Interactive Evolutionary Design of Handbag Integrating Bamboo Weaving Material

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Abstract

The integration and development of fashion products and intangible cultural heritage have gradually become the highlight of product design. Following thousands of years of evolution, bamboo weaving patterns offer a rich resource library for use by designers. However, the designers cannot predict which bamboo weaving pattern can be adopted into women's handbags to satisfy consumers' aesthetics. Therefore, taking the form design of women's handbags as an example, this study develops an artificial intelligence-based program through which consumers can codesign with designers to effectively match the bamboo weaving pattern with the design style of women's handbags. First, based on the coding, selection, and mutation processes of interactive genetic algorithms, consumer preferences, and perception evaluations are effectively incorporated into product design. This ensures that the evolved product solutions meet consumer preferences. Second, considering evaluator fatigue in human–computer interaction evaluation, the decision tree algorithm is used as a proxy for evaluation. Finally, the developed interactive system supports mass-generated bamboo-woven bags of different styles, allowing prediction of consumers' preferences for the design of women's handbags. Furthermore, the system can assist designers and bamboo craftsmen in designing other bamboo or wooden products.

With the rapid development of society, science, and technology, the diversity of modern culture has compressed the living space of traditional handicraft culture, and numerous handicraft cultures with difficulties in inheritance are gradually on the verge of extinction. For example, the traditional Chinese bamboo weaving cultural heritage is gradually declining because traditional bamboo weaving no longer conforms to the aesthetics of modern people. Only by constantly innovating the design form of bamboo weaving can the traditional bamboo weaving culture be conserved. For example, bamboo weaving technology is integrated into the design of several international brands of women's handbags, such as the Hermes brand. In recent years, product design methods based on machine learning or intelligent algorithms are being developed to protect bamboo weaving handicraft culture. Artificial intelligence (AI) technology has increasingly become an important approach and method for product design (Wang 2022). Interactive genetic algorithms (IGA) is an intelligent computing method for solving optimization problems with hidden indicators (Takagi 2001). By combining users' evaluation with evolutionary algorithms, it enables users to participate in intelligent design. In recent years, this method has been successfully applied in industrial product and clothing designs.

Consumer needs analysis has become the key to designing creative cultural products to meet the increasingly prominent individual product design needs (Chen et al. 2020). The intelligent optimization algorithm represented by the IGA can analyze the user's demand preference for traditional handicrafts, and based on the intelligent design mechanism and path of traditional handicrafts of human–computer interaction, a form design scheme satisfying the consensus of consumer groups' image preference and satisfaction is generated (Yang et al. 2021). Therefore, we aim to meet the individual needs of customers and give users opportunities to participate in intelligent design. Thus, based on IGAs, user evaluations and evolutionary algorithms are combined to design product form schemes in line with customer preference. In product design, aesthetic fatigue in the online evaluation process of designers may affect the recombination of product design schemes based on the decision model of the decision tree because the decision tree model is closer to the human decision-processing mechanism; it is applied to the evaluation process of interactive

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evolutionary design of traditional handicrafts to realize the human–computer interaction of product evolutionary design system. It helps designers refer, evaluate, and improve design schemes in product design, promote the inheritance of traditional handicrafts, and integrate contemporary creative products and traditional handicrafts.

Literature Review

Application of interactive genetic algorithm in product design

In traditional product design, the designer's scientific and objective evaluation is the key to accurately obtaining users' preferences and quickly reflecting them in product design. Product design is complex and involves time, environment, technical progress, and other external changes, which further increases the difficulty of product design evaluation. However, incorporating the advantages of decision-makers into the evolutionary design approach can reduce the complexity of product design using evolutionary algorithms and realize the interactive evolutionary design of product styling and customer demands (Wang and Zhou 2020).

With the dynamic development of service economy and buyer's market, combining product design and user interaction has become the key to enterprise development and product design (Chen and Martinez, 2012). However, evolutionary algorithms can continuously iterate to form design schemes and reduce design time. Through the continuous evolution of user evaluation information and product form design scheme, the cultural product form design schemes that customers are satisfied with can finally be obtained (Inoue et al. 2013, Jiang et al. 2018). Wang et al. (2020) have designed a customized application system for anthropomorphic chairs by combining shape grammar and IGA in an intelligent design system and personalized design process for home appliances. In addition, Guo et al. (2021) have proposed an intelligent product design approach based on carbon emission assessment and interaction with the help of IGAs to better capture the comprehensive feedback on, and interaction of users with, potential candidates. Hai (2020) has applied an IGA to fractal artistic image design to effectively implement a coloring technology approach that combines human–computer interaction concepts.

Application of decision tree algorithm

As a popular and effective machine learning method, decision tree has a short running time and high flexibility. Aiming at the problem of user evaluation fatigue, which is easily generated by IGAs, the neural network model can be used as a proxy for user evaluation behavior. For example, Bao et al. (2017) have taken advantage of the optimization capability of a genetic algorithm to generate a cultural product model that meets users' preferences by performing crossover, mutation, and selection operations on existing cultural product components and further building a relatively complete learning process by applying artificial neural network to reduce operation errors caused by user fatigue. However, the neural network algorithm, which is a gradient descent method, has a slow convergence rate. There is no unified and complete theoretical guidance for parameter setting and selection of algorithm network structure. In contrast, the decision tree has few parameters and a fast convergence rate, which can effectively reduce overfitting and other problems (Chen and Mišić 2022). Among them, the ID3 decision tree, which uses information theory to measure information, can quickly find out the ordered rules from a large pile of unordered data features with fast convergence and high accuracy, which is helpful for decision optimization in the product design process (Ture et al. 2009). Therefore, an evolutionary product design system was built based on the ID3 decision tree method and IGA. In addition, the mapping relation between bamboo-woven product design elements and user product design was discussed to provide new ideas for the research of interactive product design methods.

