Extraction and evolution of grader's bionic morphological feature line using shape structure behavior function model

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Abstract: To improve the innovation of agricultural machinery product styling, this paper proposes a shape structure behavior function (SSBF) model suitable for the industrial design field. The feature line evolution method combining shape grammar and genetic algorithm was used for modelling the of the grader, which not only maintains the product style characteristics but also reflects the typical identification characteristics of the bionic prototype and produces a new product modelling scheme. By conducting cognitive and recognition experiments on product styling features, the ranking of product styling features and the contribution of each component to product styling were determined. The method of combining shape grammar and quadratic Bézier curve was used to express and encode feature lines, and genetic algorithm was used to evolve biomimetic forms to form product feature lines with typical biological morphological features; The extracted form bionic elements were integrated into the grader modelling design, and the interaction evaluation was carried out through the genetic algorithm evolution scheme. The basic form elements were extracted and analyzed, and the deduction rules were formulated and reorganized. The derived feature line geometric data considered the product's image features and the bio-inspired prototype, which can be used for the follow-up guidance of industrial design schemes.

Keywords: bionic design, shape-structure-behavior-function, SSBF, biologically inspired design, BID, shape grammars, Quadratic Bézier curves
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1 Introduction

The application of biomimetic modelling in the fields of engineering machinery and agricultural machinery is becoming increasingly frequent[1].The key to biomimetic modelling design is to extract and apply biological form feature lines to the target product while preserving the image perception of the biological prototype, forming a modelling style feature consistent with the biological prototype's image perception[2]. The biological form is a phenotype in biological genetics, and product styling feature lines are dominant features that form and evolve product style features. The shape feature line is the main factor determining the product styling style, which can clearly and effectively indicate the product shape features. The line organization relationship of the product contour and the proportion contour relationship of the lines will directly affect the results of styling design[3].

Design Bionics takes the form, color, function, structure, and even sound of various living creatures in nature as the object of study and adopts design-related product innovation design theories to provide new ideas, principles, methods, and approaches for design. Design methods that use knowledge related to the field of biology to stimulate design thinking and thus solve engineering problems through the simulation of biological phenomena or processes can provide an endless source of creativity for design thinking. Among them, Liu et al.[4] proposed a structured bio-inspired design framework to utilize bio-inspiration for smart product design. Biomorphology-inspired design mainly imitates biological structures and forms, making products with typical morphological characteristics of living things, showing bionic morphological imagery, and forming unique product style features. Any product has lines forming its outline, and morphological bionic design should pay attention to the line organization relationship of the product outline and adjust the product morphological feature lines by determining the relationship between imagery and feature lines, which can better generate product styling design solutions that meet the user's perceptual imagery.

Shape grammars are applied in the field of product styling design to analyse, describe and generalize existing product features, as well as to reproduce and develop original product features to form new product style features[5]. One of them, James McDermott[6], proposed a new interactive evolutionary 3D design system based on shape grammars. The results of a user-driven run were demonstrated, reflecting the flexibility of the representation. Ruiz-Montiel et al.[7] gave some fuzzy generalizations for deriving and computing concepts with shape grammars. Fuzzy definitions were provided for rule application and shape matching, and software prototypes were developed to test these ideas. Terry Knight et al.[8] adapted the shape grammar to a grammar for computing things and proposed a computational theory of shape algebraic manufacturing based on the shape grammar for design and

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manufacturing. Su et al.[9] applied shape grammar for innovative research in order to study how to make the shape design of mechanical equipment can be effectively continued, which can provide ideas and methods for a series of subsequent shape designs.

2 Overall design requirements

The product design feature lines are generally free curves. The design genes belong to physical appearance features, mainly composed of external biological forms with recognition features and the evolution of product design feature lines. These biomimetic genetic units, whether appearing in conjunction with organisms as a whole or individually, have strong biometric recognition, maintaining the heritability of these morphological genes. The main feature parts of the product maintain the typical biological morphological genes, and the overall image style of the product shape remains unchanged regardless of how other non-main component shapes change[10]. This paper takes the bionic modelling design of grader as an example to study the evolution of the modelling design scheme with the biological prototype image style on the premise of maintaining the biological prototype image characteristics.

3 Shape structure behavior function (SSBF) model

The industrial design model comprises four types of information: function, behaviour, structure, and shape. Creating and expressing product shapes are the main goals of industrial design innovation. They are the results of designers' reasonable configuration of design tasks and organization of design actions. The process of product shape design can be described as follows: first, determine the function of the product based on user needs, conceive the behaviour of the product, Designate the structure and form that generate expected conduct and achieve functionality, and then make judgments and evaluations of the structure, form, and function[11].

In the "Shape Structure Behavior Function (SSBF)" model, the function is a description of the design intention, that is, the purpose and purpose of the product. The product function should meet user needs, and the behaviour should achieve the changing state of the product function. The structure is the structural relationship of the components that complete the product behaviour, including spatial position and interaction relationships. The shape includes the geometric shape and size that meet the product structure; as an objective form of product structure and function, product form is the primary medium for functional information such as practical and spiritual aspects of the product. Product design should meet people' s functional needs. From functional requirements to designing product shapes that implement this function, it is called function to shape mapping or functional reasoning, which plays a crucial role in the conceptual design stage of the product. The functional domain (F) represents a collection of design tasks, constraints, and other information; the Behavior domain (B) corresponds to the designer's design process; The set of related parameters corresponds to the product component set in the structural domain (ST); The formed domain (SH) is the external representation of a product that satisfies the structural constraints of its physical components. Functions can include both actual and intentional functions. Actual functions refer to the functions achieved by natural systems and manufactured products in reality, while intended functions refer to the functions people hope to obtain. There is an abstract and concrete and concrete hierarchical relationship between functions. The relationship between a product's functions and its components' subfunctions is the composition relationship between the whole and the parts. To realize the function of a product, the subfunctions of its components must coordinate with each other to produce the desired function of the overall system.

The function of natural biological systems is limited by the organism itself and determined by its internal structure; The functions of artificial systems are externalized and must be analyzed and defined before designing the internal structure. Shape (SH) is a form of expression that satisfies the premise of Structure (ST), and product structure is the carrier of function and behaviour. The changes in its state and structure are Behavior (B), and the role of behaviour is Function (F). Assuming that the form domain SH is a collection of all modelling components, the structure domain ST is a collection of all structural elements, and the behaviour domain B is a collection of all behavioural components. The function domain F is a collection of all functional features, then the form, structure, behaviour, and function have the following relationships: The shape space SH, structural space ST, behavioral space B, and functional space F constitute the product design space $\boldsymbol{D}$:

$$\boldsymbol{D} = \left(SH \overset{\leftrightarrow}{\cup} ST \overset{\leftrightarrow}{\cup} B \overset{\leftrightarrow}{\cup} F \right) \tag{1}$$

The four spatial components in the SSBF model constitute the product design space. Four subspace components can represent each design process, with certain mapping relationships between each subspace. Shape space describes the geometric shape and dimensions of the product and its components; The structural space describes the form symbols of products and components, as well as their topology, location, and equipment relationships; The behaviour space is composed of characteristics derived from products and various components; The functional space defines the purpose and objectives of the product and its components.

