Visual System Design of Textile Packaging Guided by Sustainability

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ABSTRACT With the rapid development of intelligent manufacturing and digital information technologies, sustainable packaging design has become increasingly important for improving resource efficiency and enhancing visual communication in modern textile systems. Advanced digital visualization and interactive information presentation also provide new opportunities for future smart packaging and sensing-oriented applications. To address the limitations of conventional textile packaging in environmental sustainability and consumer perception, this study proposes a systematic visual design framework guided by life cycle assessment (LCA). Environmental impacts throughout material selection, production, transportation, and end-of-life treatment are quantitatively evaluated to identify key optimization opportunities for reducing resource consumption and carbon emissions. By integrating ecological design theory with visual communication principles, a sustainable visual identity system is developed using recyclable material symbols, infographics, and green color psychology to strengthen environmental recognition and brand awareness. Packaging structure optimization is further combined with virtual modeling techniques to improve material utilization and transportation efficiency while maintaining visual consistency. Experimental results demonstrate that the proposed design strategy significantly enhances consumer recognition of environmentally responsible packaging and improves aesthetic evaluation, while simultaneously reducing environmental impacts and promoting recycling performance. The proposed framework provides an effective methodology for sustainable textile packaging design and offers useful references for intelligent visual information presentation, digital interaction, and future smart packaging systems supported by advanced communication and sensing technologies.

INDEX TERMS sustainable packaging, life cycle assessment, visual communication, textile packaging, smart packaging

I. INTRODUCTION

As the world increasingly faces global environmental challenges, the textile industry, being a major area of resource consumption and pollution emissions, is in urgent need of transformation and upgrading. Traditional designs in textile packaging generally don't consider the principle of sustainability, therefore resulting in large amounts of resource waste and environmental pollution [1,2]. Examples of issues are excessive packaging, the use of non-recyclable materials and the environment being affected by transportation [3,4]. As customers grow in their environmental awareness, there is a need to balance market demand with environmental accountability through innovative design, and promote the emergence of green packaging [5,6]. Thus, there is great practical and social significance in investigating the design of textile packaging visual system under the sustainable concept [7,8]. In general, a great deal of academic research has done work on the sustainability of textile packaging design in recent years [9,10]. Some academics, diminishing the environmental impact, focused their attention on using environmentally-conscious materials and limiting the number of layers of packaging [11,12]. In this stream of research, biodegradable materials and redesigned packaging structures could greatly reduce carbon emissions [13,14]. Additionally, life cycle assessment methods have also been used to assess the long-term sustainability of packaging materials and have provided a solid quantitative analysis. Unfortunately, current research is predominantly focused on material selection, neglecting the fundamental link between visual system design and consumers' awareness of environmentally-aware design. Thus, a relatively unknown sustainable design concept remains a concept for consumers and has failed to sustain the overall outcomes of sustainable packaging [15,16]. While some researchers are trying to devise a synthesis of visual communication design with sustainability, the overall application of ecological design theory is still limited [17,18]. For instance, green color psychology has been introduced into packaging design to visualize environmental concern and has gathered a small amount of user feedback. Virtual reality technology has been used to develop an optimized packaging structure to minimize the use of packaging materials. However, current research has exhibited the following problems: visual systems and environmental awareness are not integrated sufficiently and there is not enough consideration of integrated optimization of environmental performance throughout the development of packaging [19,20]. Thus, I propose a new method that considers and synthesizes ideas of the main flaws from literature by exploring visual system design within life cycle assessment methodologies. This study aims to understand a holistic solution to decrease waste and pollution of resources via sustainable visual system design for textile packaging. This paper employs a life cycle assessment method to assess the environmental effects of packaging materials and processes. Through an eco-design approach and green color psychology, this paper offers a visual system that achieves both environmental requirements and communicates the core value of the brand. Research suggests that packaging designs optimized via this method had recycled rates of over 60% in four regions (large cities, medium, small, and suburb), with increased consumer awareness of the brand's environmental credentials, creating new thoughts and practice for the sustainable development of the textile packaging. The focus of this study is a central research question – how to systematically improve environmental performance and consumer acceptance of sustainable textile packaging using an integrated design approach that employs life cycle assessment, green color psychology, and structural optimization. Life cycle assessment creates the scientific basis of material and process selection while working toward reducing the objective measures of environmental impacts. Green color psychology extends that environmental basis to a visual language to establish a connection between the environmental attributes of a package and consumer thinking; this an implicit and an explicit connection. The further evaluation of consumer perception and recycling behavior assesses how effective this integrated approach was. The logic here is to move from objective assessment of environmental performance to subjective consumer response with the empirical hypothesis being that a design that visually communicates that external relevance grounded in science while defining structure that is optimized in that context will lead to lower ecological impact and better marketing.

