

A Review of Product Design Research Based on Green Design Concepts

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Abstract. This paper analyzes and summarizes the research on product design based on green design concepts to provide a comparison and reference for the subsequent related design research. Through literature research, firstly, we understand the definition and principles of green design concept, secondly, we analyze the application of green design concept in contemporary product design, and discuss and analyze the product design methods and strategies under the green design concept, which provides reference and reference for the subsequent related design research. At the same time, the practical application of product design under the green design concept is analyzed, and the practical experience and innovative strategies of green product design are summarized. The research in this paper provides a reference for the subsequent theoretical research and industrial development based on the green design concept, which helps to enhance product competitiveness and promote the further development of sustainable design.

Keywords: Green design concept; product design; sustainable development; design method; case study.

1. Introduction

Against the backdrop of the "Opinions on Accelerating the Comprehensive Green Transformation of Economic and Social Development" issued by the CPC Central Committee and the State Council, green design, a key approach to green development, is vital for meeting the inherent demands of high - quality productive forces and enabling their leap forward [1]. It not only promotes the sustainable development of the economy, society, and environment but also holds growing significance in product design. Lately, green design has emerged as a research focus in product design, with active domestic and international research and continuous development of related theories and methods. Thus, product design research grounded in the green design concept is highly significant for promoting the comprehensive green transformation of the economy and society, elevating product design standards, optimizing resource utilization, reducing environmental pollution, and satisfying consumer demand for green products. In - depth exploration of the green design concept in product design is particularly urgent.

In this study, using the literature research method with the China Knowledge Network (CNKI) as the database, and searching by subject terms "green design concept" and "green design", 614 relevant documents were retrieved from 2016 to the present. After manually filtering out information and design works, 418 articles were retained. These were analyzed and organized through skimming and in - depth reading to provide factual and theoretical support for the conclusions and outlooks in this paper.

2. Definition and Principles of Green Design Concept

2.1 Definition of Green Design Concepts

The green design concept centers on environmental protection, emphasizing the efficient use of resources and ecological conservation. It integrates the ideas of environmental protection, sustainability, and energy conservation & emission reduction throughout the design process, aiming for the sustainable development of the environment, society, and economy [2]. In product design, it

minimizes environmental impact and promotes sustainability by rationally choosing eco - friendly materials, optimizing processes, conserving resources, and reducing pollution. Its core goals are: reducing resource consumption and waste, minimizing the impact on the ecological environment, and enhancing product recyclability and sustainability [3].

2.2 Principles of Green Design Concepts

The green design concept is based on the 3R principle: Reduce, Reuse, and Recycle. The Reduce principle emphasizes minimizing raw material and energy consumption, as well as waste and pollutants during product design and production. This is achieved by optimizing design and production processes. The Reuse principle requires that products and their components, after proper treatment, can be used again, thus extending product lifespan and reducing resource waste. The Recycle principle focuses on product recyclability. Designers should consider material recycling so that products can be effectively retrieved and reprocessed at the end of their life cycle, enabling resource recycling. These three principles form the core of green design, aiming to achieve efficient resource use and environmental protection through design, thereby promoting sustainable development (see Table 1).

Table 1. Core principles of green design concepts

Principles	Describe
Reduce	Design to maximize resource efficiency and minimize environmental impacts
Reuse	Designing reusable products or components that Extend product life and minimize resource waste
Recycle	Design to promote recycling of materials and energy and reduce waste generation

These principles are interrelated and together form the theoretical foundation of green design, guiding designers to make more environmentally friendly and sustainable decisions in the product development process.

3. The Application of Green Design Concept in Contemporary Product Design

Currently, the green design concept is widely applied in product design across diverse fields like packaging, furniture, and transportation design. Xu Xiao proposed specific ways to implement green design in gift box packaging, such as choosing eco - friendly materials, rational packaging design, and using renewable energy [4]. Duan Jiahao et al. suggested the application of green design concepts in agricultural product packaging to boost their market competitiveness and promote agricultural sustainability and rural revitalization [5]. Ma Zihan noted that green development is a global trend, with more designers drawing inspiration from nature and integrating original ideas into food packaging [6]. Ma Xiaozhan explored the use of leather products in interior design under the green design concept, combining functionality and sustainability to enrich interior design [7]. Zhao Shan proposed integrating the green design concept into intelligent toilet styling design. By incorporating intelligent functions to enhance user experience, the concept was applied to aspects like function, materials, and styling, inspiring users to adopt green consumption habits [8]. Yang Bing et al. took the old - young sharing sofa as a research object under the "double carbon" goal, integrating the connotations and principles of green design into such furniture product design [9]. The application of the green design concept enriches design in various fields. In product design, it drives the upgrade and development of green products and guides modern humans to pursue a more natural and simple lifestyle.