4 SSBF decomposition case of grader

The SSBF model was used to conduct morphological decomposition and industrial design and development of grader products, and the grader products are subject to morphological decomposition. The behavioural decomposition was continued according to the morphological characteristics of the decomposed products. The behavioural characteristics of each part of the product components were analyzed and mapped to specific functional characteristics, as shown in Figure 1.

At the morphological level, the main appearance modelling components of the grader are divided into five parts: "cab", "head", "frame", "wheel", and "engine compartment". Each appearance component can be subdivided into sub morphological layer or structural layer according to the structural characteristics; At the structural level, each part of the product components corresponds to a certain number of structural components. Most of the structural components are industry-common or standard structural components, mainly divided into two categories: brackets that support, connect, and fix each component, hinge structures, and transmission, control, and other mechanisms that achieve the main functions of the product. For example, the driver's cab' can be divided into visible styling components such as "side door", "front windshield", "side windshield", "rearview mirror", "handle", and "interior components"; The "front end" can be divided into visible components such as "lights", "front bulldozer", "front panel", "cast steel seat", "cockpit base", etc; The "wheel" can be divided into visible components such as "steering wheel", "driving wheel (front or rear)","tire", "wheel hub", and "tire tread"; The "engine compartment” can be divided into visible components such as the “hood ”, “exhaust pipe ”, “heat dissipation hole”, “towing hook”, and “rear scarifier”; The “frame” can be divided into structural components such as “bow shaped longitudinal beam”, “swing frame”, “scraper”, “traction frame”, “rotary table gear ring”, “scraper lifting oil cylinder”, “front frame”, “rear frame”, “hinge steering oil cylinder”, “soil scraper”, “bearing seat”, “rear crossbeam”, “rear axle”, and “laser leveling device”. The scraper is the main working component, and the scraper, soil scraper, and bulldozer are optional additional working devices; The behaviour layer realizes the correlation between the functions that can be provided and achieved by appearance and structural components and the actual or expected functions of the product. It is usually composed of expert systems or industry standards to form evaluation indicators for the behaviour layer, which maps and constrains the form, structure, and function in terms of process, efficacy, safety, comfort, cost, and aesthetics. The behavioural constraints and evaluation indicators from the perspective of industrial design mainly focus on shape and CMF (Color, Material, Finishing) as the primary consideration indicators; The appearance parts and structural parts of the grader are decomposed under the constraint of the behaviour layer to obtain the actual functional attributes that need to be maintained and improved as well as the expected functions that are expected to be realized by the grader.

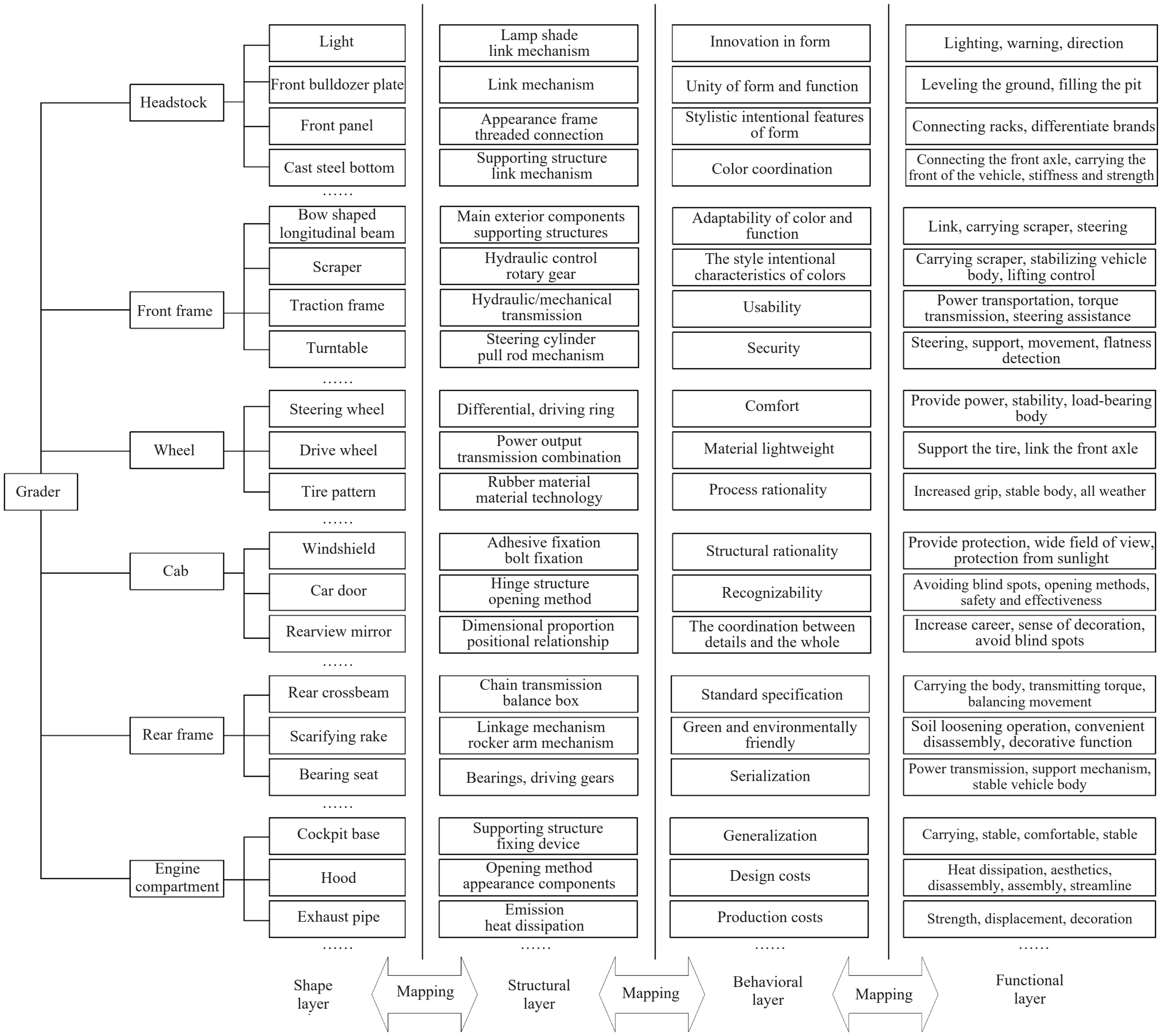


Figure 1 SSBF exploded view of whole grader

The image vocabulary of the SSBF model mainly reflects the functional attributes of the target product while also possessing the attribute requirements of the form and structure of the target product. Compared to the data obtained through traditional expert interviews or survey questionnaires, it is more in line with the target product’s form, structure, and function requirements and has more substantial specificity. Taking the “front frame” as an example, it can be further subdivided into structural components such as “connecting frame”, “ripper retracting cylinder”, “lifting cylinder”, “swing mechanism”, and “drawbar leading out cylinder”. The SSBF model is adopted for decomposition, and each structural component corresponds to the behaviour level of realizing its function. The functional requirements and descriptive phrases at the functional level (as shown in Figure 2) of the most product style features of the grader are obtained by decomposition. After refining and screening, the representative image words of the SSBF model of the “front frame” component of the grader are “transmitted”, “connected”, “load-bearing”, “dynamic”, “stable”, “powerful”, “moving”, “supported”, etc.