Research on bamboo weaving materials and their form design

Bamboo has advantages, including good splitting performance, high mechanical strength, high elasticity, and strong bending performance. Designers and weaving craftsmen often use bamboo to weave flat or vertical daily necessities with different patterns. Regarding the research on bamboo, e.g., Vos (2010) studied using laminated bamboo materials as composite materials. There are many studies on the form of traditional bamboo weaving. For example, Luo et al. (2020) compared traditional and modern styles of bamboo weaving products, studied the evolution and innovation of bamboo weaving, and believed that integrating modern elements into bamboo-woven products can promote the sustainable development of traditional bamboo-woven products. Yudianto et al. (2020) found that in the activities of weaving bamboo handicrafts, the geometric shapes of bamboo-woven patterns were related to the concepts of mathematical measurement. Wan et al. (2021) explored the design of bamboo furniture. Lin et al. (2021) designed a safety helmet using the good splitting performance and mechanical strength of bamboo, which provided a basis for the technical improvement of bamboo-woven safety helmets. However, there are few studies on applying IGA technology to the form design of bamboo weaving.

Research review

Synthesizing the main research progress of the previous results, it can be found that, firstly, the subjective feeling and aesthetic manner of the designer in the product design process may bring difficulties to the design evaluation in terms of design problems and uneven responses from experts or experimenters, which lead to difficult or impossible analysis of the recovery and statistical analysis of the evaluation data. Secondly, the exponentiation, product, and other errors of traditional machine learning algorithms for mathematical operations on fuzzy subjective emotion data will be further amplified, resulting in more severe data evaluation errors. Finally, there is little research on applying machine learning technology to the evaluation and design of intangible bamboo weaving. However, the machine learning technology has the advantage of obtaining the experimenter's emotional preference objectively and directly. The user-centered product design philosophy is helpful for designers to further clarify users' emotional preferences and better apply them to the intellectualized inheritance design process related to the intangible cultural heritage of bamboo weaving.

In spite of the application of intelligent methods in product design, two aspects remain unaddressed and need further exploration. First, how to obtain the users' visual cognition and emotional preference for intangible bamboo weaving with the help of intelligent technology, and overcome the problem of fatigue in users' participation in product evaluation? Second, how to find out the best combination scheme of intangible bamboo-woven elements through genetic algorithm, and generate new intangible bamboo-woven modeling recur to decision tree, to improve the evolution efficiency of intangible bamboo-woven modeling? Therefore, this research will address three major problems in the current bamboo-woven design from the users' preference for intangible bamboo weaving with the help of intellectualized inheritance and deep developed technology. First, the consideration of simply transplanting traditional elements into bamboo-woven product design makes product design lack cultural connotation. Second, the limited research on innovative designs systems in intangible bamboo-woven, with traditional designers often lacking systematic thinking when optimizing bamboo-woven design. They tend to focus only on the external imagery aspects, overlooking the content innovation crucial for integrating into the modern living environment. The third issue pertains to the overreliance on the experience and ability of the designers in the innovative design of intangible bamboo weaving. This heavy reliance on designers' subjectivity during the product evaluation stage can potentially lead to subjective product evaluation link. Therefore, how to design user-friendly intangible bamboo weaving efficiently with the help of artificial intelligence technology is a pressing problem to be addressed at present.

Product Design Framework based on IGA

Interactive collaboration of product design elements and customer needs helps to better capture customer needs and lead the interaction between product design aesthetics and consumer psychology. Taking bamboo-woven bags as an example, we start from the design elements of bamboo-woven bags and the extraction of traditional Chinese traditional bamboo weaving craft feature. We analyze the interaction between typical characteristics of bamboo-woven textures and the product demand of bamboo-woven bag, and draw on ideas of genetic evolution in genetic algorithm to build a creative product evolution system based on IGA. This system exploits users' interactive evaluation and psychological perception on product form design schemes; and it selects, crosses, and mutates the existing modeling code of bamboo-woven bags to obtain the creative product shape preferred by users.

Considering that users are prone to be affected by multi-scheme evaluation in the interactive evaluation process, the effectiveness and efficiency of interactive evaluation of form design schemes in the system will be significantly reduced, which is not conducive to the interactive coordination between users and product design. The decision tree algorithm has started to be used in the research of graphic product design because it can effectively build the relationship between input and output without specifying the relationship between input variables and output results. Therefore, to effectively study the interactive design between innovative product design elements of bamboo-woven bags and users, the decision tree algorithm is introduced into interactive evaluation of users to improve the efficiency and rate of the innovative product form evolution as well as the fatigue error value in IGA interaction.

As shown in Figure 1, this study proceeds in three stages in the evolution design of bamboo-woven bag creative products to finally obtain the design evolution system of bamboo-woven bag creative product. The first stage is the morphological analysis stage. The representative samples of bamboo weaving process are determined by collecting historical samples of bamboo-woven bags, and the morphology of bamboo-woven bags is analyzed to complete the extraction of design elements of bamboo-woven bags. For realizing mapping of bamboo weaving process and bamboo-woven bag product design elements, the binary coding design of the bamboo-woven bag form design scheme is carried out. The user evaluation model is built based on the IGA in the second stage. Firstly, the weights of various evaluation indicators and the genetic operation parameters are set to further generate the initialized population individual. Under the condition that the threshold value of evolution iterations does not meet the specific conditions and the evaluator is not fatigued, the selection, crossover, and mutation operation of the IGA achieves a certain number of iterations of population individual updates. The individual fitness value is obtained through manual scoring, to decode the new individual performance form. The third stage is to build the evaluation model of the form design scheme based on the decision tree with the help of the historical evaluation data obtained from the evolutionary system. If the human evaluator feels tired, the user can continue the manual evaluation or use the ID3 algorithm to simulate the evaluation. Aesthetic fatigue means that users will easily fall into fatigue during the long-term interactive evaluation, and the accuracy of the evaluation will be affected.