II. METHODS

A. PACKAGING DESIGN POSITIONING BASED ON LIFE CYCLE ASSESSMENT

This article assesses the environmental impact of traditional packaging materials, including common materials such as plastics, paper, and textile materials, and assesses environmental indicators such as carbon footprint, energy consumption, and water consumption over their life cycle. The software GaBi 8 is used to model the Life Cycle Assessment (LCA). The environmental impact of each material is quantitatively assessed based on ISO 14044, focusing on the materials' recyclability, degradability, carbon emissions inferred during transportation, and post-disposal methods for waste. For example, in the selection of plastics, this paper calculates the life cycle carbon footprint of PET (Polyethylene Terephthalate), traditional plastics, and biodegradable plastics. Bio-based plastics are finally selected as the main material because of their low environmental load in resource consumption and waste disposal. The carbon footprint calculation formula is:

$$CF = \sum_{i=1}^{n} (Emissions_i \times Amount_i) \tag{1}$$

In Formula (1), CF represents carbon footprint; $Emissions_i$ is the greenhouse gas emission coefficient of each material; The carbon footprint (CF) is measured in kilograms of CO_2 equivalent. The emission factor ($Emissions_i$) is derived from the GaBi 8 software's built-in database and the Ecoinvent v3.8 database, and is measured in kilograms of CO_2 equivalent per kilogram of material. $Amount_i$ is the amount of each material used. In the packaging production stage, GaBi 8 software is used to perform a life cycle analysis of the production process, ensuring methodological consistency across all assessment stages. Especially in the production of paper packaging, it is found that the energy consumption in the drying process is high. It is recommended to use low-energy production processes and select environmentally certified recycled paper materials to reduce resource consumption and emissions in the production process. The energy consumption calculation formula is:

$$Energy\ Consumption = \sum_{i=1}^{n} (Energy_i \times Amount_i) \tag{2}$$

In Formula (2), $Energy_i$ is the energy intensity of each process, and $Amount_i$ is the input of the process. Energy consumption is reported in megajoules (MJ), where $Energy_i$ is the energy intensity per unit process with values from the GaBi 8 software database integrated with the Ecoinvent database, and is stated in MJ per kilogram of process input. The transportation process includes the weighing, distance travelled, and transportation method of the packaging materials. The transportation carbon footprint of each type of packaging material is calculated within the GaBi 8 environment, utilizing its built-in transportation emission models and logistics parameters. The use of folding structure and compressed materials effectively reduces the packaging volume and transportation carbon emissions. In terms of waste treatment, the environmental impacts of material recycling, incineration with or without energy recovery, and landfill are evaluated separately. The packaging design using PET recycled materials and biodegradable plastics alters the material's end-of-life distribution, increasing the proportion directed to material recycling and reducing the fraction destined for landfill. The end-of-life distribution and recycling performance of different materials are summarized in Table 1.

TABLE 1. End-of-life distribution of packaging materials across waste management pathways

Waste Management Pathway	PET Recycled Material Distribution (%)	Biodegradable Plastic Distribution (%)	Traditional Plastic Distribution (%)
Recycling	85	60	10
Incineration	10	10	30
Landfill	5	30	60

Table 1 shows the end-of-life distribution of different packaging materials among various waste management pathways. Specifically, it analyzes the recycling performance of three common packaging materials (PET recycled material, biodegradable plastic, and traditional plastic) under different waste treatment methods (recycling, incineration, and landfill). Based on the LCA analysis results, this paper proposes optimization recommendations: recyclable and biodegradable materials are prioritized to reduce the use of petroleum-based plastics; low-energy production processes are adopted to simplify packaging structures and reduce packaging layers; transportation routes and methods are optimized to reduce transportation carbon emissions. The life cycle assessment is conducted based on a functional unit defined as the packaging required for one hundred finished textile garments. The system boundary is cradle-to-grave, encompassing raw material acquisition, packaging production, transportation to the distribution center, and end-of-life treatment. The primary packaging for a standard garment is the research object. The material mass for the baseline packaging design is 150 grams per functional unit. The production phase assumes location within China and employs the Chinese national grid mix for electricity. Transportation of raw materials to the production facility assumes an average distance of 500 kilometers via heavy-duty truck. End-of-life scenarios are modeled based on average waste management infrastructure in China, with distributions for material recycling, incineration, and landfill derived from national statistics. The assessment evaluates tread categories of Global Warming Potential (GWP) at the 100-year time horizon, and Cumulative Energy Demand (CED). Characterization factors for GWP 100 were based on the IPCC 2021 AR6 method, while other impact categories were developed using the CML 2001 impact assessment method. Background data for the materials and energy were obtained from the GaBi 8 professional database, and the Ecoinvent v3.8 database, focusing on data sets for the years 2020-2023. A mass-based allocation to the recycled material input and multi-output processes was applied to the analysis. To analyze the effect of data variability onto GWP results for sensitive input in the analysis like distance transportation and material composition, there was also a sensitivity analysis through Monte Carlo simulation.