The evaluation weight value of each feature component can be calculated based on the contribution rate of each component’s modelling features to the overall style image. The load values of each image vocabulary factor of the grader’s key modelling components (frame, cab and head) correspond to Tables 1, 2 and 3, respectively, which serve as the demand of the grader’s product form structure function and guide the subsequent design.

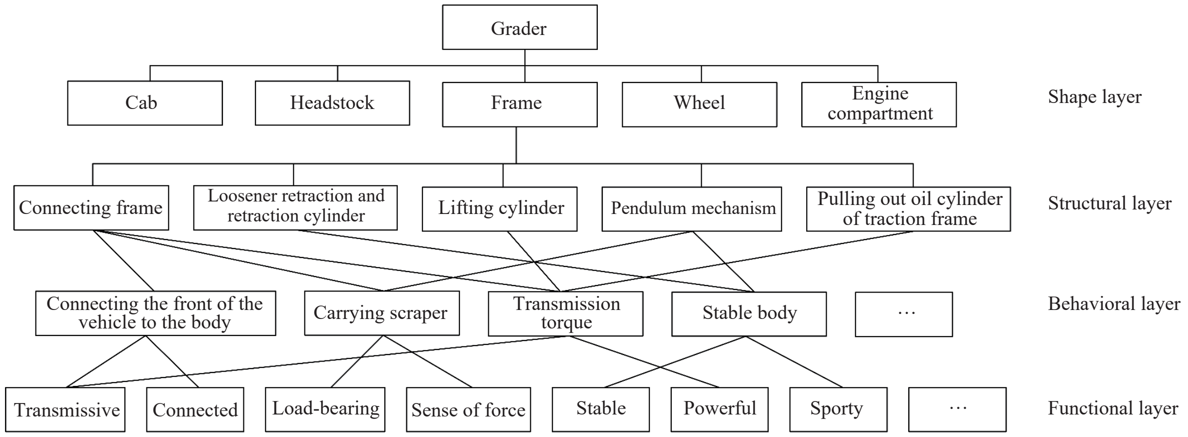


Figure 2 SSBF Decomposition Diagram of grader Front Frame

Table 1 Factor load table of representative words of grader frame image

Imagery words	Factor load	Imagery words	Factor load	Imagery words	Factor load	Imagery words	Factor load
Transmissive	0.786	Stable	0.875	Connected	0.648	Powerful	0.621
Load-bearing	0.793	Sporty	0.842	Dynamic	0.763	Supported	0.801

Table 2 Factor load table of representative words of grader cab image

Imagery words	Factor load	Imagery words	Factor load	Imagery words	Factor load	Imagery words	Factor load
Transmissive	0.649	Stable	0.685	Connected	0.851	Powerful	0.792
Load-bearing	0.682	Sporty	0.706	Dynamic	0.863	Supported	0.648

Table 3 Factor load table of representative words of grader head image

Imagery words	Factor load	Imagery words	Factor load	Imagery words	Factor load	Imagery words	Factor load
Transmissive	0.594	Stable	0.526	Connected	0.541	Powerful	0.857
Load-bearing	0.649	Sporty	0.607	Dynamic	0.624	Supported	0.752

5 Shape inference based on shape grammar

Shape grammar can parameterize the description of modeling genes, transform the concrete graphics into parametric computer language, and realize operations such as genetic algorithm through programming[12]. Bioprototypes directly affect the explicit and implicit features of biomimetic products, playing a crucial role in the style and image perception of new products. The formation of product design is a process of continuous matching, evolution, and iteration between the contour lines of biomimetic prototypes and product feature lines. New products retain certain features of the biological prototype, and their shape is jointly dominated by the biological prototype and product design DNA. It is also influenced by factors such as technical conditions, functionality, and structure. The deduction process is shown in Figure 3.

Product form features include form feature points, lines, and form feature surfaces. The side contour lines of a product are representative geometric entities that can be expressed[13]. Product form feature lines play a decisive role in product form imagery. The form feature lines of side views have been widely studied and applied. This article takes the side view as an abstract, simplified view of product biomimetic form genes.

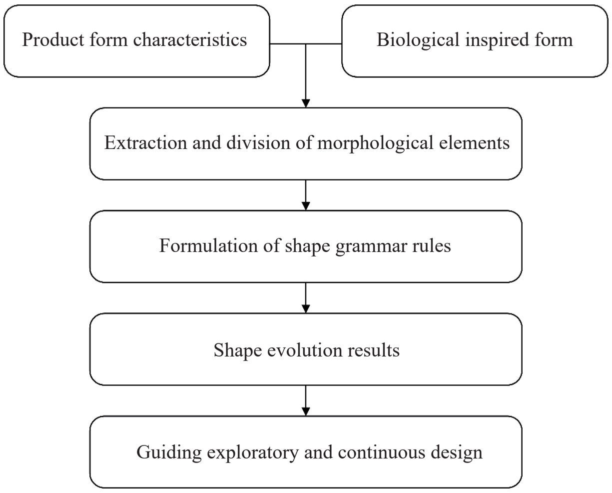


Figure 3 Basic flowchart of feature line deduction

5.1 Evolution of shape grammar

There are three essential elements to form shape grammar: Shape is the essential word in grammar; Rule is a grammar for organizing shapes[14,15]; Shape design calculations are mainly achieved through transformation, substitution, and hybridization[16].

This section takes the bionic design of grader modelling as an example to study the application of shape grammar in the evolution of shape deduction and verify the effect of IGA in evaluating feature line evolution. The shape deduction of the grader bionic modelling feature line is divided into four stages: grader and biological prototype analysis stage, shape grammar analysis stage, shape deduction stage and feature line interactive evaluation stage.

