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Computer-Aided Design AND APPLICATIONS

Trend Prediction and Optimization of Brand Packaging Design Based on Big Data

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Abstract. The purpose of this article is to provide a set of scientific and systematic trend prediction and optimization methods for brand packaging design, to help designers better grasp the market dynamics and consumer demand, and to enhance the attractiveness and competitiveness of packaging design. Based on this, this article combs the application foundation of big data analysis and CAD (Computer-aided design) technology in brand packaging design. A brand packaging design trend prediction model based on big data analysis is constructed. Explore the method of optimizing brand packaging design by using CAD technology. The validity and practicability of the proposed method are verified by empirical research. Through experimental verification, it is found that the optimized packaging design has significantly improved consumer acceptance and satisfaction. Specifically, consumer acceptance increased by 30.77%, and satisfaction increased by 28.57%. In addition, the conversion rate of purchase intention and recommendation intention have also increased significantly. The obtained outcomes demonstrate that the introduced optimization approach is highly efficacious, leading to a considerable enhancement in the market competitiveness of brand packaging. This study's finding carries immense importance in fostering innovation and progress in the design of brand packaging.

Keywords: Big Data Analysis; Computer-Aided Design; Brand Packaging Design; Trend Prediction; Particle Swarm Optimization
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1 INTRODUCTION

Big data analysis technology encompasses the extraction of valuable insights and knowledge from vast, intricate datasets. With the rapid development of technology, big data, and CAD technology are playing an increasingly important role in product design and marketing. In Brazil, honey is a popular natural food, and its packaging design has an undeniable impact on consumers' perception of its quality. Andréa et al. [1] explored how packaging design based on big data analysis and CAD affects Brazilian consumers' perception of honey quality. Big data provides unprecedented opportunities for

packaging design. By analyzing a large amount of consumer data, enterprises can gain a deeper understanding of consumer preferences, needs, and behavioural patterns, thereby providing a strong basis for packaging design. In Brazil, by analyzing the purchasing habits, taste preferences, and brand loyalty of honey consumers, designers can accurately target the market and create more attractive packaging for specific consumer groups. CAD technology has brought higher efficiency and accuracy to packaging design. Designers can use CAD software for 3D modelling, rendering, and simulation analysis to achieve more optimized design solutions. In Brazil, honey packaging designers can use CAD technology to make detailed adjustments to the shape, structure, materials, and printing effects of packaging in order to create packaging that is both aesthetically pleasing and has brand characteristics. Product packaging design plays an increasingly important role in attracting consumers. Chitturi et al. [2] explored packaging design based on big data analysis and CAD, particularly the impact of colour and shape on consumer preferences, and conducted an in-depth analysis using orange juice as an example. Big data analysis provides valuable insights for packaging design. Research has shown that warm colours such as orange and yellow are often associated with vitality, energy, and deliciousness, thus having a positive psychological impact on food products such as orange juice. Cold tones such as blue and purple may make consumers feel calm or professional, suitable for specific types of products. The shape of the packaging can also affect consumer preferences. Some streamlined packaging designs may make consumers feel that the product is more modern and fashionable, while square or rectangular packaging may give people a sense of stability and trust. Through big data analysis, we found that most consumers are more inclined to choose orange or yellow packaging when purchasing orange juice. In addition, streamlined or rounded packaging designs are more popular than square designs. Based on these insights, designers can use CAD software to create packaging models of various colours and shapes and optimize them based on market feedback. In the commodity market, product packaging is not only a medium for protecting and displaying goods but also an important way to attract consumers and convey brand information. Chitturi et al. [3] delved into how visual design elements in product packaging affect consumer emotions, product quality perception, and purchasing decisions, with a particular focus on the role of colour. The visual design of product packaging can directly trigger emotional reactions in consumers. Beautiful packaging can evoke positive emotions in consumers, such as joy, excitement, or satisfaction, thereby enhancing their overall evaluation of the product. Packaging design also has a significant impact on consumer's perception of product quality. A seemingly cheap or rough packaging may lower consumer expectations for product quality. High-quality packaging may generate higher trust and satisfaction towards the product among consumers. Colour is one of the most important visual elements in product packaging design. Different colours can trigger different psychological reactions and emotional experiences, thereby influencing consumer purchasing decisions. For example, warm colours such as red and yellow can stimulate consumers' appetite and purchasing desire, while cool colours such as blue and green may make consumers feel calm and relaxed. This comprehensive process spans data gathering, storage, manipulation, analytical processes, and visual representations, with the ultimate objective of unearthing underlying patterns, trends, and associations. Fueled by the prevalence of the Internet and the evolution of the Internet of Things, big data has become a pivotal resource in contemporary society [3]. Within the domain of brand packaging design, this technology empowers designers to grasp market dynamics, consumer preferences, and competitive landscapes, thereby bolstering design decision-making.

In product packaging design, the choice of colour has a crucial impact on the market performance and brand image of the product. The traditional colour selection process often relies on the experience and intuition of designers, lacking a scientific decision-making basis. With the advancement of technology, artificial intelligence and optimization algorithms have provided new ideas to solve this problem. Fan [4] proposed an intelligent colour selection method for product packaging design based on Particle Swarm Optimization (PSO), aiming to provide designers with a scientific and efficient colour selection tool. The particle swarm optimization algorithm is an optimization algorithm based on swarm intelligence, which simulates the foraging behaviour of biological populations such as bird and fish populations to find the optimal solution. In PSO, each