When the evaluator experiences aesthetic fatigue, the system will enter the decision tree evaluation process and analyze the design by setting the range of each morphological value of the individual; the genetic algorithm is further optimized to obtain the optimal fitness values of the individual. The optimal form design scheme is obtained when the algorithm iteration meets the stopping condition. At this time, the algorithm stops and outputs the optimal form design scheme combination of creative bamboo-woven bag products.

Building of bamboo weaving texture elements and product modeling components

Taking the bamboo-woven bag as the typical object, the core components of the product element feature are extracted from bamboo weaving craft; the core components of a bamboo-woven bag are divided into three parts—bamboo weaving texture, external shape, and handheld form—to closely combine bamboo-woven bags with the intangible cultural heritage of bamboo weaving craft. Specifically, 50 groups of pictures of the Chinese bamboo weaving process from the Internet and books were selected in this study. Finally, 10 groups of bamboo weave textures, 10 groups of external forms, and 3 groups of handheld forms were selected as inspiration sources for the design of parts and features of bamboo-woven bags (as shown in Table 1) by integrating traditional techniques, design elements, cultural forms, and other various aspects. Furthermore, employing questionnaires and network selection, the three component elements were applied in the design process of bamboo-woven bags.

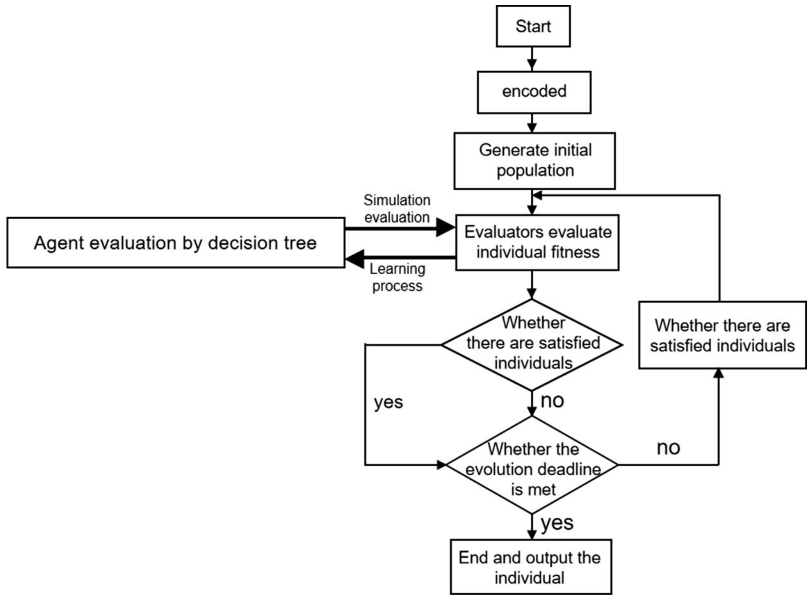


Figure 1.—Proposed technical route.

Coding mode of bamboo-woven bag creative product design

The most important step in the interactive algorithm (IGA) is to genetically encode product design elements. As far as coding modes are concerned, there are mainly binary coding, real number coding, natural number coding, block coding principle, minimum character set coding principle, floating point coding, Gray code coding, and multiparameter cascade coding. Considering the three component elements of bamboo-woven bag craft products, chromosome coding can be realized through the most widely adopted binary coding to reduce encoding and decoding time. Different form design schemes of bamboo-woven product craft are composed of the aforementioned three elements, so they have the same coding length in terms of chromosome encoding, thus increasing the efficiency and rate of genetic operation of decoding and operation.

As illustrated in Figure 2, the genetic algorithm encoding form of the bamboo-woven bag product can be obtained. Binary coding is adopted to select design elements in the product design. Suppose the first style of bag shape is selected. The chromosome gene of the first design component is represented as 0000, and the texture selects the second form; the encoding method is 0001. If the handheld form element of the second style is selected, the code is 01. Therefore, the combination of the bag form design scheme can be obtained by coding the aforementioned three design elements. This involves mapping the chromosome genes in the genetic evolution map to the bamboo-woven bag product design elements to form an interactive relationship. Similarly, a form design scheme may be obtained by combining three design elements. Subsequently, a more satisfactory product form design scheme with a higher evaluation score is obtained through a series of iterative processes.

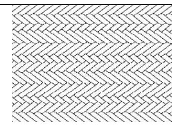
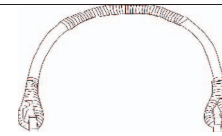
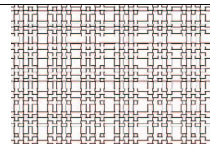
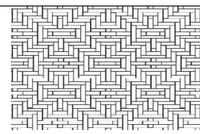
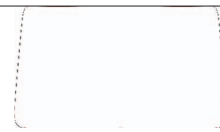
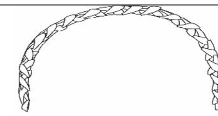
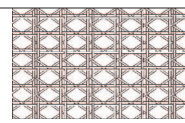
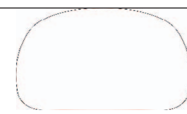
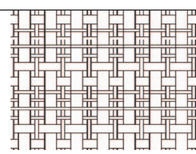
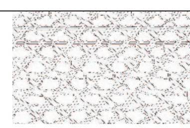
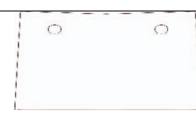
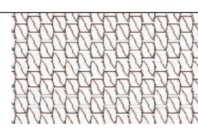
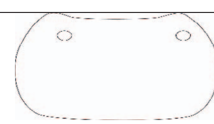
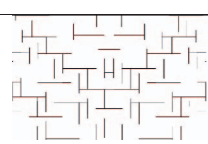
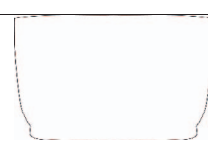
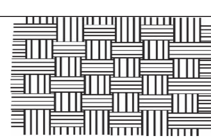
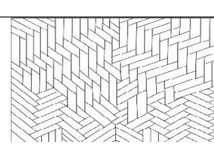
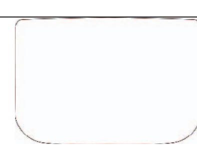
Genetic evolution strategy of IGA

The IGA operators are divided into selection, crossover, and mutation. The selection operation selects individuals from the overall population for crossover and mutation. The roulette selection method is shown in Figure 3. The procedure is as follows: the probability of an individual being selected in the overall population is proportional to the value of the corresponding fitness function of the individual. First, the fitness values for all individuals in the overall population are accumulated and then normalized. Eventually, similar to the spinning roulette wheel in a random casino, the corresponding individual to an area into which the random number falls is selected by a random number.