B. PRELIMINARY OPTIMIZATION SOLUTION FOR SUSTAINABLE PACKAGING

Based on the principles of green color psychology, green represents nature, health, and sustainability - it is an ideal color for communication around environmental awareness within packaging design. This paper utilizes research around consumer behavior to determine the emotional reaction of target consumers to green and, in particular, to its connection with environmental awareness. Data is collected via questionnaire surveys and follow-up in-depth interviews that refer to investigations of the effects of packaging design against various shades of green in their influence on brand credibility, environmental awareness and consumer purchasing decisions. The survey was conducted in accordance with the Ethics Committee of Sanya University School. Participants were made aware of the purpose of the study and the data collected for the purposes of the study prior to completing the survey. All responses were anonymous and no identifiers associated with individuals were kept. The study gathered data on consumer views about green packaging design by utilizing surveys and in-depth interviews. The sampling strategy employed a stratified random sampling method by considering different demographics, namely age, gender, or location. A total of 500 questionnaires were sent out and successfully completed a total of 482 valid responses from participants aged 18 to 55 years. The questionnaire was based on a five-point Likert scale that examined color preference, environmental identity, and purchasing intention. The scale showed at least an acceptable level of internal consistency (Cronbach's alpha = 0.84). To ensure nonresponse bias, the demographics of the respondents were compared to the targeted population demographics, suggesting no significant differences. Thirty representative consumers were interviewed using semi-structured interviews around the themes of green and sustainability. The researcher analyzed the data collected from the study utilizing SPSS software to perform descriptive statistics, as well as correlations. The data presented in Table 2 represent the consumer psychological response data from both the survey and interview portion of the study. Based on the results of the research, natural tones such as dark green, grass green and moss green are selected because it represents a fresh, nature and environmentally friendly message. Specifically, based on the color contrast experiments, the impact of green's saturation and brightness on visual effects was established. For example, dark green conveys when somebody sees it that it is stable/high-end, while grass green gives people a comfortable and refreshing feeling. To ensure the visual contrast effect of the various tones, this paper will be calculated using the color contrast calculation formula:

$$Contrast\ Ratio = \frac{L_1 + 0.05}{L_2 + 0.05} \tag{3}$$

In Formula (3), L_1 and L_2 are the brightness values of the two colors, respectively, to ensure good visual readability and impact under various lighting conditions. The use of dark green for brand logos, fonts, and key elements, grass green and moss green for backgrounds and secondary elements in the packaging design creates a sense of hierarchy for visual guidance. To further build on an environmental protection concept, the design team incorporates green with a natural element like leaves and land patterns using color matching theory and visual contrast principles. The combination of green with neutral tones such as light wood color, off-white, and gray creates visual unity and coordination, and bolts the visual strength of green. Moreover, the use of gradient green (such as the bold gradient from grass green to dark green) supports the representation of "green from nature to the future" symbol of continuity. The designers stabilized the color constant and visibility during the color adjustment stages by adjusting saturation in the HSV color model. Green can express different meanings and emotions based on cultural contexts. Psychological experiments will indicate that green evokes aspects of environmental protection and health in North American and European markets and suggests prosperity and hope in the Asian market. Using this information, the proportion and regional arrangement of green are modified so that consumers in different markets receive a consistent signal about the environment.