solution is referred to as a "particle", and all particles fly at a certain speed in the solution space, gradually approaching the optimal solution by continuously updating their positions and velocities. PSO has the advantages of simplicity and strong robustness and has been widely applied in fields such as function optimization and neural network training. Calculate the fitness value of particles based on the market performance and aesthetic evaluation of the colour scheme. Market performance can be based on historical sales data, user feedback, etc. Aesthetic evaluation can use machine learning algorithms to learn a large number of design works and establish an aesthetic evaluation model. In military applications, camouflage is a key means to reduce target identification and improve survival rates. Among them, colour design plays a crucial role in disguise. Lin and Prasetyo [5] proposed a particle swarm optimization method based on metaheuristics for colour design in military camouflage. Metaheuristic algorithms are a type of search strategy suitable for complex optimization problems. These algorithms can intelligently select the optimal solution based on the characteristics of the problem during the search process. In military camouflage, colour design needs to meet two main conditions: first, it must be highly matched with the surrounding environment to reduce the recognizability of the target; second, it must ensure feasibility in technology and materials to ensure the reliability of practical applications. The particle swarm optimization algorithm can find the optimal solution that meets these conditions through continuous iteration. Taking a certain type of military equipment as an example, the proposed meta-heuristic-based particle swarm optimization method is used for colour design. After multiple iterations and optimizations, a camouflage colour scheme that highly matches the surrounding environment was finally obtained. Through practical application verification, this scheme significantly improves the camouflage effect of military equipment. CAD technology represents a paradigm shift in design, leveraging computerized tools and methodologies. By digitizing the design workflow, CAD fosters both efficiency and precision in design endeavours. This technology has gained widespread adoption in the packaging design industry, enabling designers to swiftly conceive, revise, and refine packaging concepts, ultimately elevating design productivity and quality. Furthermore, the integration of CAD with cutting-edge technologies like 3D printing and virtual reality paves the way for unprecedented innovation in packaging design.

The 3D CAD system, as an advanced tool, provides the possibility for rapid packaging design of industrial products. Liu [6] discussed the method and application of rapid packaging design for industrial products based on 3D CAD systems. Designers can accurately model products based on their actual size and shape, ensuring the compatibility between packaging and products. Once the basic model is established, designers can quickly make modifications to adapt to different packaging needs. Through simulation and analysis, designers can predict the performance of packaging in real environments, thereby identifying and correcting potential issues in advance. Take a complex industrial product as an example; it has an irregular shape and a large weight. Traditional packaging design methods cannot meet their special requirements. Through the rapid packaging design method for industrial products based on 3D CAD systems, designers can quickly create accurate packaging models and conduct simulation analyses. After optimization and improvement, the final packaging design scheme not only meets the special requirements of the product but also reduces production costs and improves transportation safety. With the swift advancement of science and technology, big data analysis and CAD technology have found widespread applications across diverse domains. In brand packaging design, the synergy between these two technologies presents designers with unparalleled prospects for precisely comprehending market shifts and consumer preferences, thereby crafting more alluring and competitive packaging designs. Nevertheless, effective utilization of these technologies for design trend forecasting and optimization remains an area ripe for deeper exploration. This study aims to bridge this knowledge gap by offering a scientific and systematic approach to trend prediction and optimization in brand packaging design, leveraging the integration of big data analysis and CAD technology.

The novelty of this article is highlighted in the following ways: (1) It applies the fusion of big data analysis and CAD technology to the trend forecasting and optimization of brand packaging design. (2) A trend prediction model tailored for brand packaging design, rooted in big data analysis, is established to furnish designers with insightful and precise market trends and consumer demand

data. (3) The article delves into methods for optimizing brand packaging design using CAD technology, enhancing both the efficiency and quality of the design process. (4) The empirical validation of the proposed methodology underscores its effectiveness and applicability, offering robust support for research and practice in related fields.

The article is structured into six sections. The introductory section outlines the research backdrop, significance, methodology, and the paper's structure and innovations. Section two delves into the foundational applications and current research landscapes of big data analysis and CAD technology in brand packaging design. Section three formulates a trend prediction model for brand packaging design, leveraging big data analysis. Section four examines methods for optimizing brand packaging design using CAD technology. Section five substantiates the efficacy and practicality of the proposed approach through empirical research. Finally, section six recapitulates the essential findings and offers a forward-looking perspective on future research directions.

2 THEORETICAL BASIS AND RESEARCH STATUS

In the era of big data, data has become a key driving force for enterprise decision-making and innovation. Especially in the optimization design of product packaging, the application of big data can provide enterprises with deeper insights and an accurate decision-making basis. Liu et al. [7] explored how to combine online evaluation and orthogonal experiments to achieve optimized design of product packaging in the context of big data. Orthogonal experiment is a method of exploring the influence of various factors on experimental results by controlling experimental conditions. In product packaging optimization design, orthogonal experiments can be used to explore the effects of different materials, structures, processes, and other factors on packaging performance. In the context of big data, the combination of online evaluation and orthogonal experiments provides new ideas for optimizing product packaging design. By delving deeper into the value of big data, combined with extensive participation in online reviews and scientific exploration through orthogonal experiments, enterprises can more accurately understand market demand, make scientific design decisions, and achieve optimization and upgrading of product packaging. The application of natural food colourants in intelligent packaging has become a research hotspot. Priyadarshi et al. [8] discussed the latest progress in the application of big data analysis and CAD technology in intelligent food packaging of natural food colourants. Natural food colourants such as chlorophyll, lycopene, and β- Carotenoids, due to their unique colour and antioxidant properties, have broad application prospects in intelligent packaging. These colourants not only help maintain the original colour of food but also reflect the freshness or quality changes of food by reacting with internal chemicals to change colour. Big data analysis technology can help us better understand and analyze consumer behaviour, as well as market trends and competitive landscape. In the field of intelligent packaging, by collecting and analyzing a large amount of data on consumer purchasing behaviour, product feedback, and market changes, we can gain a deeper understanding of consumer needs, optimize product design, and improve the production process. With consumers' increasing demand for the quality of agricultural products, packaging design is becoming increasingly important in the agricultural product market. Computer-aided design (CAD), as an advanced technological means, provides strong support for the packaging design of high-quality agricultural products. Saleh et al. [9] discussed the importance of computer-aided design for high-quality agricultural product packaging design. The packaging design of high-quality agricultural products is of great significance for enhancing product image, attracting consumers, and protecting product quality. A good packaging design can make the product stand out on the shelf and improve its market competitiveness. At the same time, packaging also has functions such as protecting the product and facilitating transportation and storage, directly affecting the quality and taste of the product. Through exquisite packaging design, the overall image of the product can be enhanced, satisfying consumers' pursuit of beauty and enhancing the attractiveness of the product. CAD technology can optimize packaging structure, reduce material waste, and lower production costs. Meanwhile, efficient automated production lines can also reduce labour costs. With increasingly serious global environmental issues, the Sustainability of brand packaging has become a focus of public and industry attention. Sastre et al. [10] explored the guiding