Following the selection of elite individuals, the crossover operation begins. The paternal and maternal individuals correspond to two bamboo-woven bag form design schemes, in which the abstract genes are crossed and exchanged, as shown in Figure 4. First, the form of the pendant and connector of the bamboo-woven bag is randomly selected and these two design elements are crossed to obtain two new creative product schemes. In the initial two form design schemes, the second bamboo-woven bag shape, the sixth bamboo weaving texture, and the second handheld form were selected as parent 1, while the third bamboo-woven bag shape, the fourth bamboo weaving texture, and the first handheld form were selected as parent 2. Following crossover, two new offspring can be obtained from the parent. In this case, the first offspring consists of the ninth bamboo weave texture, the second external shape, and the first middle handheld form, while the second offspring consists of the fourth bamboo weaving texture, the first external shape, and the first handheld form. Likewise, a series of new individual solutions can be obtained through crossover operators.

Biological diversity comes from genetic mutation, which refers to the phenomenon where different individuals of the same species have different shapes and physiological characteristics, and mutation makes species evolve continuously. In the genetic algorithm, to achieve gene mutation, it is necessary to set the probability of mutation phenomenon, generally between 0.05 and 0.22. The mutation operator determines the gene to be mutated according to the set mutation probability. Figure 5 illustrates the mutation operation paradigm of binary encoding.

Table 1.—Feature diagram of bamboo-woven bag components extracted from bamboo weaving craft.

	Bamboo weaving texture	External shape	Handheld form
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

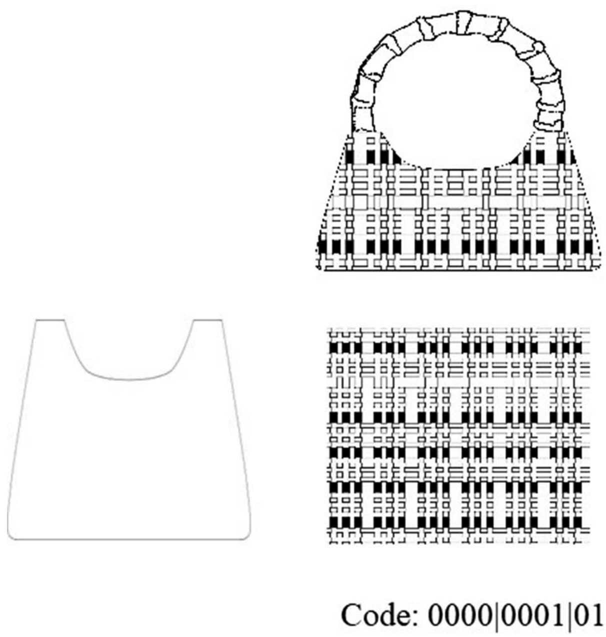


Figure 2.—Genetic algorithm coding of bamboo-woven bag products.

Decision tree algorithm design

Following roulette selection, crossover, and mutation, a series of new individual schemes was obtained. Multiple evaluators evaluated the form design scheme of each iteration. Users tend to experience aesthetic fatigue during multiple iterations; therefore, the fitness evaluation stage of the IGA cannot obtain a clear relationship between the users' psychological perception and the design elements of the product form. However, obtaining real customer demand is crucial to clarify the cultural direction of form design schemes and the optimal combination of design elements. The decision tree algorithm allows multivariate parametric and nonparametric analysis and can use the prior information to deal with the nonhomogeneous relationship between the data effectively. Moreover, it is easy to operate, can deal with numerous problems in various fields, and is robust. Based on the advantages of the decision tree algorithm in dealing with nonlinear relationships and its closeness to the processing mechanism of human decision-making, this study uses the decision tree algorithm to optimize the training data of users' evaluation scores of product design solutions.

The ID3 algorithm will select attributes by calculating information gain to obtain the maximum category information about the tested sample when each node is tested. Its clear theory, simple method, and strong learning ability result in the ID3 algorithm being suitable for large-scale learning problems and it was adopted in this study. According to the evaluation of information gain and selection feature in information theory, the feature with a significant information gain is selected as the evaluation and judgment module of interactive product design to avoid evaluator fatigue.

Let (D,Y) be the sample space of a classification system. D is represented as the sample with m features, while Y is represented as n categories with values of C_1, C_2, ... C_n.

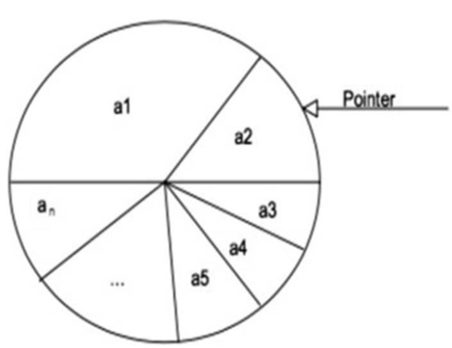


Figure 3.—Schematic diagram of roulette.

Figure 4.—Schematic diagram of crossover process.

