellent design is not just about appearance; its deeper value lies in the perfect unity of function and form, which is the core pursuit of functional biomimicry. Functional biomimicry breaks away from the direct imitation of shape and instead delves into the efficient mechanisms that organisms have optimized to adapt to the environment during long evolution and apply these principles to improve product performance. In terms of aerodynamics, why can the albatross's outstretched airfoil achieve long-distance efficient gliding, and why does the tuna have such low fluid resistance? These natural mysteries provide a continuous source of inspiration for optimizing the drag coefficient of small vehicles when traveling at high speeds, and their shapes may present a streamlined form sculpted by "airflow" [10]. In terms of structural mechanics, natural features such as the hexagonal grid structure of honeycomb, the hollow and segmented stems of bamboo, or the complex internal support system in bones all demonstrate the optimal solution for achieving maximum stiffness and strength with minimal materials. Applying these structural principles to the design of load-bearing components such as frames and wheels can achieve extreme lightweighting while ensuring safety, thereby directly improving the vehicle's range and handling agility.

Beyond the practical aspects of form and function, the highest level of biomimetic design lies in the communication of imagery. Imagery biomimicry is no longer confined to specific biological forms or physical mechanisms, but rather strives to capture and refine the spirit, movement, or cultural symbolism inherent in a particular organism, and injects it into the product through abstract design language [11]. Such as a personal vehicle designed to convey the concept of "speed" might not directly replicate the cheetah's spots, but rather abstractly

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express this sense of speed and aggression through a sharp forward lean, taut muscle lines, and a poised stance. Similarly, to convey the imagery of "stability and reliability," designers might draw inspiration from the steady gait of an elephant or the sturdy shell of a beetle, using a low center of gravity, wide wheelbase, and a full, powerful volume to create a sense of visual stability. This design pattern endows products with a strong personality and narrative ability, elevating them from simple means of transportation into symbolic objects that can resonate with users spiritually, express individuality and attitudes towards life, and greatly enrich the cultural connotation and emotional value of the products.

4 BIOMIMETIC DESIGN PRACTICES AND CASE STUDIES OF MINIATURIZED PERSONAL VEHICLES

To place the theoretical models under real-world scrutiny, this section selects three representative conceptual designs or market products in bionics applications as analytical objects. The selection criteria for these cases are based on the typicality of their bionic prototypes, the clarity of their design goals, and the differences in their application levels, aiming to form an analytical spectrum that covers multiple dimensions such as form, function, and imagery [12]. Our analysis will unfold around a unified framework: first, identifying the biological prototypes and core demands of their bionic designs; then, deconstructing the transformation path and specific techniques from biological characteristics to design language; and finally, evaluating the comprehensive effects achieved in terms of aesthetics, function, and user experience.

First, we examine an electric scooter design based on the "cheetah." The core goal of this design is to convey an extreme sense of speed and agility. Its bionic logic transcends simple pattern pasting, deeply capturing the dynamic posture and physiological characteristics of the cheetah as the king of land speed. The designers highly abstracted and refined the streamlined spine, taut muscle lines, and powerful limb proportions of a cheetah in motion, translating them into the low-slung, forward-leaning frame of a scooter, its slender yet powerful neck (stance), and its wide, grippy rear wheel. This not only creates a dynamic aesthetic of poised readiness in a static state but also optimizes drag reduction in aerodynamics. When users perceive this design, even when stationary, they can quickly associate it with the cheetah's speed, thus emotionally establishing an expectation and recognition of the product's high performance, satisfying the user's psychological need for efficiency and excitement.