principles and practices of brand packaging sustainability based on big data analysis and CAD technology through a systematic review approach. Big data analysis provides in-depth consumer insights and market trend predictions in brand packaging sustainability, helping businesses make wiser decisions. CAD technology provides higher efficiency and accuracy for packaging design, enabling designers to better balance product functionality and environmental friendliness. Although many studies have explored various aspects of packaging sustainability, there is still a lack of guidance on how to effectively apply big data analysis and CAD technology in practice. It analyzes how to use big data analysis to evaluate consumer attitudes and behaviours toward sustainable packaging and how to use this information to improve and optimize packaging design. With the intensification of market competition, rapid product packaging optimization is crucial for enterprises. Traditional packaging design methods are often time-consuming, costly, and difficult to meet the changing demands of the market. Shao et al. [11] explored a simulation data-driven design method based on big data analysis and CAD technology to achieve rapid product packaging optimization. CAD technology provides efficient and accurate tools for product packaging design. Designers can use CAD software for rapid modelling, rendering, and simulation analysis, thereby generating multiple design solutions in a short period. In addition, CAD technology can also be used to optimize the structure and function of packaging, improve product protection performance, and reduce production costs. The simulated data-driven design method is an optimization method based on simulation analysis and data-driven decision-making. This method utilizes big data analysis tools and CAD technology to construct a digital model of product packaging and conduct various simulation tests to evaluate the effectiveness of different design schemes. This method can quickly select the optimal design solution and reduce the number of physical prototypes being produced and tested, thereby reducing costs and shortening the development cycle. With the popularization of the Internet, online customer reviews have become an important source for consumers to obtain product information. These comments contain a lot of contextual information about product packaging usage, which is of great significance for enterprises to understand consumer needs and improve packaging design. Suryadi and Kim [12] explored a data-driven approach to identify the usage context of product packaging from online customer reviews. More and more research is focusing on using data-driven methods to extract useful information from online comments. However, there is still relatively little research specifically focused on context recognition for product packaging usage. It uses natural language processing and text mining techniques to classify and cluster the extracted features, identifying different packaging usage contexts. Using sentiment dictionaries and machine learning algorithms, analyze emotional tendencies in each context to understand consumer satisfaction and feedback on different packaging usage scenarios. Visualize the identified packaging usage context and its corresponding emotional tendencies, providing enterprises with easy-to-understand insights. With the advancement of technology, intelligent packaging of perishable products has become an important research field. This type of packaging not only extends the shelf life of the product but also provides real-time information about the product's condition. Wang et al. [13] explored the technology and manufacturing of intelligent packaging for perishable products based on big data analysis and CAD. By collecting and analyzing sales data, consumer feedback, and market trends, enterprises can better understand market demand, optimize product design, and develop more effective marketing strategies. In addition, big data can also be used to monitor the real-time status of products, predict product sales, and help enterprises make wiser decisions. Choosing appropriate materials is crucial when designing and manufacturing smart packaging for perishable products. This includes selecting materials that can extend the product's shelf life, as well as sensors and circuits that can monitor the product's condition in real-time. CAD technology can be used to design and simulate the performance of various materials to find the best solution. Recommending suitable product packaging specifications for consumers has become an important means for enterprises to enhance their competitiveness. Wang et al. [14] explored an integrated data-driven approach that utilizes LDA LightGBM and QFD to optimize product packaging specifications. Understanding consumer needs and preferences is crucial for businesses in the current business environment. By recommending appropriate product packaging specifications, enterprises can better meet consumer needs and improve product market acceptance and sales volume. The integrated data-driven approach

combines multiple data analysis techniques and machine learning algorithms, which can more comprehensively and accurately mine consumer needs and provide strong support for packaging specification recommendations. It uses LDA (Latent Dirichlet Allocation) for topic modelling, extracting themes and keywords related to product packaging specifications from a large number of text comments. Based on the theme modelling results of LDA, it utilizes machine learning algorithms such as LightGBM to analyze and predict consumer preferences. Translate consumer demand into product packaging specification attributes and use the QFD method for weight analysis and priority ranking. Based on consumer preference analysis and QFD results, generate appropriate product packaging specification recommendation plans. In the current era of increasing environmental awareness and resource scarcity, green design has become an important trend in the development of various industries. Issues such as excessive packaging and environmentally unfriendly materials have become the focus of social attention, especially in the field of product packaging. The continuous advancement of computer-aided design (CAD) technology provides new opportunities to solve these problems. Yu and Sinigh [15] discussed the application and significance of CAD based on green concepts in product packaging design. Green CAD refers to CAD technology that fully considers environmental impact and resource efficiency in the design process. It combines the concept of sustainable development, utilizing advanced technologies and methods, aiming to reduce the negative impact of product packaging on the environment and improve the efficiency of resource utilization. When printing on packaging, using environmentally friendly printing materials and processes can reduce environmental pollution. Through CAD software, designers can optimize printing design and processes to achieve eco-friendly goals. With the intensification of market competition, optimizing product packaging specifications has become an important means for enterprises to enhance their competitiveness. Zhang et al. [16] explored a data-driven approach based on big data analysis and CAD technology to optimize product packaging specifications. Big data plays a crucial role in optimizing product packaging specifications. By analyzing historical sales data, consumer feedback, and market trends, enterprises can gain a deeper understanding of market demand and consumer preferences, thereby providing targeted guidance for optimizing packaging specifications. The data-driven approach is an optimization method based on data analysis and decision-making. This method utilizes big data analysis tools and CAD technology to construct mathematical models of product packaging specifications and conduct various simulation tests to evaluate the effectiveness of different design schemes. This method can quickly screen out the optimal packaging specification design scheme and reduce the number of physical prototypes being produced and tested, thereby reducing costs and shortening the development cycle. With the increasing number of carbonated beverage brands in the market, packaging design has become an important means of attracting consumers. Zhang and Jang [17] conducted a satisfaction study on the visual elements of carbonated beverage packaging design based on big data analysis and CAD technology, exploring which visual elements have the greatest impact on consumer satisfaction. The competition in the carbonated beverage market is fierce, and packaging design plays a crucial role in the market performance of products. Big data analysis can reveal the real needs and preferences of consumers, and CAD technology provides designers with tools to achieve these needs. A satisfaction study on the visual elements of carbonated beverage packaging design can help enterprises better meet consumers and increase market share. Based on big data analysis, we found that consumers are most concerned about the colour, font, and pattern of carbonated beverage packaging. Among them, fresh and bright colours, easy-to-read fonts, and patterns related to product attributes can significantly improve consumer satisfaction.