Stage 1: In the stage of grader product and biological prototype analysis, it focuses on the comparison of grader and bionic prototype (mantis) morphology and analysis based on shape grammar;

Stage 2: In the phase of shape grammar analysis, shape grammar rules are formulated for the side shape characteristics of the grader and the side shape characteristics of the mantis by using shape grammar;

Stage 3: In the shape deduction stage, the quadratic Bézier curve describes the grader modelling feature line and the mantis shape feature line. The purpose of shape deduction is to match and evolve the geometric shape of the unified data specification;

Stage 4: In the interactive evaluation stage, users and designers participate in the IGA evaluation process to generate new feature line schemes.

5.2 Target product and bioprototype analysis

Investigate grader products at home and abroad, such as Shangong, XCMG, Sany, Shantui, Liugong, Caterpillar, etc. The critical modelling components of the grader include the frame, wheel, cab, engine compartment, frame placing mechanism, price raising cylinder, traction frame, scarifier, scraper, etc. The components that determine the modelling style of the grader are mainly the frame, cab, engine compartment and other significant components. The shape elements of the side modelling of the grader are extracted and divided, as shown in Figure 4. The subsequent design and research are based on this fundamental shape element for shape grammar analysis.

5.3 Feature line extraction and shape grammar analysis

As shown in Table 4, take #8 grader as an example to describe

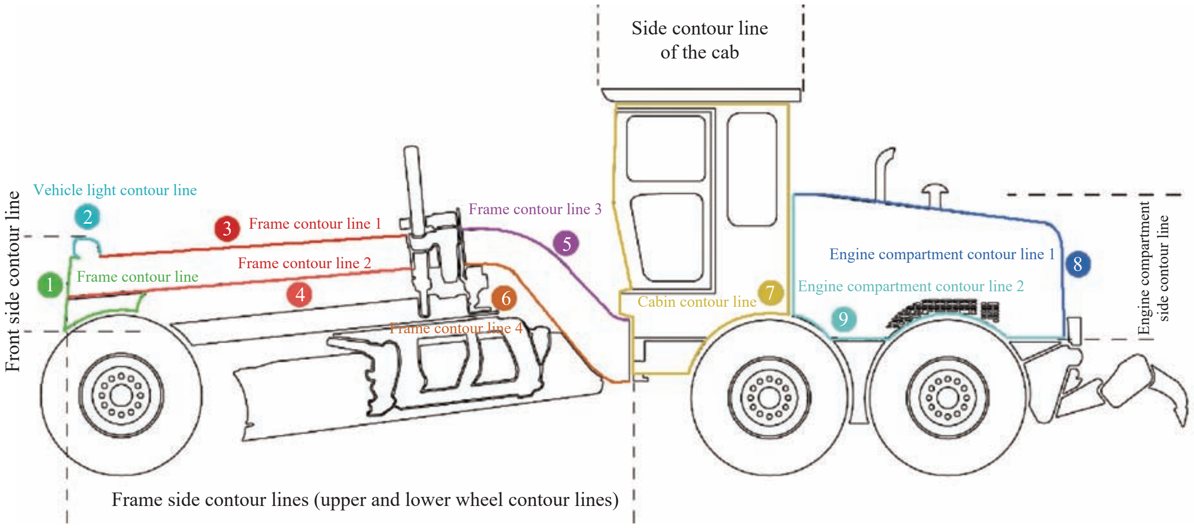
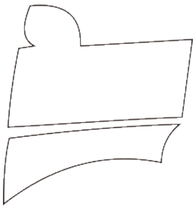
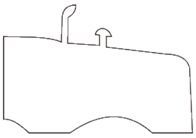
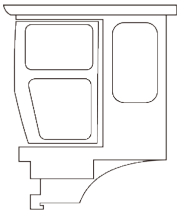
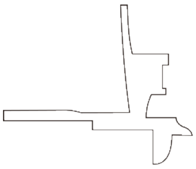
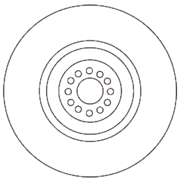
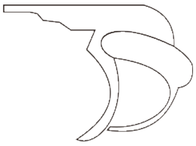
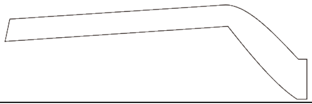


Figure 4 Side view characteristic line of grader frame

Table 4 Form decomposition and image feature contribution table of main components of grader.

Grader(#08)

Component name and line diagram		Contribution rate(%）		Component name and line diagram		Contribution rate(%）	
		Sense of force	Supported			Sense of force	Supported
Headstock		6.2	3.7	Engine compartment		15.6	19.9
cab		16.7	14.3	Traction frame		5.8	13.5
wheel		14.5	12.2	scraper		13.7	6.8
Frame						26.1	30.8

the characteristics of 7 modelling components with high attractiveness index (frame, wheel, cab, engine compartment, headstock, traction frame, scraper). According to the theories and experiments related to image modelling[17-22], typical morphological contours of praying mantis were selected for biometric feature line extraction, with side view shapes as the main form but not limited to plane view shapes. For the four common praying mantis shapes, the morphological features of their forelimbs and heads that best reflect their sense of strength, support, and agility were extracted, and their morphological feature lines were extracted, as shown in Figure 5.