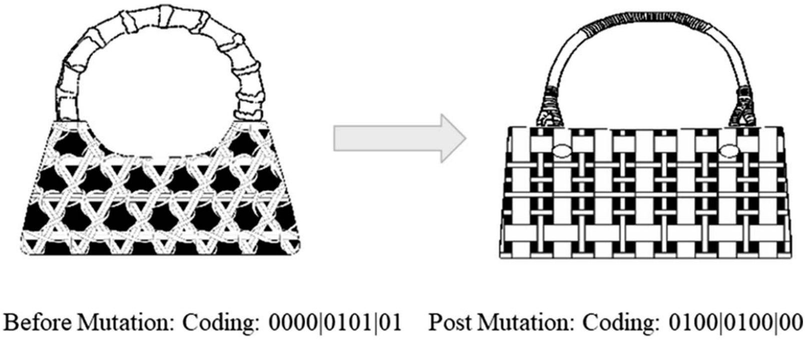


Figure 5.—Schematic diagram of mutation operation.

The probability of each category is $P(C_1)$, $P(C_2)$, $\ldots P(C_n)$ and the entropy of the classification system is $H(C) = \sum_{i=1}^{n} P(C_i).logP(C_i)$ in the discrete distribution. The probability of the category occurrence can be obtained through the number of category occurrences and sample summary. For a continuous distribution, it needs to be discretized by dividing the categories into blocks. In addition, according to the definition of conditional entropy, the conditional entropy of a sample can be obtained when a certain characteristic X of the sample is fixed. The possible value of the characteristic X is x_1, x_2, $\ldots x_n$, so the conditional entropy is Equation (1):

$$H(Y|C) = \sum_{i=1}^{n} P_i H(C|X = x_i) \quad (1)$$

In product design, when designers are faced with different product combinations, they will have different perceptions and emotions about different product combinations. Therefore, a decision tree can be adopted to effectively establish the relationship between users' emotional reactions to products and different product element combinations.

In summary, the intellectualized inheritance design system of the intangible cultural heritage of bamboo weaving based on artificial intelligence can be obtained as follows:

Step 1: Morphological analysis stage: Collect historical samples of bamboo-woven bags to determine representative samples.
Step 2: Analyze the shape of the bamboo-woven bag morphologically, extracting the bamboo weaving texture and other morphological elements.
Step 3: Perform binary coding for the form design scheme of bamboo-woven bags.
Step 4: Set different evaluation indicator weights according to different industries and types of human evaluators; calculate the total evaluation fitness to obtain the bamboo-woven bag form design schemes preferred by different industries and types.
Step 5: Initialize IGA, including population and parameters. To increase the diversity among individuals, the initial population is randomly generated; the number of each generation is set to 8, the evolutionary algebra is 200, the crossover coefficient is 0.9, and the mutation coefficient is 0.1.
Step 6: Generate an interactive genetic evolution strategy. The comprehensive score of shape features of the bamboo-woven bag form design scheme is generated randomly per fitness function. The system will train the decision tree with the comprehensive evaluation score of the user for bamboo-woven bags. If the decision-maker is satisfied, go to step 8. Otherwise, go to Step 7.
Step 7: Determine whether the termination condition of the algorithm is satisfied. If so, output the optimal solution. Otherwise, optimize and go to Step 2.

The final conditions of the algorithm are as follows:

Condition 1: When the user evaluation satisfies the following equation for more than three consecutive generations, the interactive genetic process will stop, and the optimal solution for the appearance design of the bamboo-woven bag product is obtained.

$$f(x) \geq \beta \times f_M \quad (2)$$

where β represents the optimal solution factor; a large value of β indicates high optimal solution quality. f_M represents the users' maximum evaluation value of bamboo-woven bag product design.

Condition 2: When the interactive genetic evaluation has reached a preset termination algebra (i.e., after 200 generations), the algorithm will terminate and the system will output the best solution for the shape design of the bamboo-woven bags.

Step 8: Determine whether the user is fatigued. If the user is fatigued, the user evaluation will be simulated through the decision tree, and step 7 will be executed. Otherwise, go back to step 6. The decision tree training error function is calculated as follows:

$$MSE = \frac{\sum_{k=1}^{p} (y_k - y_k^*)^2}{p} \quad (3)$$

where y_k is the actual output of the decision tree algorithm, y_k^* is the target output of the decision tree, and p is the number of decision trees.

Step 9: Optimize the genetic algorithm for decision tree input. Set the range of values for each morphology of an individual, optimize the evaluation indicators, and obtain the optimum fitness individual.

Step 10: Decode individual optimal fitness values to obtain the optimal form design scheme.

Experimental Results and System Design

This section takes the evolutionary design of bamboo handbags as a study case. Firstly, 10 traditional bamboo weaving patterns, 10 women's handbag appearance styles, and 3 handbag handle styles are selected to build a database for the evolutionary design of handbags. Subsequently, through a questionnaire survey, the users' emotional evaluation vocabularies for the bamboo handbag were collected, and the weight value of each emotional vocabulary was obtained. Finally, the interactive evolution system of bamboo creative products was constructed based on the IGA and decision tree algorithm. The specific operation will be discussed from the following aspects:

Construction of modeling element database of bamboo-woven bag products

To obtain the basic design elements of bamboo-woven bags, we conducted an extensive investigation and analysis of consumer demand. First, the pictures and comment data of the most popular bamboo-woven bags in the market were collected from online e-commerce platforms and fashion magazines to study the attractiveness characteristics of the products and information on customer demand dimension. The collected images were then processed to A4 paper size; the resolution was set to 100 dots per inch, the image was decolorized, and the background was removed through Adobe Photoshop and other image processing software to unify the image samples. In addition, 50 experienced designers (23 males and 27 females between the ages of 18 and 38) with 3 to 5 years of experience in bag design participated in the demand investigation. The results included 124 median, 256 subordinate, and 523 superior evaluation items.