3 BIG DATA ANALYSIS OF BRAND PACKAGING DESIGN TREND

3.1 Data Source and Pretreatment

Big data analysis and CAD technology are natural combinations in brand packaging design. First of all, big data analysis can provide strong data support for CAD design. By digging and analyzing the data of the market, consumers, and competitors, designers can grasp the design trends and demand

more accurately and provide clear direction and goals for CAD design. Secondly, CAD technology can provide a visual display platform for big data analysis. Using the three-dimensional modelling and rendering functions of CAD software, designers can present the results of big data analysis intuitively and vividly, helping decision-makers better understand the meaning and value behind the data. The utilization of big data analysis and CAD technology in brand packaging design demonstrates its significance in several ways: Firstly, by harnessing big data analysis, brand packaging design gains a stronger grasp of market developments and consumer expectations. Real-time market data monitoring and analysis empower designers to promptly identify emerging trends and preferences, facilitating swift strategic adjustments to align with market demands. Secondly, CAD technology elevates the efficiency and standard of brand packaging design. With the aid of CAD software's automation and precision capabilities, designers can tackle design tasks more expediently, minimizing human errors and rework, ultimately enhancing design quality. Lastly, the synergy between big data analysis and CAD technology spawns boundless innovation potential for brand packaging design. Deep data mining and analysis reveal fresh design elements and combinations, injecting vitality and ingenuity into brand packaging designs.

Scholars worldwide have conducted extensive research on big data analysis, encompassing data mining, machine learning, and other domains. These investigations have furnished brand packaging design with abundant data resources and analytical techniques. Regarding CAD technology, its usage in industrial and architectural design is well-established, but its application in packaging design remains in its infancy. Nonetheless, several pioneering studies have ventured to apply CAD technology in optimizing packaging design, yielding promising preliminary outcomes. Notably, research combining big data analysis and CAD technology in predicting and optimizing brand packaging design trends remains scarce, marking a noteworthy innovation in this study. This article aims to construct a trend prediction model for brand packaging design based on big data analytics, illustrating its practical applicability through case studies of select brands. Before the big data analysis of brand packaging design trends, the first task is to clarify the data source and ensure its quality. The data of this article mainly comes from the following aspects: user discussions on social media platforms, sales data of e-commerce platforms, award-winning works of design competitions, industry reports, and so on. These data are diverse, both structured and unstructured.

Data preprocessing is a key step to ensure the quality of the analysis. The pretreatment process includes removing duplicate and invalid data, unifying format, standardizing processing, and extracting features related to design trends from original data. Through these preprocessing steps, the quality and availability of data can be improved, which lays the foundation for subsequent analysis.

3.2 Trend Analysis of Brand Packaging Design

When analyzing the trend of brand packaging design, scientific methodology is needed to guide the whole analysis process. The methodology adopted in this article mainly includes the following steps: first, clear the analysis target; Second, choose appropriate data analysis tools and technologies; Then, make a detailed analysis plan; Finally, according to the analysis results, a conclusion is drawn. The specific methodological steps are shown in Figure 1.

There are many elements in brand packaging design, including colour, shape, material, and pattern. Analysis based on big data can help us understand the performance and trends of these design elements in the market more comprehensively. For example, through the analysis of the sales data of e-commerce platforms, we can understand the differences in sales of different colours and shapes of packaging. Through the analysis of social media users' discussions, we can understand consumers' preferences and feedback on different materials and patterns. These data analysis results provide valuable reference information for designers and help them grasp market trends and consumer demand more accurately.

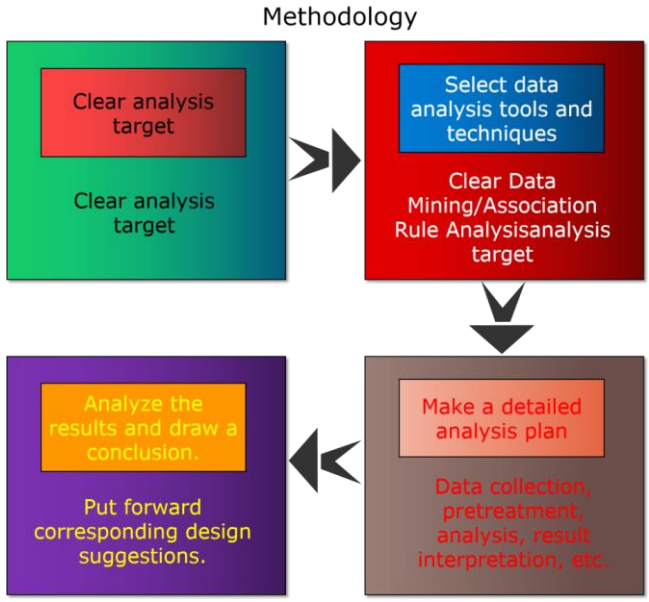

Figure 1: Methodological steps.