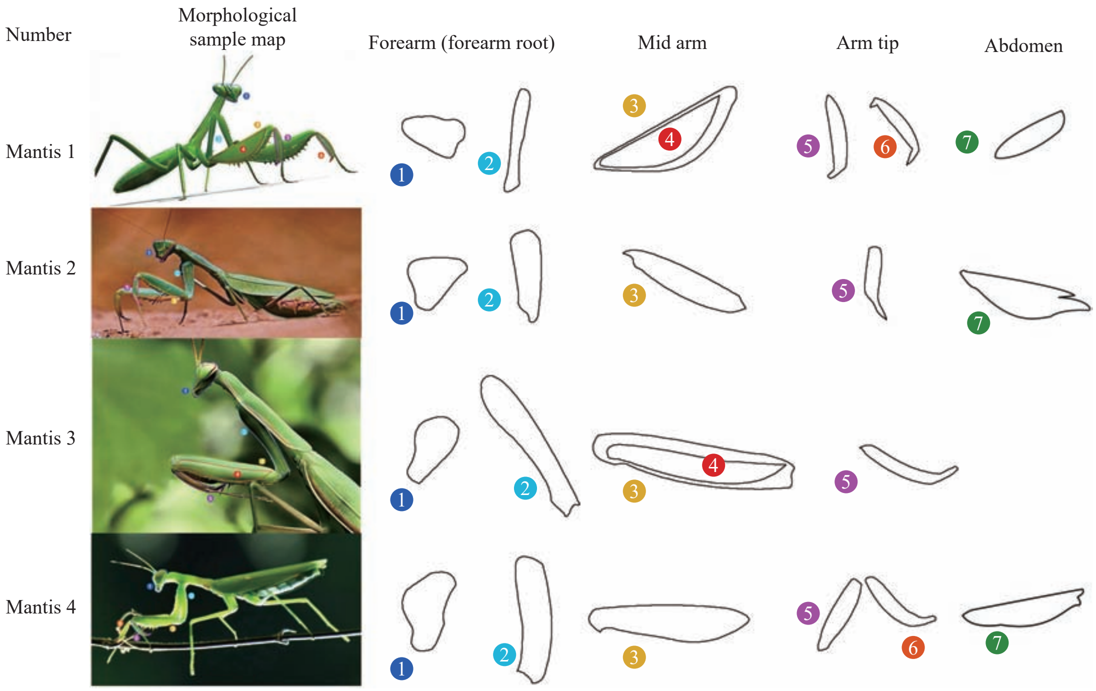


Figure 5 Analysis of morphological characteristics of mantis

The frame, cab and engine compartment are the main style feature components of the grader, which significantly impact the overall modelling image of the grader. Therefore, eight grader samples are selected to extract the product shape contour lines of the frame, cab and engine compartment (as shown in Figure 6), represented by Bézier curves.

Taking the side contour lines of the front frame of the grader (numbered #3, #4, #5, #6 in Figure 6) as an example, the collection of morphological characteristics of the front frame of the grader is:

$$C_T = \{T_{i1}, T_{i2}, \ldots, T_{im}\}, m = 8, i \in [1, 8] \tag{2}$$

The set of morphological feature lines for the m-th product sample is T_{im}.

Taking the mantis morphological feature lines (numbered #2, #3, #4, #5, #6 in Figure 5) as an example, the set of mantis morphological feature lines is:

$$B_K = \{K_{j1}, K_{j2}, \ldots, K_{jn}\}, n = 4, j \in [1, 4] \tag{3}$$

The set of morphological feature lines for the n-th product sample is T_{jn}.

With the help of the Coreldraw SDK development kit (as shown in Figure 7), the number of times and similarity $Sim(B_K, C_T)$ of form inference can be defined, and the product form scheme set P_I can be automatically generated exhaustively.

5.4 Characteristic line deduction of grader front frame

The visual feature evolution of grader modelling is the operation of modelling feature lines. The front frame of the grader is represented by a quadratic Bézier curve, as shown in Figure 8.

The deduction process of grader frame shape is as follows:

Step 1: The frame shape of the grader (take #08 as an example) is encoded in the initial state. The geometric description of the grader modeling key feature line can be summarized as several continuous line segments S_n and their positions and attribute relationships. The product feature line curve $S_{n(i,j)}$ can be represented by the endpoint $P_i (i = 1, 2, \ldots n)$ and the control point $C_i (i = 1, 2, \ldots n)$ using the Bézier curve:

$$S_{n(i,j)} = \{P_{ni}, C_{ni}, P_{nj}\},\ \ 1 \le i \le n, j = i + 1 \tag{4}$$

where, i, j, n is a natural number; P_i is the starting point of segment $S_{n(i,j)}$; P_j is the endpoint of segment $S_{n(i,j)}$; and C_i is the control point of segment $S_{n(i,j)}$. Since the lifting oil cylinder and the swing mechanism are linked to the frame (the lifting oil tank and the swing mechanism are not considered as the main modeling parts in the bionic design of the grader modeling), the side feature line of the grader frame is divided into four sections, which are respectively expressed as S_3, S_4, S_5, S_6, and the set of initial feature lines $I = \{S_3, S_4, S_5, S_6\}$.

Step 2: The mantis shape feature lines #03-4 and #04-6 (as shown in Figure 5) are selected as the shape bionic reference lines, and they are simultaneously input into the shape deduction engine with the initial feature line of the grader to execute the shape grammar rules.

Step 3: Using the quadratic Bézier curve model to represent the initial feature line $I = \{S_3, S_4, S_5, S_6\}$, each curve is represented by two endpoints and a control point. The initial feature line can be represented as:

$$S_i = \begin{vmatrix} p_{i1} & c_{i1} & \cdots & p_{i2} \\ p_{i2} & c_{i2} & \cdots & p_{i3} \\ \vdots & \vdots & \cdots & \vdots \\ p_{in} & c_{in} & \cdots & p_{i(n+1)} \end{vmatrix} \tag{5}$$