C. SUSTAINABLE PACKAGING VISUAL SYSTEM DESIGN

This article evaluates the packaging structure design using life cycle assessment analysis with the goals of decreasing material and increasing simplicity of the packaging format to conserve capital and protect the environment. Using 3D modeling and virtual reality technologies, this article discusses preliminary evaluations and simulations of the packaging form to ensure feasibility of design and production while respecting the environment. Subsequently, based on LCA analysis, a functional analysis of the layers of packaging is completed to determine where there are issues with traditional packaging, specifically the waste of materials and redundant packaging processes. For example, one can eliminate unnecessary lining and cushioning materials used and reduce the number and size of layers of packaging. Additionally, if one develops a packaging structure that is adjustable, there is no need to use multiple layers of materials. To achieve stability as a design element and thus limit the waste of materials, one can optimize designs and decrease material. Material decreased is expressed in Figure 1. The left graph in Figure 1 depicts the number of layers in the packaging design along the X-axis, and the package volume (in cubic centimeters) along the Y-axis. The pre-optimization design demonstrates that the overall package volume increases as the number of layers increases, as each layer become larger in size. The package volume increased from 100 cubic centimeters for 1 layer to 350 cubic centimeters for 5 layers of packaging. After the optimization was complete, there was a decrease in package volume, which now ranged from 100 cubic centimeters to 250 cubic centimeters across the same range of layers. The reduction in overall package volume due to the structural optimization that resulted in fewer layers, minimizes the amount of material that can be minimized in all layer counts. The right graph measures material mass (grams) for three types of material (A, B, and C) before and after design optimization. The comparison baseline used is the amount of each material used for packaging in the original pre-optimization design. Each of the three material designs uses A - plastic, B - cardboard, C - foam. The Y-axis depicts the amount of material used in grams for every design. The optimized packaging design exhibits a significant reduction in material use for all the three materials. For example, the material A usage will go down to 30 grams the material B will go down to 40 grams and the material C usage will go down to 20 grams. The goal of optimizing the packaging structure considers not only the simple appearance but also approaches the optimal material selection and reduction of materials used. This work incorporates a LCA analysis of material selection focusing on materials that are lighter and recyclable while trying to avoid as much as possible the increased usage of non-environmentally friendly materials. A finite element analysis is then performed to analyze the strength of the packaging structure so that protective performance can be achieved while using less material overall.

D. FINAL DESIGN INTEGRATION

The design showcases a modern, neat sans serif font alongside a custom, environmentally friendly font with structured reasoning that uses smooth line work. The green font establishes the brand's environmentally friendly certification but allows for visibility of the brand name and key messaging in conjunction with graphic elements in the background. Environmental symbols using plants, leaves, and the globe have been utilized to convey exposure to nature as part of unique visual system in the design. Morphological analysis has been implemented in design by abstracting natural forms into geometric shapes for clarity and efficiency. The primary packaging graphic design is by nature predominantly an abstract leaf structure pattern that again has smooth, rounded lines that fit an ideation of sustainability, health, and harmony. The design typography is somewhat interesting in that it is grid based pattern order and readability. Key details such as the brand name, eco-friendly logo, and sustainability statements are visually distinct through expanded font size and multi-layered text. The text and graphics contrast visually but are appropriately spaced from each other to curb clutter at the same time creating a clear and engaging message. The eco-friendly packaging design for the brand is illustrated in Figure 2. Figure 2 shows the holistic frame and logic of implementation for the brand's eco-friendly packaging design. The frame illustrates the connection among design concept, method, and specific measures. The color palette strengthens the brand's green and eco-friendliness philosophy. The primary color is green applied with natural shades having gradients making for