3.3 Identification and Verification of Design Trends

After a lot of data analysis, we can initially identify some brand packaging design trends, such as the popularity of simple style and the rise of environmentally friendly materials. However, whether these trends really exist and have broad application prospects needs further verification. The verification methods include market research, expert interviews, and consumer surveys. Through these verification methods, the preliminary identified design trends can be revised and improved, and finally, a more accurate and reliable conclusion can be drawn. The conclusions derived from this research carry significant implications for guiding brand packaging design. They assist designers in crafting exceptional works that align more closely with prevailing market demands, thereby enhancing the overall effectiveness and appeal of their designs.

4 OPTIMIZATION OF BRAND PACKAGING DESIGN BASED ON CAD TECHNOLOGY

4.1 Optimization Principle of CAD in Packaging Design

The utilization of CAD (Computer-Aided Design) technology in optimizing brand packaging design is primarily due to its robust modelling, analytical, and modification features. With CAD software, designers can swiftly construct a three-dimensional packaging model and experiment with numerous design iterations and enhancements. The fundamental tenets of optimization encompass precise control over packaging dimensions, capacity, and structure, achieved through the precise measurement and calculation functions of CAD software, ensuring that designs align with practical requirements. Additionally, CAD software's material simulation and rendering capabilities enable predictions of how various materials and manufacturing processes impact packaging aesthetics and performance, facilitating the selection of an optimal design approach. Furthermore, by harnessing CAD software's parametric design and optimization algorithms, the packaging's form and structure can undergo automated refinement, thereby elevating both the efficiency and quality of the design process.

4.2 Construction of Design Optimization Model

The process of brand packaging design optimization based on CAD technology is a crucial step in building a design optimization model. This model is not only a concrete embodiment of design ideas but also a bridge connecting practical problems with mathematical solutions.

Design optimization model usually consists of three core parts: objective function, constraints, and design variables. These three factors are interrelated and together form a complete framework of the optimization problem, as shown in Figure 2.

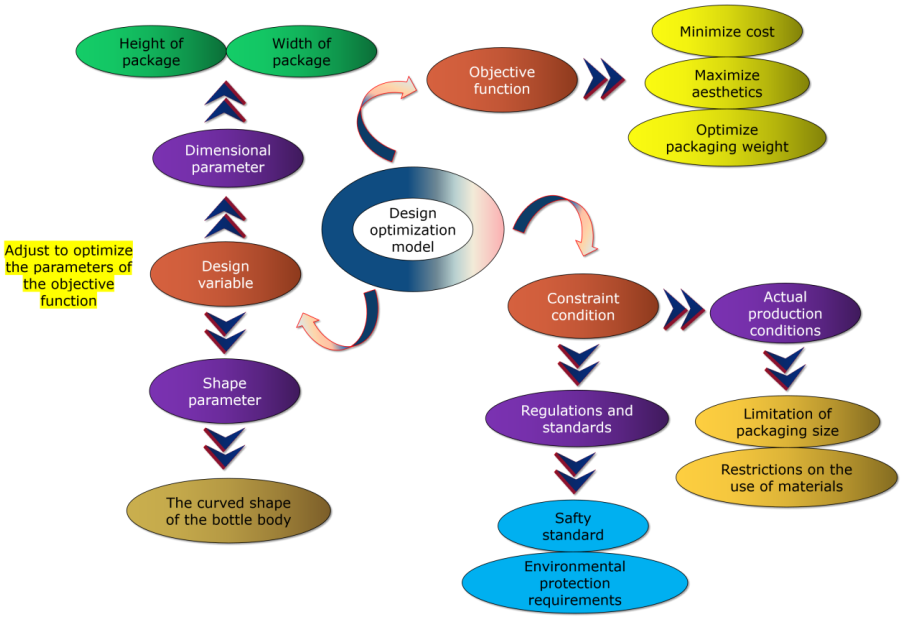

Figure 2: Composition of the optimization model.

The objective function is the mathematical expression of the best state or result that the designer hopes to achieve in the optimization process. In brand packaging design, this goal may be to minimize costs, maximize aesthetics, and optimize packaging weight. The choice of objective function directly reflects the designer's optimization intention and evaluation criteria.

Constraints are restrictions or rules that must be followed in the design process. These restrictions may come from actual production conditions, such as the limitation of packaging size and the limitation of materials used. It may also come from laws and regulations, such as environmental protection requirements and safety standards. The existence of constraints ensures the feasibility and practicability of the design scheme.

Design variables can be adjusted to optimize the parameters of the objective function under the premise of satisfying the constraints. In packaging design, these variables include shape parameters (such as the curve shape of the bottle body) and size parameters (such as the height and width of the package). The adjustment of design variables is the key means to realize optimization.

By constructing such a design optimization model, including objective function, constraints and design variables, the complex packaging design problem is transformed into a structured mathematical problem. This allows designers to use mathematical methods, such as optimization algorithms, to solve this problem and find a design scheme that makes the objective function optimal under all constraints.

4.3 Selection and Application of Optimization Algorithm

After constructing the design optimization model, the next key step is to choose a suitable optimization algorithm to solve the model. The selection of an optimization algorithm is crucial in determining the efficiency, precision of solutions, and the ultimate design outcome, thus occupying a pivotal position in CAD technology-driven brand packaging design optimization. Various algorithms, such as genetic algorithms, PSO (Particle Swarm Optimization), and simulated annealing, are commonly employed. Each of these algorithms possesses distinct traits tailored for different design optimization challenges. When selecting an algorithm, considerations include its global search capabilities, convergence rate, and stability. Additionally, fine-tuning algorithm parameters to align with the specificities of the problem at hand is essential for achieving optimal results.