However, the higher the morphological features, the larger the range of possible solutions in the IGA, increasing the likelihood of user fatigue and reducing the convergence rate of the evolution algorithm. Therefore, similar vocabularies and specific modeling functions were merged to achieve the dimensionality reduction of the evaluation item. Finally, the results, including seven superior evaluation items, were obtained, considerably reducing the search range of the interactive evolution algorithm and improving its efficiency.

Extraction of evaluation vocabulary for creative cultural products

In this stage, positive and negative questionnaires were created to investigate the users' responses, regardless of the adequacy of each semantic expression. According to the results obtained during the demand interview, seven adjectives were considered attractive evaluation vocabularies. In addition, the following top four items were selected from the number of user evaluations: lively; warm and amiable; vivid and interesting; friendly and reliable. In addition, there are three other perceptual vocabularies that are less mentioned. Our study invited 80 graduates majoring in industrial design to complete the experimental research. The reliability of the questionnaire data from the 80 graduates were comprehensively evaluated by calculating Cronbach's coefficient α, which lies between 0 and 1. The greater the Cronbach value, the greater the reliability of the evaluation index value of the bamboo bag evaluation vocabulary.

In this study, $\alpha = 0.76$, thus verifying the credibility of the investigation.

$$\alpha = \frac{K}{K-1}\left[1 - \frac{\sum_{i=1}^{K} {\delta_{Y_i}}^2}{\delta_x^2}\right] \tag{4}$$

where K is the number of items in the scale, δ_x represents the total score variance of the questionnaire, and δ_{Y_i} represents the variance of the total score of all respondents to the observed items.

Design initialization of bamboo-woven bag

Chromosomal encoding transforms the product design elements into the chromosomal gene form of the evolution algorithm. The form design scheme of the bamboo-woven bag was randomly initialized to increase the search space of product design. The total number of populations was set to 8. If the population size is extremely large, the calculation results will be difficult to converge and resources will be wasted. We set the evolutionary generation to 200; if the set value is extremely small, the population is not yet mature. Conversely, if the set value is extremely large, the population is premature to reconverge again, and continued evolution will only waste time and resources. The general setting of the termination evolution algebra is 100 to 500. The crossover rate is set to 0.9; i.e., when the population size reaches 100, 90 individuals will perform the crossover operation. If the mutation probability is small, the diversity of the population will drop too fast, leading to the rapid loss of effective genes. If the mutation probability is excessively large, the population diversity can be guaranteed by setting the mutation rate; the mutation rate is set between 0.05 and 0.2. When the iteration stop condition is satisfied, the algorithm exits the iterative process and the final bamboo-woven bag form design scheme will be output.

Binary coding is used to select design elements in the product design, so the chromosome gene of the first design component will be 0001 if the second style is selected for the shape of the bag; if the sixth form of the pattern element is selected, the code is 0101; if the handheld form is selected in the second style, the code will be 01. Accordingly, the chromosomal genes and bamboo-woven bag product design elements in genetic evolution were mapped by coding the above three design elements. During initialization, the three design elements are randomly combined to obtain eight initial form design schemes, and the fitness values are calculated. An enhanced satisfactory form design scheme can be obtained by evaluating and analyzing the form design scheme and customer satisfaction.

Comprehensive fitness function of interactive evaluation

Different people in different occupations and groups have different preferences for perceptual indicators; therefore, the system provides a window for weight setting, with different weights for different types of people and the same weights for the same types of people. We selected four perceptual vocabularies to determine the weight of the four perceptual evaluation

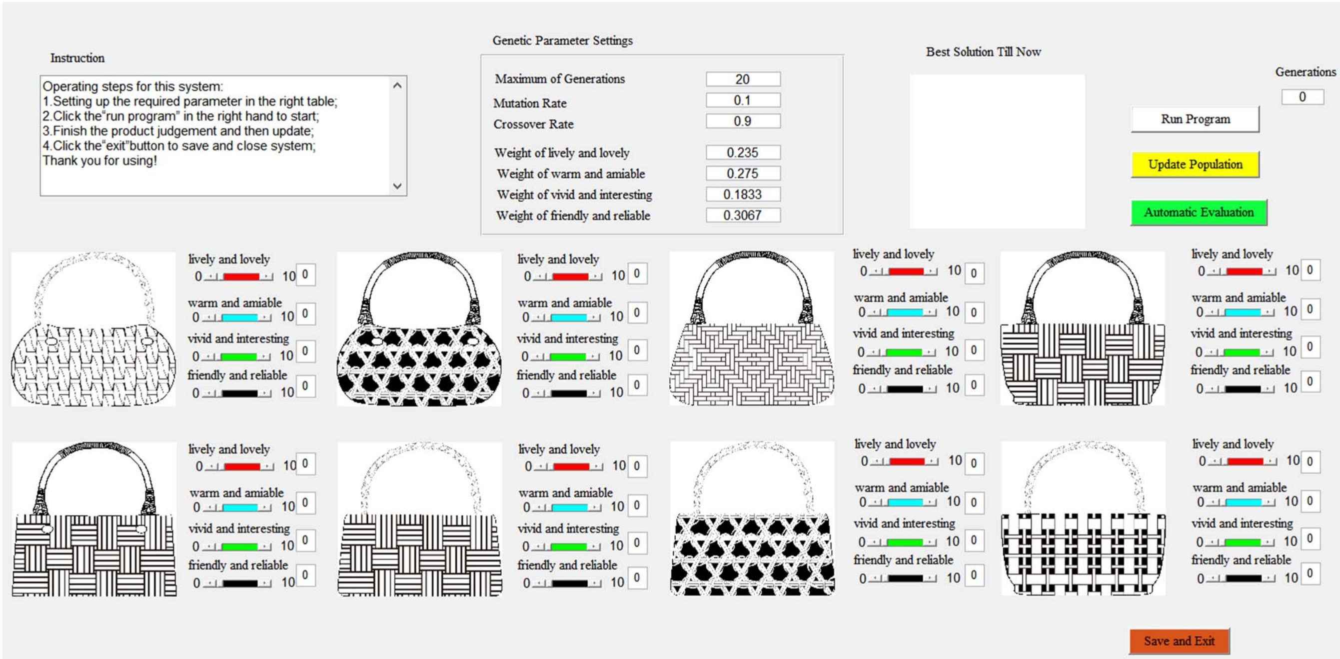


Figure 6.—The initial operation interface for the evaluator to evaluate the bamboo-woven bag.

vocabularies in the system running process: "Lively," "Warm and amiable," "Vivid and interested," and "Friendly and reliable." Questionnaires were used to collect the preferences of different experts and designers for each perceptual evaluation vocabulary. Furthermore, weights were assigned to different perceptual evaluation vocabularies based on the calculation results. The weight values of the four types of perceptual vocabularies were set as follows: 0.235, 0.275, 0.1833, and 0.3067.