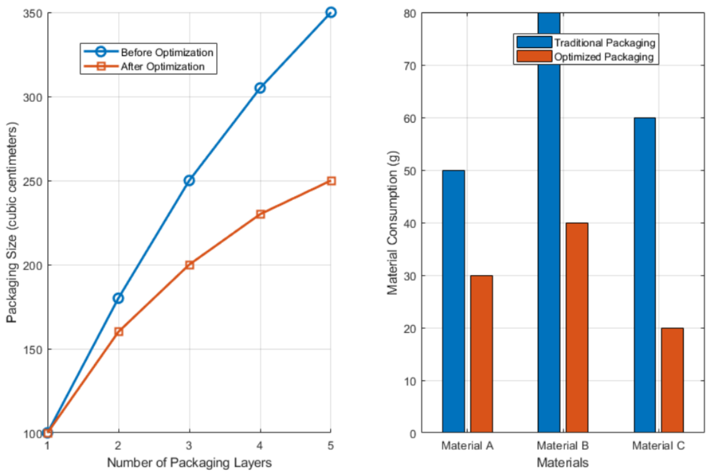

FIGURE 1. Packaging material reduction

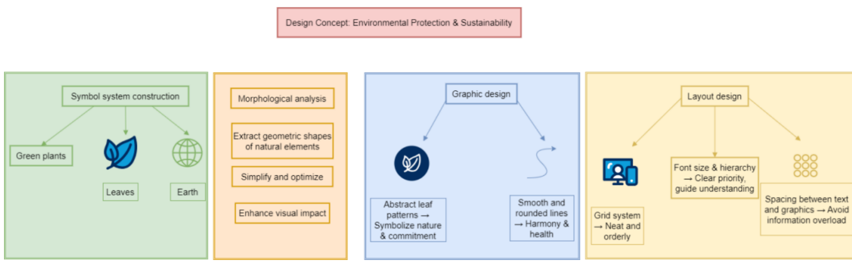

FIGURE 2. Brand's eco-friendly packaging design

layering and visual appeal. Using color contrast, green is contrasted with more neutral colors of white and gray to emphasize key information and create an overall brighter visual effect. Additionally, green has a calming and soothing psychological effect on consumers, creating positive psychological representations associated with environmental protection and health, resulting in subtle brand identification as exhibited in Table 2.

TABLE 2. Color pairing and consumer perception

Color Combination	Consumer Psychological Response	Environmental Identification	Health Perception	Natural Association
Green + White/Grey	Calm, soothing, easy to accept	High	High	High
Green + Natural Gradient	Relaxing, enhanced natural feel	Medium	Medium	High
Green + Dark Green	Strong sense of trust and stability	High	High	Medium

Table 2 presents the psychological impact of various color combinations on consumers and their resultant performance regarding environmental identity, health perception, and associations with nature. Green + white/gray combination is the most straightforward and effective environmental design solution, optimizing the communication of environmental and health messaging, and it generates associations with nature in consumers with limited stimulation. Green + natural gradient colors can be considered somewhat balanced in environmental and health perceptions, and particularly in natural associations, making them appropriate for concepts that promote unity and connection with nature. Green + dark green hues evokes trust and stability, appropriate for designs that associate brands with credibility and longevity, despite likely having limited stimulation in health and natural associations.

III. EXPERIMENTAL EVALUATION

A. ENVIRONMENTAL IMPACT ASSESSMENT

This experiment assesses the environmental impact of three packaging materials throughout their lifecycles, focusing on greenhouse gas emissions and energy consumption. Using a life cycle assessment model, the experiment analyzes CO_2 emissions at each lifecycle stage and calculates energy consumption based on production, transportation, and disposal. The chart located at the top of Figure 3 plots the several stages of the product packaging material lifecycle on the horizontal axis (X-axis) and greenhouse gas emissions on the vertical axis (Y-axis). The materials represented are Material A (plastic), Material B (cardboard), and Material C (foam). Material B has high emissions associated with the production process. Material C has low emissions pertaining to the production process compared to other stages but has high emissions during the use stage. The lower chart shows the various stages of the packaging material lifecycle on the X-axis with the Y-axis expressing energy consumption during each lifecycle stage. Material B shows energy consumption at the maximum during production and then slowly decreases as the lifecycle stages progress. Energy consumption is relatively low during use and disposal stages. Material C has low energy consumption during the production process but does slowly increase energy consumption as the production stages implement.

B. TRANSPORTATION AND STORAGE OPTIMIZATION EVALUATION

The transportation efficiency and storage space utilization of three different packaging designs are assessed and the packaging structural design is modified in order to improve resource utilization and lower transportation and warehouse/distribution costs: (1) Design A: compact transportation design; (2) Design B: typical bulk product design; and (3) Design C: maximized stacking design. Each design differs structurally, and in terms of the materials selected and how it stacks for transportation or storage. Each design is typical as a packaging solution, which fulfills a functional use and/or a market need. Evaluation criteria will include: (1) Transportation efficiency: Transportation efficiency measures the packaging transportation space utilization, which is the space allocated to the packaging solution for transport divided by the total space made available to the packaging. to (2) Warehouse space utilization. Warehouse space utilization measures the packaging design space utilization as the stacking density of the packaging design in the warehouse divided by the total warehouse space. The left figure of Figure 4 illustrates the space occupancy (%) for the various packaging designs at different life cycle stages (production, transportation, storage). Design A has lower space occupancy in the production stage, but higher space occupancy rates during transportation and storage, which may indicate significant packaging space waste during transportation. Design B's space occupancy rates are slightly higher than Design A, but largely it's similar during the production stage, with greater occupancy even more so during transportation and storage. Potentially, this may indicate design B is larger, or may be indicative of inefficient stacking, with the overall packaging bringing about a higher logistic space occupancy rate than design A. Design C has relatively high space occupancy rates at the various life cycle stages, which may indicate a complex packaging design; however, high space occupancy rates may lead to more packaging material being used, and inefficient space use during transportation and storage. The graph on the right illustrates transport efficiency and storage efficiency (in percentage form) of each packaging design. Design A exhibits the highest transport efficiencies, implying that the packing optimizes spatial allowance while on transport. Conversely, designs B and C demonstrate lower transport efficiencies, possibly due to their larger size or suboptimal packing shape. Design C demonstrates the highest rate of spatial allowance while caching to storage, suggesting that it's packing shape permits more compact stacking in the warehouse and discourages space waste. Design B, on the other hand, has low storage efficiency and may exhibit space waste through stacking when leaning towards their overall size. The graph in Figure 4 (left) describes space occupancy; occupancy essentially conveys the physical occupied volume by a single packaging unit itself, therefore, higher values demonstrate larger package sizes. The graphs in Figure 4 (right) displays storage efficiency; a characteristic of storage which describes the compactness while stacking multiple units in warehouse pallet form. Once again, higher values display increased efficient space utilization. Design C showcases teaming space occupancy and storage efficiency as described in Figure 4.