where, n represents the number of curves that make up the shape in

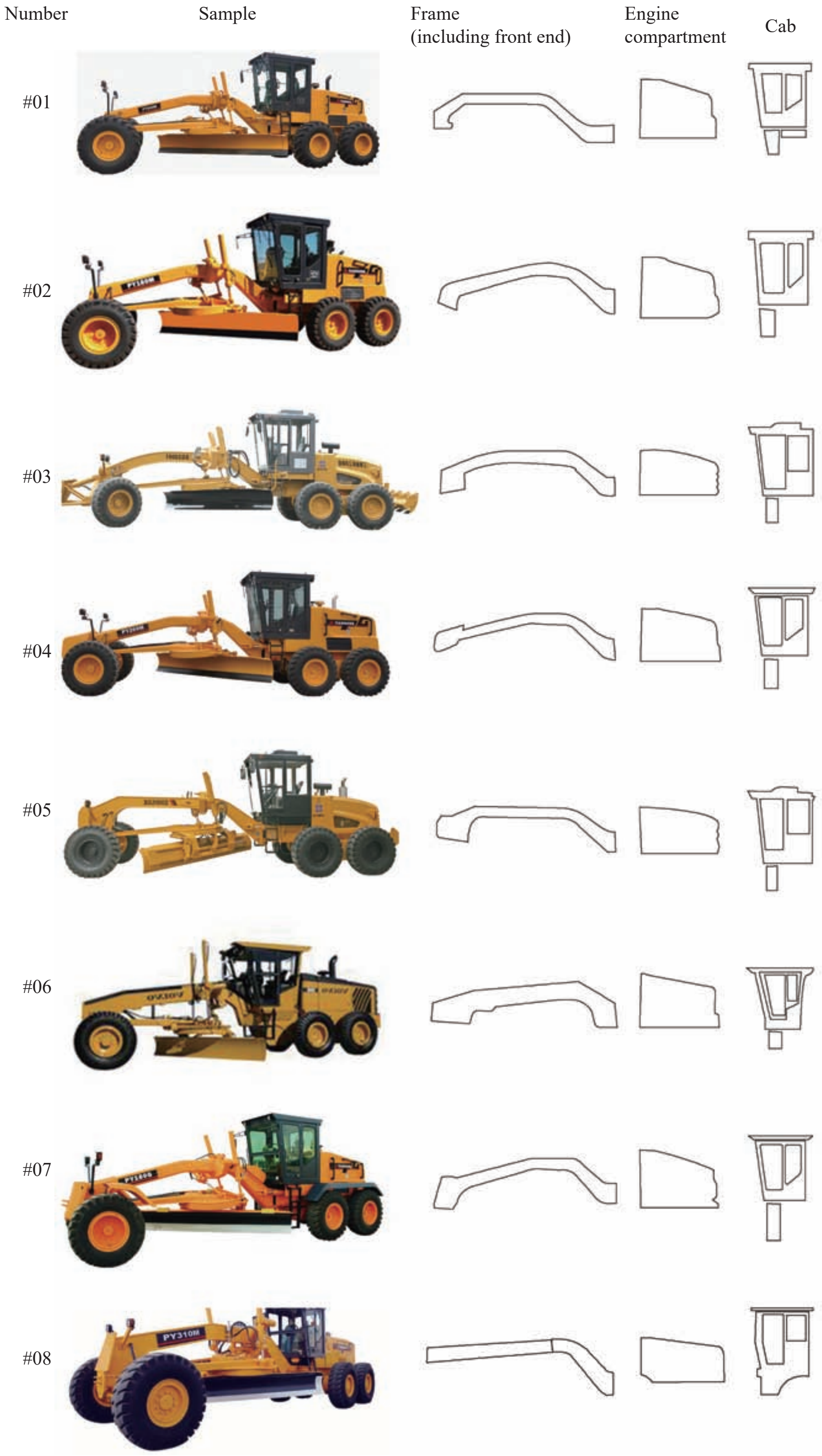


Figure 6 Extraction drawing of grader frame shape

S_i. For the j-th curve in S_i, $P_{ij}(X_{ij}, Y_{ij}), j = 1,2,\ldots,n$ refers to the first endpoint coordinate of the curve in a clockwise direction, $P_{ik}(X_{ik}, Y_{ik}), k = j+1, j = 1,2,\ldots,n$ is the second endpoint coordinate, and $C_{ij}(X_{cij}, Y_{cij}), j = 1,2,\ldots,n$ is the coordinate of the P_{ij} control point.

As shown in Figure 8, the quadratic Bézier curve of the characteristic line of the grader frame. Line $P_{31}P_{32}$ represents curve S_3, which is the modeling characteristic line of the top of the front section of the frame. Line $P_{41}P_{42}, P_{42}P_{43}, P_{43}P_{44}$ represents curve S_4, which is the characteristic line of the top of the front section of the frame. $P_{31}P_{41}$ is the connection between the frame and the head. The position and size remain unchanged and must be kept vertical, that is, $X_{31} = X_{41}$; Due to structural constraints, $P_{41}P_{42}$ must be horizontal, that is, $Y_{41} = Y_{42}$; Line segments $P_{32}P_{44}$ and $P_{51}P_{61}$ are artificial dividing lines reserved for the lifting oil cylinder and swing mechanism, taking $\begin{cases} Y_{32} = Y_{44} \\ Y_{51} = Y_{61} \end{cases}$; The line segment $P_{51}P_{52}$, $P_{53}P_{54}$ represents the curve S_5, which is the top shape feature line of the rear section of the vehicle frame. The line segment $P_{53}P_{54}$ is connected to the vehicle body and must be kept tangent horizontal due to structural constraints, that is, $Y_{c52} = Y_{53}$; The line segment $P_{61}P_{62}, P_{63}P_{64}$ represents the curve S_6, which is the bottom shape feature line of the rear section of the vehicle frame. The line segment $P_{63}P_{64}$ is connected to the vehicle body and is constrained

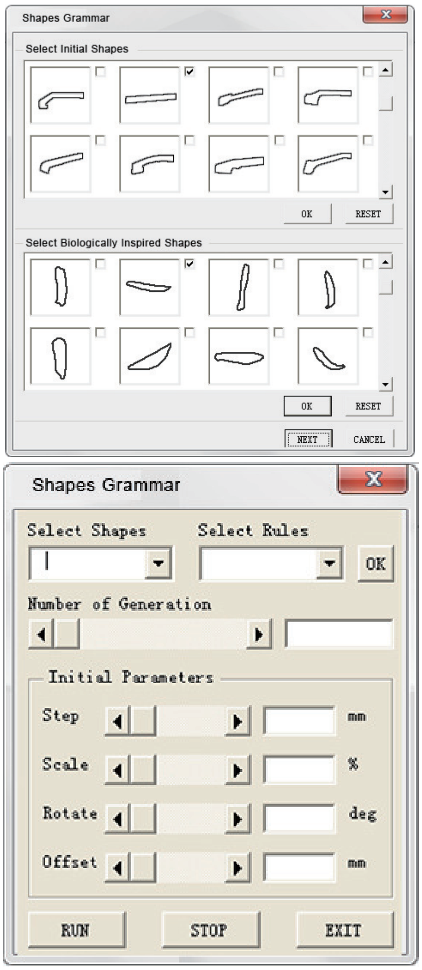


Figure 7 Shape Grammar Engine Based on Coreldraw SDK

by the structure to maintain a tangent level, that is, $Y_{c62} = Y_{63}$; Line segment $P_{53}P_{63}$ is a non-main shape feature line, defining $X_{53} = X_{63}$.

Step 4. Conduct secondary development on CorelDRAW X4, establish a shape grammar inference engine, and perform inference on the initial shape. Based on the experience of relevant research foundations[23-25], the variation probability value can be appropriately adjusted within the range of $P_m \in [0.2, 0.4]$ during the evolution process of product feature lines. Set the number of iterations to 200, adjust the coordinates and offset the offset by 10cm, scale by 50%, and rotate by 5° to generate a partial population scheme as shown in Figure 9.

Crossover and variation are two key operations in the biomimetic feature line evolution of actual product form. Crossover can realize the random exchange of individual information and generate new gene combinations. Mutation can avoid the emergence of a single population that cannot evolve in the algorithm process, increasing the characteristics of global optimization. Due to the limitations of complexity and case samples, the population size cannot meet the corresponding requirements, and the interactive evolution strategy[26,27] is adopted. Designers participate in fitness evaluation and individual selection, and the population size can be limited to the controllable range of manual operation.

5.5 Characteristic line deduction of grader front frame

The evolution evaluation of the overall scheme of the grader is carried out by selecting ten sets of schemes for each of the 20th, 40th, 60th, 80th, 100th, 120th, 140th, 160th, 180th and 200th iterations of the shape of the front frame, engine compartment and cab of the grader (as shown in Figure 10). Binary coding is carried out for the shape scheme of the front frame, engine compartment and cab of the grader derived from the shape grammar. The system randomly combines to select the corresponding shape from the shape elements of each shape component of the grader. Generate eight sets of solutions per generation. Applying VBA language for secondary development in Coreldraw X4 can achieve an interactive evaluation of design solutions, as shown in Figure 11. The evaluation system utilizes the Matlab neural network toolbox to construct a neural network model and train, apply, and update the neural network model through interaction with VBA.