The comprehensive evaluation of consumers on the product form design scheme and the satisfaction value was acquired after obtaining the weight value of each perceptual vocabulary. The fitness function of the product form design scheme is calculated as follows:

$$f(x) = \sum_{i=1}^{t} \sum_{j=1}^{n} W_i \times v_{ij}(x) \qquad (5)$$

where t is the number of evaluation semantics in the interactive evaluation, and n is the number of evaluation semantic vocabularies; $v_{ij}(x)$ represents the evaluation value of the user on the semantic preference; w_i represents the weight value of each preference; and the individual fitness reflects the evaluator's comprehensive evaluation value for the bamboo-woven bag product form design scheme and its interactive evaluation relation to individual population, while it also indicates the evaluator's preference. The final evaluation result score aligns with the overall quantitative law and the evaluator's emotional appeal for creative products to map product design and customer demand effectively.

An IGA calculates individual fitness based on the evaluator's preference score for bamboo-woven bags. If the evaluator feels tired, it will result in inaccuracy in the evaluation plan, and the user can select automatic evaluation. The system will call the ID3 decision tree for automatic evaluation and enters the incremental learning process. The incremental learning result is judged through error threshold value p. If $p \leq 0$, the execution of the decision tree will be carried out through which the user's evaluation of the bamboo-woven bag is simulated. The result is fed back to the interactive algorithm evaluation stage after evaluation. If $p > 0$, it will return for individual fitness evaluation.

Design of product evolution system

The interaction and collaboration between product design elements and customer demands can help designers and manufacturers understand customer demands and achieve product innovation. The customer evaluation of the product form design scheme is a perceptual process and is prone to customer fatigue because of the repetitive nature of work during preliminary sketch concept, sketch model derivation, and project evaluation. Considering that consumers' subjective evaluation tends to fall into aesthetic fatigue, an evolution

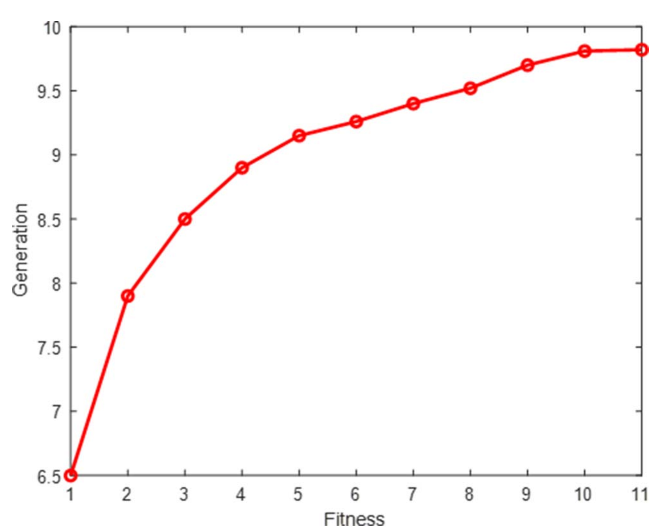


Figure 7.—Maximum fitness change diagram in the evolution of interactive design system.