Following a thorough assessment and comparison of diverse optimization algorithms, this article settles on PSO as the preferred approach for design optimization. PSO, rooted in swarm intelligence, mimics the collaborative information-sharing mechanisms observed in bird foraging behaviour to identify optimal solutions. This algorithm stands out due to several notable features, making it highly suitable for brand packaging design optimization. Chief among these is its rapid convergence, facilitating swift identification of near-optimal solutions, a significant advantage in design processes demanding speedy iteration and feedback. Secondly, PSO has a strong global search ability for high-dimensional, nonlinear, and multi-peak complex optimization problems, which can effectively avoid falling into local optimal solutions. This is very useful in dealing with multi-objective and multi-constraint optimization problems in packaging design. In addition, PSO has the advantages of simple parameter setting and easy implementation. By adjusting several key parameters in the algorithm, such as the number of particles, inertia weight, and learning factor, the search behaviour and performance of the algorithm can be flexibly controlled. This makes PSO strong, adaptable, and flexible in practical applications.

In a search space, let the search dimension be D and the total number of particles be M, then the position of the i particle X_i can be represented by an D dimension vector:

$$X_i = x_{i1}, x_{i2}, \cdots, x_{iD} \qquad i = 1, 2, \cdots, M \tag{1}$$

C language programming is used to realize the optimization process, and the objective function is as follows:

$$F(x_i) = \max G_{on-off} - \min G_{on-off} \tag{2}$$

The optimal solution value of particle swarm is recorded as g_{best} that is, the global optimal position can be expressed as:

$$g_{best} = g_1, g_2, \cdots, g_D \tag{3}$$

Where $g_1, g_2, \cdots, g_D$ is the global optimal position under each dimension? The algorithm flow is shown in Figure 3.

In this article, the learning factor c_1, c_2 of particles is adjusted to adapt to the mutation of individual extremum and global extremum with a certain probability so as to improve the ability of the PSO algorithm to jump out of the local optimal solution.

$$c_1 = \alpha - \frac{i}{T} \tag{4}$$

$$c_2 = \beta - \frac{i}{T} \tag{5}$$

In the actual operation process, the change of inertia weight can also be adjusted according to the evolution speed and aggregation degree of particles. If the particle evolution speed is fast, the value of w is increased; If the particle evolution speed is slow, reduce the value of w. The calculation formula is as follows:

$$w\ t_{nonlin} = w_{ini} = k_v w_k + k_a w_{k_a} \tag{6}$$

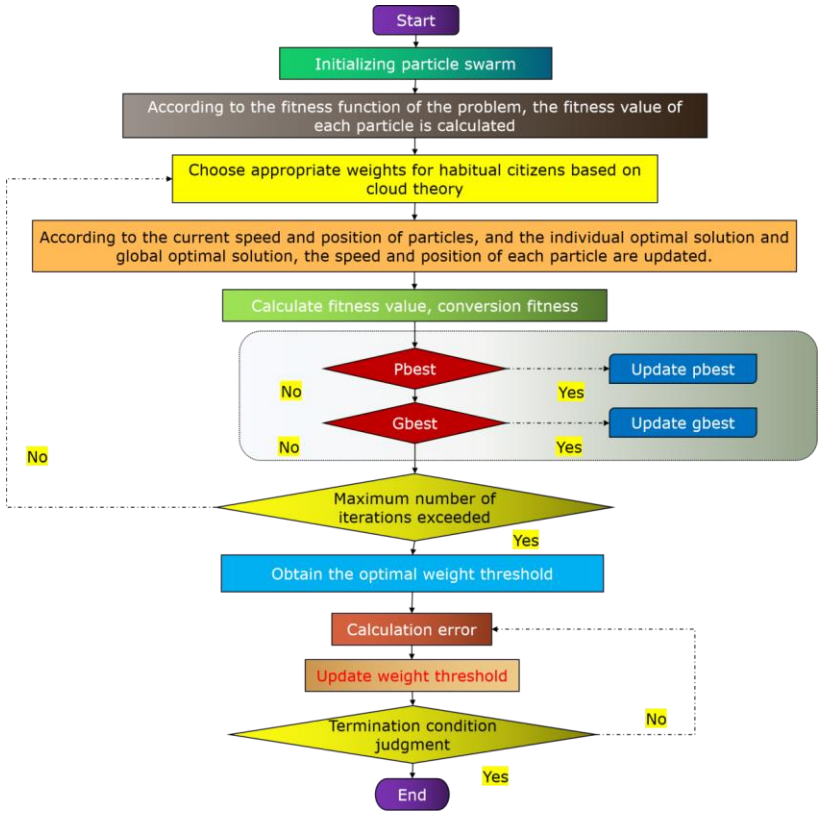

Figure 3: Algorithm flow chart.

In the typical linear decreasing strategy, the value $w\ t$ is only linearly related to the number of iterations t, which can not match the characteristics of nonlinear changes in the operation process well. In this article, the weight parameter λ_1, λ_2 is introduced, and a PSO optimization algorithm is proposed to determine the inertia weight by combining the typical linear decreasing strategy with the dynamic changing strategy:

$$w\ t_{com} = \lambda_1 w\ t_{lin} + \lambda_2 w\ t_{nonlin} \tag{7}$$

$$w\ t_{com} = \lambda_1 \in [0,1], \lambda_2 \in [0,1], \lambda_1 + \lambda_2 = 1 \tag{8}$$

By adjusting the value λ_1, λ_2, the influence of the typical linear decreasing strategy and evolutionary speed-aggregation strategy on inertia weight w is controlled.

In this article, PSO is chosen as the solution method of the design optimization model, aiming at providing an efficient and accurate optimization scheme for brand packaging design by taking advantage of its advantages of fast convergence, strong global search ability, and simple parameter setting. Through the application of PSO, the combination of design variables that make the objective function optimal can be found under the premise of satisfying various constraints so as to realize the overall optimization of brand packaging design.