C. CONSUMER PERCEPTION AND BRAND IDENTITY

This experimental study measures consumers' environmental identity and aesthetic appeal for three different packaging designs with questionnaires and two focus group discussions across five consumer groups. Group 1 (Environmentally Pioneer Consumers) is very concerned about environmental protection and prefers brands that have displayed an ecological commitment. In packaging design, sustainability must be at the forefront of the design research, including utilizing recyclable materials and sustainable production methods. Group 2 (Healthy and Eco-Friendly Consumers) acknowledges health and environmental elements as the top trait for products and packaging they prefer. They want packaging designs that represent health-friendly and environmental-friendly designs. Their purchasing behavior is based on a balance between health and environmental. Group 3 (Reasonable Eco-Friendly Consumers) supports environmental protection but is driven by value for the cost. The packaging design should reflect a balance between environmentally friendly packaging while acknowledging the cost-benefit in the packaging design - these consumers want value and functionality in the package. Group 4 (Price-Oriented Consumers) are consumers that prioritize cost or price over environmental. The aspect of the packaging being environmentally sustainable has little value decision or influence on purchasing design from a consumer standpoint; consumers are looking for low-cost, practical packaging. Group 5 (Environmentally Indifferent Consumers) are indifferent to environmental protection, and care primarily about cost and function. Eco-friendly packaging has little impact on them. The questionnaire employed a five-point Likert scale for measuring consumer perceptions. The visual appeal ratings presented in Figure 5 were collected using a separate ten-point scale. The left figure of Figure 5 shows the environmental identity ratings for the three packaging designs. Design A shows strong approval ratings among the environmentally conscious (Group 1) and the healthy and environmentally conscious (Group 2), at 83% and 79%, respectively, while approval is only 50% among the environmentally indifferent (Group 5). Design B shows a more balanced environmental identity, with strong approval ratings among Groups 1 and 2, but still relatively low among