Designers can set image evaluation indicators and weights and score or sort the iterative schemes. After completion, clicking "Next Generation" can produce eight new sets of evolutionary schemes for designers to evaluate. After n generations of evaluation, the error threshold of neural network training reaches the condition, and the neural network model can achieve automatic evolution of the schemes. After the interactive evolution in which the designer participated in the evaluation, a theoretically satisfactory solution can be obtained (as shown in Figure 12). After analysis, induction and reorganization, the shape grammar rules can be divided into the following steps to complete the modelling profile of a grader in the shape of a praying mantis.

6 Conclusions

This paper takes the shape deduction and evolution evaluation of grader side shape feature lines as an example to study the deduction and interactive evaluation methods of product shape feature lines inspired by mantis shape feature lines.

(1) A new approach to feature line representation and encoding is presented that combines shape syntax and quadratic Bézier

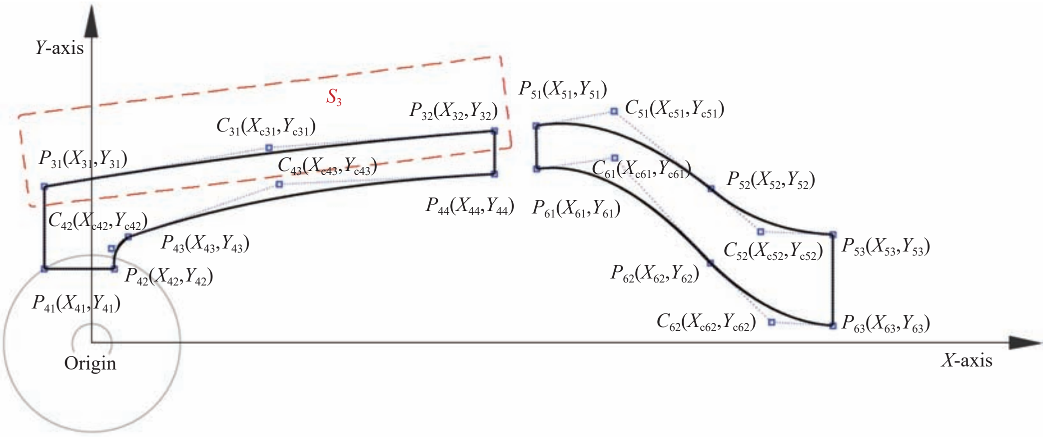


Figure 8 Coordinate diagram of grader frame shape deduction

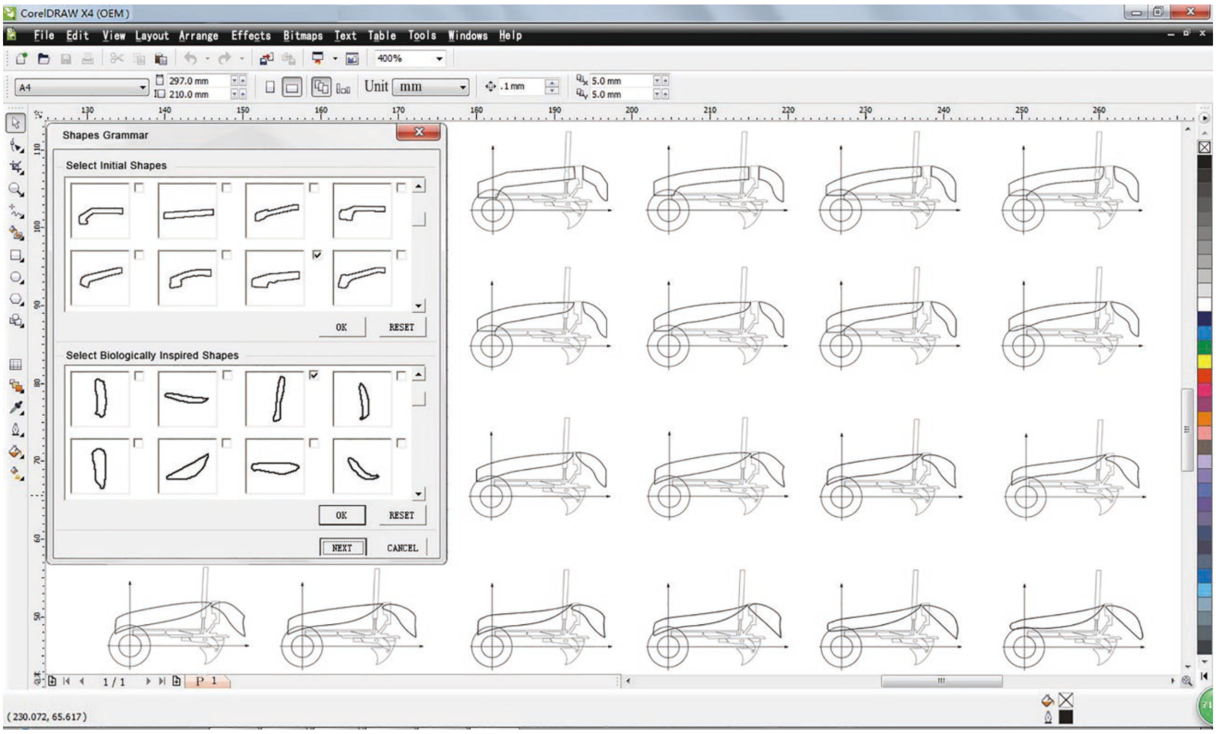
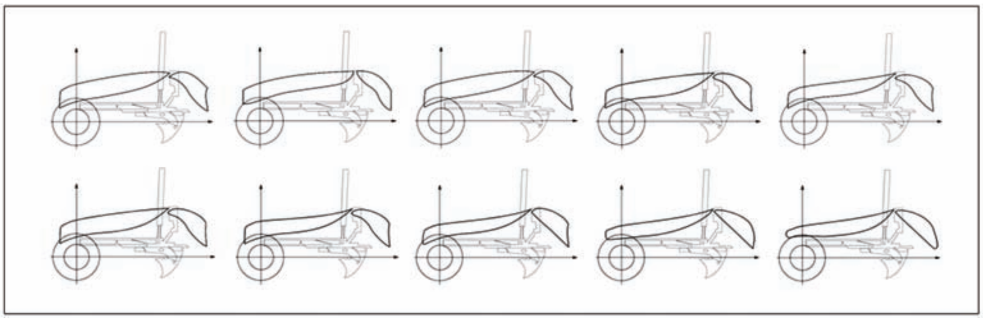
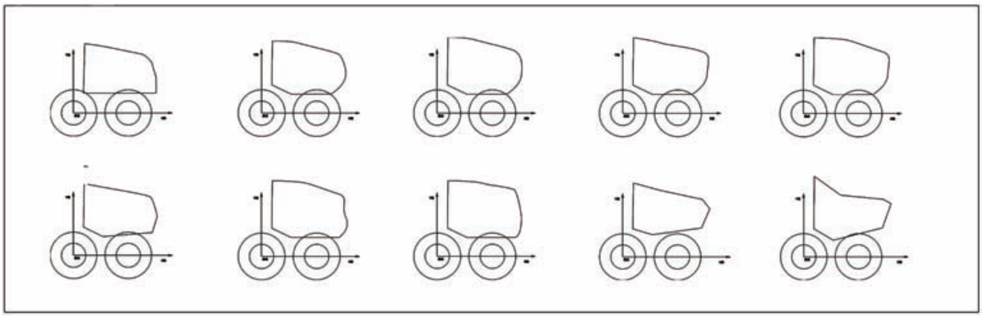