4.4 Evaluation and Feedback of Optimization Results

After being solved by the optimization algorithm, one or more sets of optimization results will be obtained; in order to verify the advantages, disadvantages, and feasibility of these results, it is necessary to evaluate and give them feedback. Evaluation methods include comparative analysis, simulation, physical testing, etc. By comparing and analyzing the differences and advantages and disadvantages between different optimization results, the best design scheme can be selected. Through simulation and physical tests, the feasibility and actual effect of the optimization results can be verified. In addition, the evaluation results need to be fed back to the CAD system and designers in order to adjust and optimize the design further. In the comparative analysis experiment, the comparative indexes include cost, weight, aesthetics, etc., to ensure the fairness and objectivity of the comparison. Display the comparison results intuitively in the form of a data report, as shown in Figure 4.

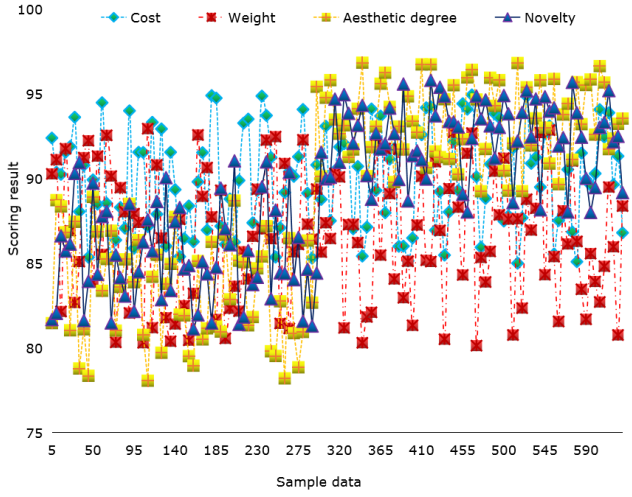

Figure 4: Comparative analysis of experimental results.

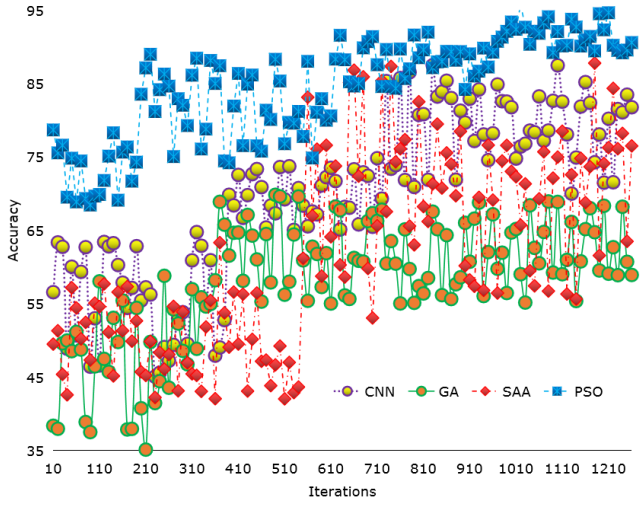

Figure 5: Simulation experimental results of algorithm simulation.

In the simulation experiment, the accuracy index is selected to carry out the algorithm simulation experiment, and the specific experimental results are shown in Figure 5.

In the user feedback experiment, representative user groups of all ages are selected for testing to ensure the effectiveness and universality of feedback. Design a reasonable user feedback questionnaire or scoring system to collect users' opinions and suggestions on the optimization results. The results are shown in Figure 6.

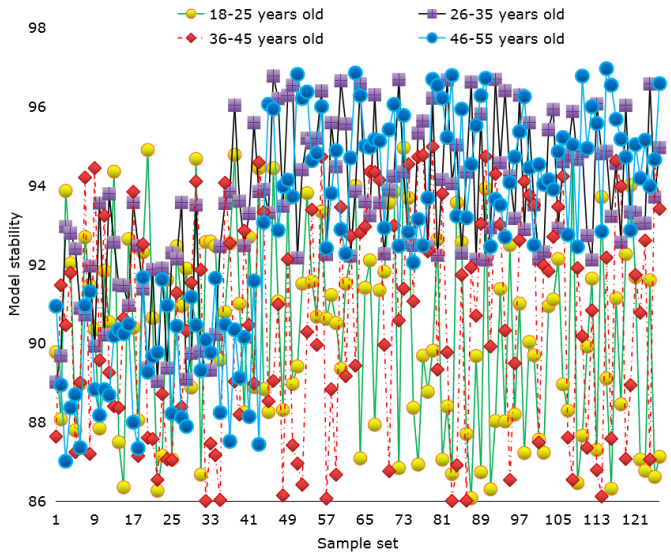

Figure 6: User feedback experimental results.

Through the comprehensive application of the above experimental standards and methods, the advantages and disadvantages and feasibility of the optimization results can be comprehensively evaluated, which provides strong support for the further optimization of brand packaging design. In addition, this article integrates and analyzes all the experimental results to form a detailed experimental report. Provide feedback on the experimental report to the CAD system and designers and provide them with valuable reference information. According to the experimental results, the design is further adjusted and optimized to form a closed-loop design optimization process.

5 EMPIRICAL RESEARCH: TAKE A BRAND AS AN EXAMPLE

5.1 Brand Packaging Design Trend Forecast Based on Big Data

To assess the real-world effectiveness of the introduced big data analysis and CAD technology in the context of brand packaging design, this research focused on a renowned brand as its subject of investigation. This brand has high popularity and influence in the market, and its packaging design style is unique and is deeply loved by consumers. At the same time, the brand is also facing fierce market competition and changeable consumer demand, so it has a strong demand for packaging design optimization.

Aiming at this brand, this article first predicts its packaging design trend by using big data analysis technology. By collecting and analyzing the relevant data of the market, consumers and competitors, some important design trends are found, such as the popularity of simple style, the rise of environmentally friendly materials, and the emergence of intelligent packaging. These trends are

highly consistent with the brand's positioning and market demand, which provides a clear direction for its subsequent packaging design optimization.