4. Product Design Methods and Strategies Under the Concept of Green Design

4.1 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a key method in green product design, which can comprehensively assess the environmental impact of the entire life cycle of a product from the acquisition of raw materials to final disposal. In the product design industry, the application of LCA is becoming more and more widespread, providing a scientific basis for quantifying the environmental impact of green design. The pathway of product design under the LCA theory can be applied to both product design and innovation, as well as guiding the design industry to implement relevant environmental protection measures, standardizing design standards, guiding reasonable consumption, and further promoting the healthy development of China's industry and economy [10]. The ideal green product life cycle is the process of “research and development - manufacturing - use - recycling”, and its industrial chain is a closed-loop system that extends the traditional product life cycle, as shown in Figure 1 [11].

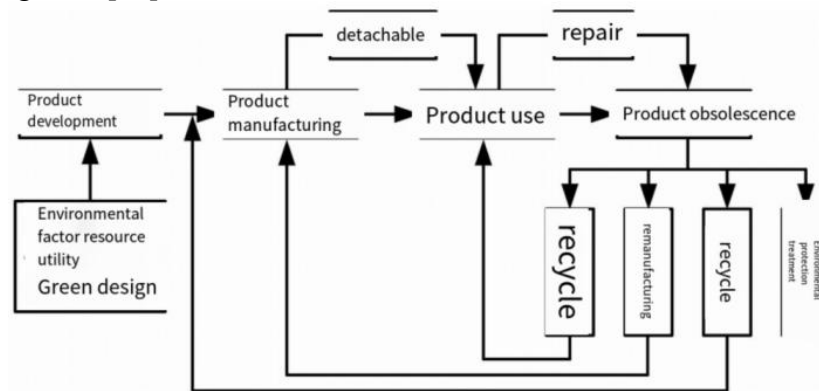


Fig. 1 Green Product Life Cycle [11]

Through LCA, designers can identify the environmental characteristics of a product's lifecycle so that they can optimize their design solutions and reduce the environmental load. For example, in the electronics industry, LCA can help designers compare the environmental impacts of different materials and production processes and choose a more environmentally friendly solution. The following table shows a simplified example of LCA results for a cell phone:

Table 2. Percentage of environmental impacts at each stage of the life cycle of a cell phone

Life Cycle Stages	Carbon emissions	Energy consumption	Water consumption	Solid waste
Raw Material Acquisition	35%	30%	25%	40%
Manufacturing	25%	35%	40%	30%
Use Stage	30%	25%	20%	10%
Disposal	10%	10%	15%	20%

As can be seen from the table, the raw material acquisition and manufacturing phases have a high environmental impact, which provides designers with a direction for optimization. The environmental footprint of a product's full life cycle can be effectively reduced by adopting recyclable materials and improving production efficiency. The use of product life cycle assessment (LCA), a quantitative method, can help designers utilize a full life cycle perspective to identify environmental hotspots of products, propose improvement strategies, and compare the advantages and disadvantages of each improvement option [12]. However, the implementation of LCA also faces challenges such as difficult data acquisition and inconsistent evaluation standards, which require the joint efforts of all parties in the industry chain to establish a better LCA database and evaluation system.

4.2 Green Material Selection

Under the green design concept, material selection, a crucial part of product design, significantly impacts a product's environmental friendliness across its life cycle. Choosing green materials matters not only for product performance and quality but also directly affects its environmental footprint and sustainability. Research and application of green materials can mitigate environmental harm and offer more sustainable solutions [13]. In today's product design industry, designers increasingly consider material environmental impacts from the start, aiming to minimize harm to the ecosystem while fulfilling functional requirements. Liu Yu discovered that bio - based, recyclable, and smart materials are key research areas for sustainable materials in product design. However, their widespread use is hindered by technical, economic, and policy factors. Thus, strategies like enhancing technological innovation, refining design methods, innovating business models, and improving policies were proposed [14]. Using materials according to their properties maximizes their characteristics and value, allowing for proper application and development in suitable fields and reducing material waste [15]. Hence, when selecting green materials, recyclable, reusable, or biodegradable ones should be prioritized, and the use of harmful materials minimized.

4.3 Modular Design

Modular design involves breaking a product into several independent modules, each having distinct functions and interchangeability. It enhances product maintainability and upgradability, reducing waste during product use. Wu Jie et al. stated that modular design can yield more revenue at lower cost and meet the diverse and personalized needs of different consumers [16]. Structural modular design facilitates assembly, replacement, disassembly, and recycling, boosts production efficiency, enables user - personalized customization, and extends related personalized service design [17]. Through modular design, enterprises can respond more nimbly to market demand changes while notably enhancing product sustainability.