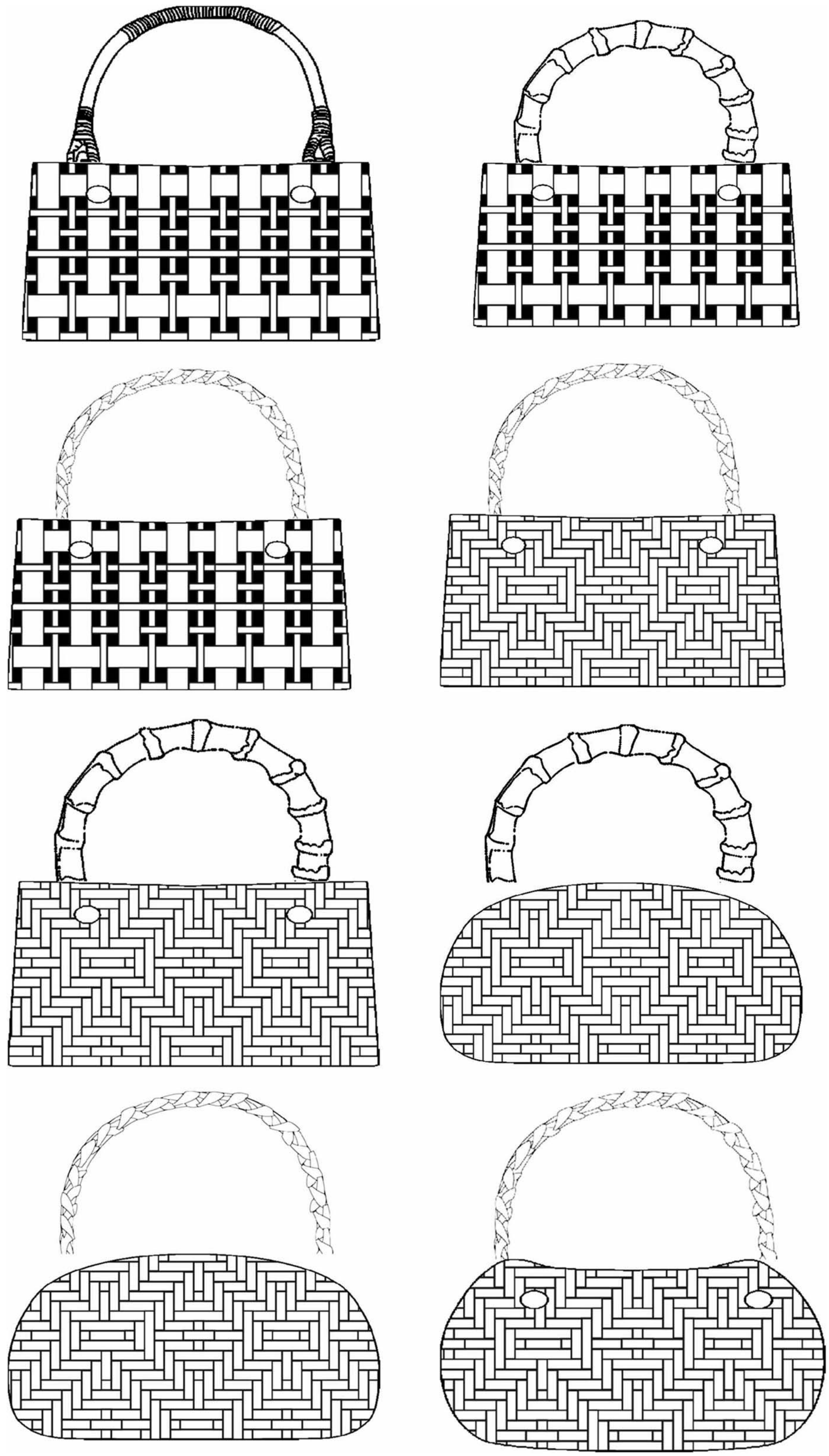


Figure 8.—Form design scheme of bag.

system of creative product design embedded with the ID3 decision tree is designed so that users can participate in the product design process.

The initial running interface of the evolution system is illustrated in Figure 6. An evaluator scores each form design scheme of the bamboo-woven bag. A 10-point scoring system is adopted in this study, with 0 points indicating extremely low and 10 points indicating extremely high levels of preference. The middle upper part of the system is the number of evolution iterations; the optional module of each individual is set. The upper right part is the user determination module during the system running process and includes the system running button

"Run Program," the population update button "Update Population," and the automatic evaluation button "Automatic Evaluation." The automatic evaluation system is designed using the decision tree algorithm. When the user experiences fatigue the system will automatically call the decision tree algorithm in the toolbox to evolve the creative bamboo-woven bag and confirm to save the evolved design pattern and evaluation data.

Practical application of creative product interactive evolution system

In this study, 20 teachers from the field of product design and master students majoring in design and interested in bamboo bag design were invited to operate the interactive evolution system and verify its effectiveness in product design. We first build an automatic evaluation model to analyze the effectiveness of the decision tree algorithm in the iterative process of the evolution system. The training accuracy was set to 0.01. The change trend diagram of the maximum fitness evaluation score is demonstrated in Figure 7. The fitness scores stabilize rapidly with the increasing number of iterations, indicating that the designed evolution system has a faster convergence rate and better bamboo-woven bag form design scheme with smaller iterations.

Moreover, some of the solutions with fitness values above 4.5 points during the evolution iteration are shown in Figure 8. In total, 8 design patterns with scores above 9.5 were obtained. The calculated specific distribution of 8 form design schemes is shown in Table 2. The combined average value and standard deviation reveal that the overall evaluation values of the eight form design schemes are highly stable. The results verify that the decision tree algorithm in the IGA can obtain the product portfolio form design schemes with better stability.

Conclusions and Prospects

This study used the optimization capability and deep learning ability of the IGA to conduct a series of operations, including crossover, mutation, and selection to the existing component coding of cultural products. We successfully obtained the users' preferences for cultural product modeling and realized the mapping between product design and users' demand. The proposed evolutionary design system for bamboo weaving of women's handbags constructed provides a technical understanding of the inheritance and innovation of traditional bamboo weaving. Its use value is manifested in that it can help companies improve design efficiency in product development and provide designers with drawings for reference to assist them in developing cultural products. The conclusions are as follows:

(1) Extensive investigation and analysis of the consumer's actual demand were conducted, pictures and feedback of the most popular bamboo-woven bag in the market were collected, and the product attraction characteristic and customer demand dimension information were analyzed. Accordingly, the user's perceptual vocabulary preference weight value in product modeling design was built, and the mapping relation between product design elements and intangible cultural heritage based on the user's actual demand was established.

Table 2.—Relevant indications for score of 8 design patterns.

Indication	Min.	Max.	Mean	SD
Numeric	9.63	9.77	9.715	0.054083

(2) Based on the IGA, we construct an interactive evolutionary design system of bamboo-woven bags that allows users to participate in the evaluation. Thus, designers can objectively and directly obtain users' emotional preferences and aesthetic direction and help revive the traditional bamboo-woven industry.

(3) The users' visual cognition and emotional preference for the intangible cultural heritage of bamboo weaving are obtained using intelligent technology by importing the ID3 decision tree algorithm into the design evolution system. The proposed system reduced user fatigue in product design and evaluation as well as improved the evolution efficiency of bamboo weaving modeling.

(4) Introducing a decision tree algorithm into the design evolution system and using intelligent technology to obtain users' visual cognition and emotional preferences for bamboo-woven bags overcomes the fatigue problem of users participating in product evaluation and improves the aesthetics of bamboo-woven bags.

The proposed creative product design evolution system can realize the interaction between users and product form design schemes. In the future, the application and efficiency of different decision tree algorithms in the evolutionary design system and different intelligent optimization algorithms in creative product design will be explored.

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