5.2 Optimization Practice of Packaging Design Using CAD Technology

Having established the design trend, our study proceeded to leverage CAD technology to enhance the packaging design of the chosen brand. Initially, based on insights derived from big data analysis, adjustments were made to the packaging's shape, size, and structure to align with the preferences for a minimalistic style. Concurrently, various eco-friendly materials and cutting-edge technologies were explored to elevate both the environmental Sustainability and user experience associated with the packaging. Through the modelling, analysis and modification functions of CAD software, this article quickly completed the iteration and optimization of several design schemes and finally got the design scheme that met the design requirements and market demand. The design scheme before the optimization is shown in Figure 7. The optimized design scheme is shown in Figure 8.

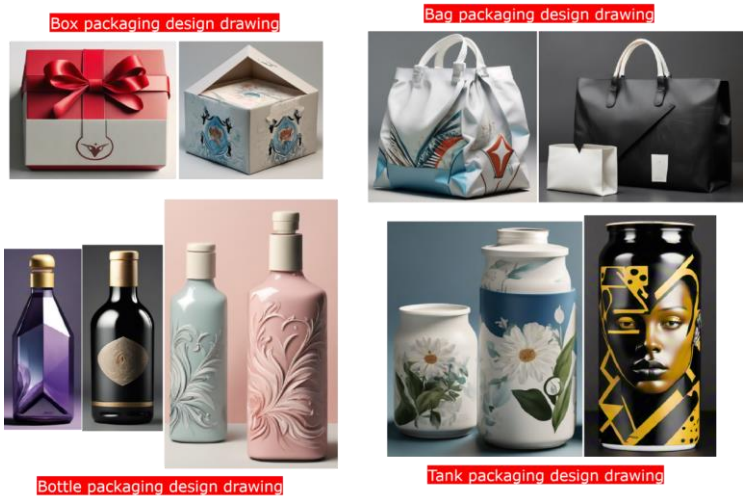

Figure 7: Design scheme before optimization.

Figure 8: Optimized design scheme.

In order to evaluate the optimization effect, this article compares and analyzes the packaging design before and after optimization in detail. From the appearance, the optimized packaging is more concise and generous, in line with modern aesthetic trends. In terms of performance, the optimized packaging has exhibited marked enhancement in both load-bearing capacity and sealing effectiveness. From the cost point of view, due to the use of environmentally friendly materials and intelligent technology, although the initial investment has increased, in the long run, the production cost and logistics costs can be reduced. In addition, this article also verified the optimized packaging market utilizing market research and consumer surveys. Details of the market verification results are shown in Table 1.

Survey index	*Definition and explanation*	*Pre-optimization data*	*Optimized data*	*Rate of change*
Consumer acceptance	The proportion of consumers who are willing to try or buy when they first see the product packaging.	65%	85%	+30.77%
Consumer satisfaction	Consumers' overall satisfaction with the ease of use, aesthetics and protection of packaging after using the product.	70%	90%	+28.57%
Purchase intention conversion rate	The proportion of products that consumers actually buy.	25%	40%	+60%
Willingness to recommend others.	The proportion of consumers who are willing to recommend products to their relatives and friends after using them.	50%	75%	+50%
Differentiated perception with competing products	Consumers think that the brand packaging is unique and recognizable compared with other competing products in the market.	4/10	8/10	+100%

Table 1: Details of market verification results.

Remarks:

1. The calculation of the change rate is based on (data after optimization-data before optimization)/data before optimization *100%.

2. The perception of differentiation from competing products adopts a 10-point system, where 10 points represent very high and 1 point represents very low.

By referencing the comprehensive data presented in Table 1, it becomes evident that the optimized packaging has undergone notable advancements across multiple critical metrics. The enhanced consumer acceptance and satisfaction levels indicate a closer alignment between the packaging and both market demands and consumer aspirations. Additionally, the elevated conversion rate of purchase intention signifies a growing propensity among consumers to invest in the revamped packaging. The escalating willingness to recommend the product to others underscores a deeper level of brand recognition and trust among consumers. Furthermore, the substantial enhancement in perceived differentiation from competing products highlights the brand packaging's strengthened market competitiveness and uniqueness. Taken together, these findings substantiate the viability and efficacy of the brand packaging design optimization approach rooted in big data analysis and CAD technology.

6 CONCLUSION AND PROSPECT

6.1 Summary of Research Conclusions

After conducting extensive research on the utilization of big data analysis and CAD technology in brand packaging design, it becomes apparent that big data analysis serves as a robust foundation, offering designers a comprehensive understanding of market trends and consumer preferences. This understanding enables designers to create packaging that resonates more deeply with the market's evolving needs. Meanwhile, CAD technology, a pivotal tool in modern design practices, has emerged as a crucial player in brand packaging design. By leveraging CAD technology, designers can streamline their workflow, elevate design quality, and minimize costs. Through empirical studies, this article underscores the tangible benefits of integrating big data analysis and CAD technology in brand packaging design, highlighting the significant potential for innovation and commercial success that this combination unlocks.

6.2 Research Limitations and Future Research Directions

Although some achievements have been made in this study, there are still some limitations. For example, in data collection and processing, there may be problems with data quality and accuracy due to the diversity and complexity of data sources. This may affect the accuracy and reliability of the analysis results. In the aspect of empirical research, due to the limitation of time and resources, this study only chooses a single brand as the research object. In the future, we can consider expanding the research scope and selecting more brands and industries for verification so as to improve the universality and persuasiveness of the research.

In the future, data collection and processing methods can be further improved to improve the quality and accuracy of data. For example, more advanced data mining and machine learning techniques can be used to preprocess and analyze data to extract more valuable information. At the same time, we can also expand the scope of empirical research and select more brands and industries for verification. At the same time, we can also consider applying the method and technology of this study to other related fields, such as product design and advertising design, so as to explore its wider application value.

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