Figure 9 Grader front frame shape deduction results

Front frame of grader



Engine compartment of grader



Cab of grader

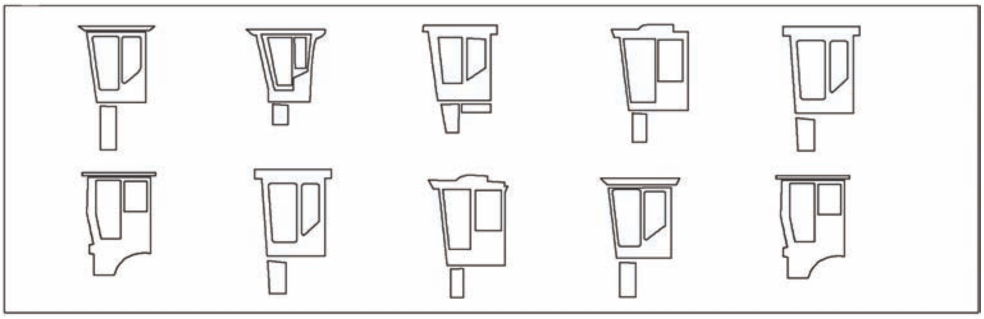
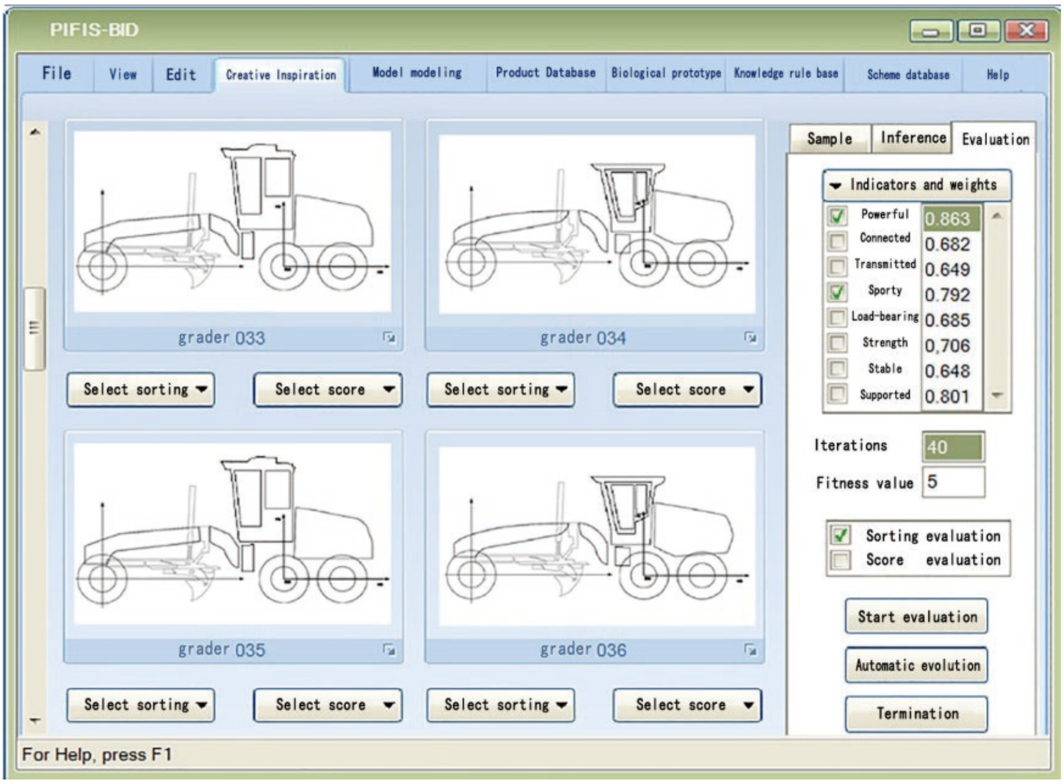


Figure 10 Iterative scheme of grader front frame, engine compartment and cab shape

curves. By combining these two tools, it is possible to represent and control feature lines in a more precise and flexible way.

(2) A genetic algorithm is used to achieve evolutionary deformation of feature lines. This enables the feature line of the



☑ Powerful 0.863
☐ Connected 0.682
☐ Transmitted 0.649
☑ Sporty 0.792
☐ Load-bearing 0.685
☐ Strength 0.706
☐ Stable 0.648
☐ Supported 0.801

Iterations 40
Fitness value 5

☑ Sorting evaluation
☐ Score evaluation

Figure 11 Interactive evaluation module for creative inspiration system

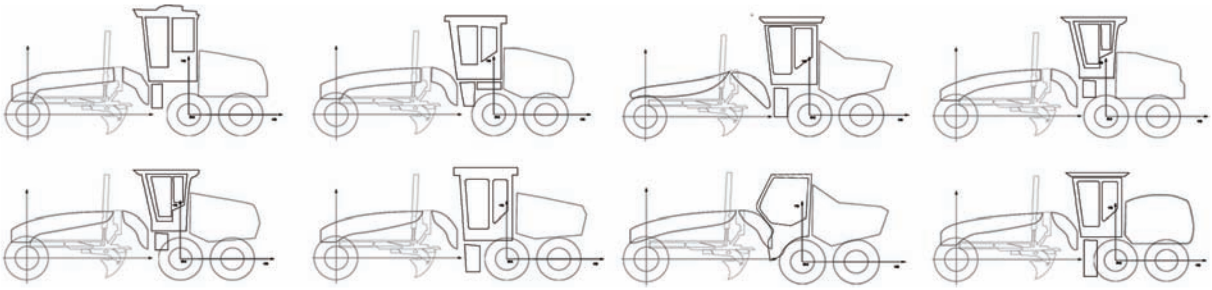


Figure 12 8 sets of grader form satisfaction solutions generated after interactive evaluation

product to better mimic the shape characteristics of living things.

(3) Interactive genetic algorithms allow designers to intervene in the evolutionary process of feature lines to generate product feature lines with typical biological characteristics. This7 approach not only helps designers to make creative designs, but also helps them to construct 3D models.

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