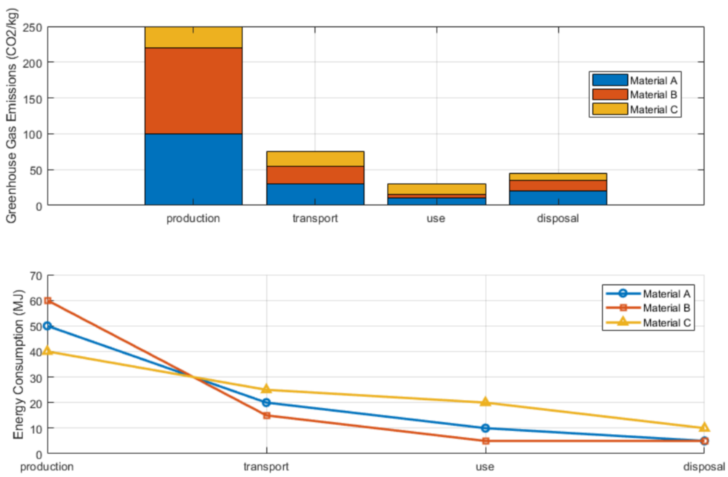

FIGURE 3. Environmental impact assessment

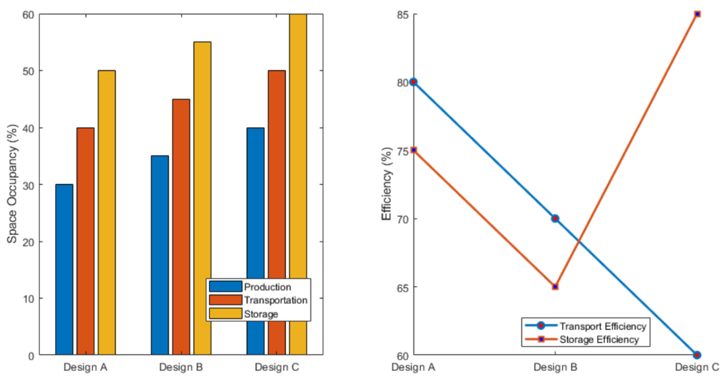

FIGURE 4. Transportation and storage optimization evaluation

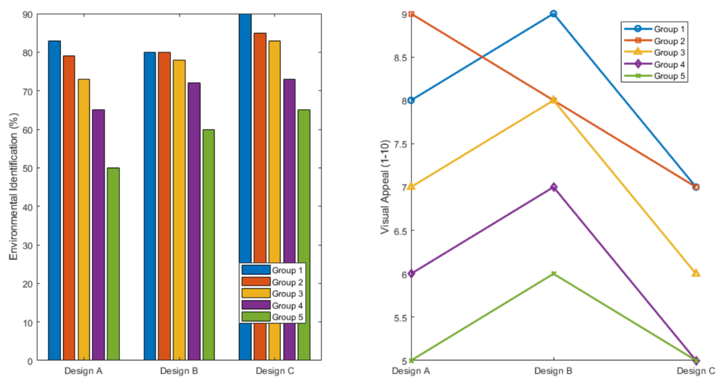

FIGURE 5. Consumer perception and brand identity

Group 5 (60%). Approval for Design C increases across the board, particularly among Groups 1 and 2, reaching 90% and 85%, respectively. The right figure shows the visual appeal ratings for the three designs. Groups 1 and 2 give Design A high ratings (8 and 9), while Groups 1 and 3 give Design B a favorable rating (Group 3 receives an 8). Group 5 assigned Design C a low score of 5, meaning that they do not see a design they like. The environmental identity score of Group 5 regarding Design A indicates that they cognitively recognized that they were looking at environmental characteristics in the design; colors and symbols facilitated their passive recognition of the attributes while making that determination, even from consumers who would generally not have sustainability considerations. While it seems plausible that there was an inclination not towards a low appeal to Design C based on their subjection aesthetic preferences, there was no sense that it was any of the environmental issues materializing. It demonstrates that cognitive awareness (i.e., environmental identity) has a different meaning than attitudinal processing, and visual appeal represents only aesthetic assumptions.

D. RECYCLING RATES

The purpose is to assess the differences in recycling rates between the three packaging alternatives (Design A, Design B, and Design C) and across four regions (Regions 1, 2, 3, and 4—representing large city, medium city, small city, and suburban areas), with the goal of understanding recycling rates by packaging design and region. The reported recoveries come from comparative tests conducted under experimental conditions. The study utilized a control packaging component, which involved using traditional plastic packaging and the recovery rate was tracked alongside the three other experimental designs under the exact conditions. One thousand participating households were directed to use test kits that included both the experimental control packaging and the traditional packaging under controlled conditions in accordance with the participant's normal disposal method. The data was collected over a four-week period and the study tracked the recycling and recovery process, to include member defined recoveries. Data from recyclery and recovery processes were tracked on a pilot study basis to verify recoveries for traditional control and experimental new material composite packages. For every design, the recycling rate was calculated according to the mass of recoverable material versus the total mass that was circulated. The regional designations were meant to reflect profiles of common waste management infrastructure, not to suggest that the qualifications reflect all the variability within any geographical classification. The results reflect observed outcomes under the conditions of that study, where material type and design were the variable of interest. They should be interpreted as performance amongst packaging designs compared to the other designs in the study, not as universal indicators of municipal recycling rates. Figure 6 indicates that the three packaging designs have different recycling rates across four regions (large cities, medium cities, small cities, and suburbs). Recycling rates, overall, exceed 60% across all of these regions. Packaging design A is the most successful design in both the large cities and suburbs, suggesting that it has some compatibility with recycling systems in those areas. Recycling rates for this packaging design decreased in medium-sized cities, suggesting that it may need to be adjusted further and/or improved at the facilities in that area. Packaging design B also shows a decline in recycling rates in medium-sized cities, which also means those rates also need to be adjusted based upon local recycling needs. Packaging design C shows the lowest recycling rates in large cities, indicating limitations on recyclability in urban or metropolitan environments. There are recyclability improvements in suburbs, but it still does not meet anticipated recycling ability these other designs. Any reference to being greater than 60% likely refers to the packaging design's performance under optimized packaging design versus a conventional comparison group, recycling percentage.