In stark contrast is a balance scooter design inspired by the shape of a beetle. The beetle provides a perfect biological metaphor for this type of product: robust, stable, and efficiently stored. The ingenious design lies in its integrated, beetle-elylope-like shell, which not only gives the product a unified, robust visual texture but also physically protects the delicate internal components. Its low and wide chassis proportions mimic the stable, ground-hugging posture of a beetle, effectively enhancing the user's sense of psychological security while riding [13]. More ingeniously, some conceptual designs transform the tightly closed shape of a beetle's elytra when stored into a foldable or retractable structure for the balance bike's pedals, allowing the product to present an extremely compact and regular geometric shape when not in use, greatly improving portability. This case fully demonstrates how biomimetic design can perfectly integrate aesthetics, protective structure, and practical function.

The third case focuses on a biomimetic "dolphin" electric bicycle, designed to achieve a smooth riding experience and excellent low wind resistance. Dolphins, as swimming champions in the ocean, have a perfectly streamlined body that greatly reduces water friction. Inspired by this, the designers revolutionized the traditional tubular frame of the electric bicycle, encasing it in a smooth, continuous, seamless shell. The front, seat, and rear wheel cover form a coherent, organic curved surface, like the body of a dolphin. This design not only gives a soft, friendly, and high-tech feel in appearance, but also directly brings a significant improvement in aerodynamic performance, helping to extend the riding range. It conveys an image of elegance, efficiency, and harmony with the environment, attracting users who value environmental protection, pursue a high quality of life, and enjoying a quiet riding experience.

Through in-depth analysis of the three typical cases above, we can gain a series of valuable design insights. First, different biomimetic objects naturally point to different design priorities: the cheetah-inspired design emphasizes dynamic imagery and speed performance, the beetle-inspired design focuses on structural protection and space efficiency, and the dolphin-inspired design focuses on fluid optimization and an elegant experience. This suggests that designers must precisely align the choice of biomimetic prototype with the core positioning of the product and the needs of the target users. Second, from the perspective of user cognition and emotional feedback, a successful biomimetic design can instantly activate positive associations and emotional memories of the creature in the user's mind, thus forming a strong sense of product identification. A scooter with a cheetah-like posture will be seen as a "high-performance toy," while a beetle-like balance bike is more likely to be seen as a "reliable partner." This emotional connection that transcends practical function is the most valuable competitive advantage that biomimetic design brings to miniaturized personal vehicles. It allows cold industrial products to integrate into the user's emotional world and become a vivid expression of personal style and lifestyle.

5 FUTURE-ORIENTED DESIGN STRATEGIES AND TREND OUTLOOK

Based on the preceding analysis of theory and practice, we can systematically construct a biomimetic design strategy for future-oriented miniaturized personal transportation vehicles. The primary strategy lies in promoting the deep integration of "form-function-emotion," meaning that design should not merely give a product a biological shell, but should pursue the synergistic unity of aesthetic appeal, performance optimization, and emotional resonance. Such as a biomimetic kingfisher beak-like shape should simultaneously be a vehicle for achieving low wind resistance and a conveyor of agility and precision. Second, the selection of biomimetic prototypes must be strategically sound, deeply integrating the psychological characteristics and usage scenarios of the target user group. For young, thrill-seeking users, prototypes like cheetahs or peregrine falcons can quickly evoke resonance; while for urban commuting women, the elegance of a swan or the agility of a cat might better suit their emotional needs. Finally, the emergence of new materials and advancements in new processes have provided unprecedented possibilities for realizing biomimetic forms. Such as 3D printing technology can efficiently manufacture the complex internal topology of biomimetic skeletons, while the application of color-changing materials allows the dynamic colors of a biomimetic chameleon to adapt to different environments, thus pushing biomimetic design from static to dynamic.

However, while embracing the enormous potential of biomimetic, we must also be keenly aware of the challenges and limitations it faces in practical applications. The most prominent contradiction lies in the conflict between many highly optimized biological forms and existing engineering manufacturing and cost control requirements. Natural forms are often complex, organic, and non-standardized, while industrial production tends towards simplicity, geometrication, and standardization; the balance between these requires repeated weighing. Furthermore, an overemphasis on biomimetic forms may lead to compromises in functionality or safety. Such as sacrificing standard battery layout space to perfectly replicate the curves of a certain organism or weakening the strength of critical load-bearing structures in pursuit of visual lightness-these are pitfalls to be wary of in design. Therefore, biomimetic design must adhere to the fundamental principle of "design following function." All form borrowing should be done while ensuring the core functionality, safety, and ergonomics of the product, avoiding the pitfalls of formalism.