IV. CONCLUSION

This paper stems from an urgency to pursue a better integrated model of environmentally sustainable textile packaging that simultaneously accounts for physical/environmental issues and human perception. The study demonstrates that the aforementioned issues concerning the inconsistency between material sustainability and consumer recognition can be effectively solved with a hierarchical approach. The life cycle assessment identifies and evaluates the key environmental trade-offs that would serve as a non-negotiable basis for the choice of materials. The principles of green color psychology are used not independently, but rather to make these underlying sustainable qualities visually clear and psychologically important. Finally consumer perception studies serve as a functional feedback mechanism to measure the efficacy of the characterization and transition from scientific optimization to socially useful communication. This research does not address the evolution of any sole link but rather highlights the wholeness of a workflow. This paper aspires to investigate a sustainable design protocol for a textile packaging product that incorporates multiple components such as: a life cycle assessment leveraged from sustainable principles, green color psychology, a structural package optimization and a visual system. The life cycle assessment considers comprehensive and sound selection of associated packaging materials and production processes while conserving resources and lowering harmful environmental impacts. In addition to the rich presentation of the concepts of environmental protection, the green color psychology will strengthen the consumer's consciousness of environmental protections. There are packaging structures that can be optimized to conserve resources and increase efficiency in transit; lastly, the detailed design of a visual system will further develop a brand's sustainable image. There are limitations to this study that should be recognized. The consumer perception information, while indicative, is based on a demographic and cultural-specific context which may inhibit broader deducibility of the results across different markets. The measurements of recycling rates were kept mindful of the designs being comparable, and do reflect the experimental structure as well as the simplified regional models being employed. The findings reflect a comparative performance under test conditions; yet inferences should be made cautiously regarding direct extrapolation to broader, real waste streams. Future studies should strive to run

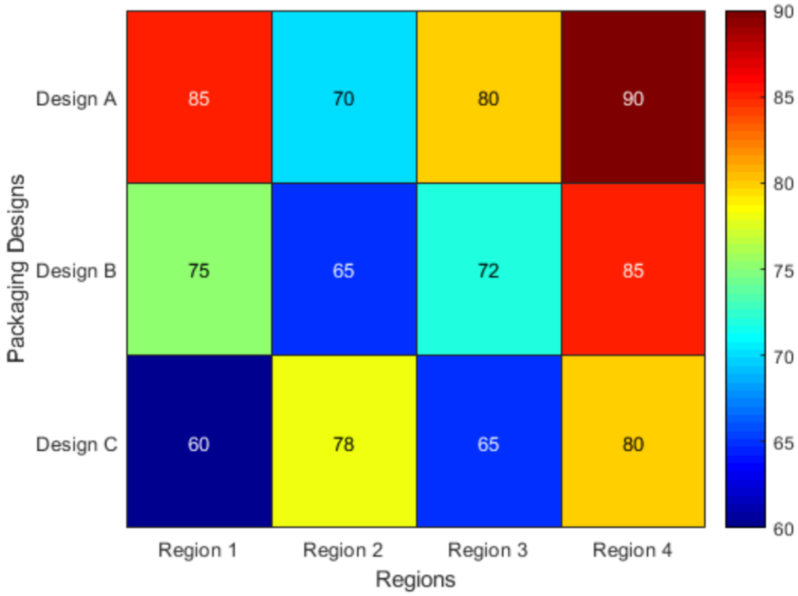

FIGURE 6. Recycling rates

longitudinal studies in real market context, examine cross-cultural reactions to sustainable visuals cues in their investigations, and attempt to factor in a more rigorous economic feasibility analysis, in conjunction with the environmental and perceptual findings examined here.

AUTHOR CONTRIBUTIONS

Conceptualization – Ruijun Chen; methodology – Ruijun Chen and Yongchao Ma; investigation – Ruijun Chen and Yongchao Ma; writing-original draft preparation – Ruijun Chen and Yongchao Ma. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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HUMAN RESEARCH SUBJECTS

This survey was conducted in compliance with the Ethics Committee of Sanya University School. Participants were informed of the study's purpose and data usage prior to participation, and responses were collected anonymously. No personally identifiable information was stored.

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Not applicable.

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