Looking to the future, biomimetic design in miniaturized personal transportation will exhibit several exciting development trends. Firstly, it will be deeply integrated with intelligent interaction technologies. Future biomimicry will no longer be limited to static shapes but will extend to dynamic, responsive interactive logic. Vehicles can perceive user intentions and environmental changes through distributed sensors, much like living organisms. Their lights might communicate with each other like fireflies, and their obstacle avoidance systems could mimic echolocation, achieving more natural and safer interactions. Second, biomimicry will play a more central role in sustainable design, expanding its scope from individual organisms to entire ecosystems. We can envision a vehicle whose energy system mimics plant photosynthesis, whose materials can degrade naturally like leaves, and whose maintenance mechanisms borrow from the self-healing mechanisms of organisms, thus forming a complete sustainable closed loop from production and use to recycling. Finally, with the maturity of flexible manufacturing and user data modeling technologies, personalized and customized biomimetic design will become possible. Users will no longer passively accept mass-produced designs but can choose or even co-create unique biological prototypes as the design blueprint for their personal vehicles based on their own preferences, making transportation a true extension and expression of personal identity and opening a new section in human-machine relationships.

6 CONCLUSION

This study systematically explores the application of biomimetic design methods in the styling of miniaturized personal vehicles. Through a combination of theoretical and case studies, we clearly reveal that biomimetic is not merely a superficial technique of form imitation, but a systematic and innovative methodology that deeply integrates aesthetic appeal, functional effectiveness, and emotional value. The study first constructs a multi-layered theoretical framework for application models, from form and function to imagery. Then, through the analysis of specific design practices, it confirms the significant value of this method in enhancing product visual appeal, optimizing aerodynamics and structural performance, and establishing a deep emotional connection with users. This research not only deepens our understanding of the connotation of biomimetic design but also provides a path derived from nature and proven effective in practice for overcoming the current predicament of homogenized product styling in the market.

The innovation of this study is mainly reflected in three aspects. First, it lies in the focused and deepened research perspective, specifically constructing a systematic biomimetic design framework for the specific and increasingly important category of "miniaturized personal vehicles," thus making up for the fragmentation and deficiencies of existing research in this field. Second, this study proposes a core strategy of integrating "form, function, and emotion," emphasizing that successful biomimetic design must involve the synergistic effect of these three levels, rather than a simple replication of a single dimension, providing more guiding principles for design practice. Finally, it forward lookingly combines biomimetic design with future trends such as intelligent interaction, sustainability, and personalized customization, expanding the boundaries of this research direction and indicating its enormous potential and evolutionary direction.

While this research has achieved certain results, some limitations remain. The case studies in this paper are mostly based on conceptual designs or limited products already on the market, lacking empirical data that precisely quantifies the emotional feedback of biomimetic forms through many user samples. This makes the analysis of user emotional aspects rely more on theoretical deduction and case observation. Furthermore, regarding the specific contradictions between biomimetic design and engineering manufacturing and cost control, this study mainly remains at the level of qualitative discussion, failing to establish a more in-depth trade-off model. These shortcomings also point the way for future research: follow-up work can incorporate empirical methods such as user surveys and eye-tracking experiments to more scientifically measure users' cognitive and emotional responses to various biomimetic shapes; at the same time, it can strengthen interdisciplinary research with the engineering field to explore better solutions for achieving complex biomimetic forms under current technological conditions. We believe that with the advancement of technology and the continuous evolution of design thinking, biomimetic design methods will play an increasingly irreplaceable role in shaping a more efficient, harmonious, and engaging personal mobile experience in the future.

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