Table 3. Key features and benefits of modular design

Features	Description	Sustainability Advantages
Functional Independence	Relatively independent functions of each module, standardized interfaces	Easy maintenance and replacement for longer product life
Flexible combination	Modules can be freely combined to meet different needs	Reduced resource waste and increased product adaptability
Easy to upgrade	Individual modules can be upgraded independently without the need to replace the entire machine	Lower upgrade costs and less e-waste
High productivity	Modules can be produced in parallel, shortening the production cycle	Improved resource efficiency and reduced energy consumption

Yu Forest et al. developed a modular sneaker system from a sustainable perspective in three ways. First, they created a detachable - structure modular system based on user needs and sustainability. No glue is used in any module, allowing each to be disassembled separately, which aids module production and recycling, boosts production efficiency, and eases recycling. Second, they prioritized natural, low - impact materials and recyclables [17]. Third, they enhanced the overall process service system and business chain design to improve user experience across the whole process and multiple links. Wang Yu et al. proposed using detachable design in packaging structure. Such product - packaging components can be flexibly disassembled and freely assembled. This not only facilitates batch - part processing to enhance efficiency but also improves packaging - assembly and recycling convenience, increasing the likelihood of part reuse [18].

Yu Xiaoying divided the modular design process into four stages: functional analysis, module division, module design, and module combination (Figure 2 - 2). Functional analysis, the prerequisite for module division, involves classifying product functions. This stage requires multi - faceted study of product functions, considering not only practicality and rationality but also industry trends. Module division, based on functional - analysis results, is the process of disassembling the

product design into a set number of functional modules and combining them to form a product system. Module design focuses on the structure, combination methods, and dimensions of each functional module. Module combination is the assembly of designed functional modules to ultimately create a product series [19].

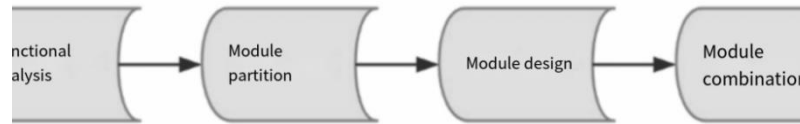


Fig. 2 Modular design process [19]

Modular design provides a new development direction for product design. Modular product design based on the concept of green design should be more in line with human needs and better reflect the aesthetic and functional value of products.

4.4 Circular Economy Design

Recycling design, also called reclaimable design, involves fully considering, during product design, the recyclability of each component or material at the end of its lifespan, the value of recycling, and whether recycling treatment methods are eco - friendly, along with all other product - recycling - related issues. This significantly boosts product utilization and reduces resource consumption by the product [20]. Circular economy design is a crucial development trend in green product design. It aims to achieve efficient resource recycling and minimize waste generation through innovative design. This concept demands considering material recycling and value maximization from the product - concept phase.

Table 4. Key strategies for circular economy design

Strategies	Description	Environmental benefits
Closed Loop Material Selection	Selection of fully recyclable or biodegradable materials	Realize closed-loop recycling of materials and reduce resource consumption
Design Remanufacturing	Design products for easy disassembly and remanufacturing	Extend product life and reduce waste generation
Shared Design	Design products to fit the sharing economy model	Improve product use efficiency and reduce resource waste
Product Servitization	Convert products into services, such as rental models	Optimize the use of resources and reduce the number of products

Liu Jiping et al. stressed that in the early product - design stage, it's essential to fully account for product recyclability and reusability. Thus, when assessing product costs, pollutant substitution, product disassembly, reuse costs, and environmental costs of special products are evaluated [21].

Chen Meilin et al. proposed encouraging consumers to actively engage in used - furniture recovery and recycling, ensuring the effective retrieval and reuse of used furniture and parts throughout the process. At the end - of - life of furniture, parts can be reasonably categorized by material or size for easier recycling management. Additionally, the furniture industry can optimize recycling - resource sharing through cooperative alliances, improving furniture - recycling and resource - utilization efficiency. They also emphasized that contemporary designers should start with green - material selection, integrating traditional Chinese and modern emerging cultures to enhance product ecological and cultural value. Meanwhile, furniture structural functions and parts should be reduced to meet different - lifecycle demand variations. Applying green design concepts in modern furniture design broadens its development path, making such furniture a future market - dominant product [22].

The circular economy design can not only significantly reduce the environmental impact of the product, but also create new business opportunities for enterprises and promote the whole industrial chain to a more sustainable direction.

5. Case study of Product Design Under the Concept of Green Design

The Japanese brand "Muji Goods", a paragon of green design implementation, adheres to the "simplify complexity" design strategy. It simplifies all needless materials and maintains a plain, unadorned style. For packaging, Muji uses recycled paper, cotton, hemp and other eco - friendly recycled materials, skipping the bleaching process to keep their natural hues. In the modeling structure, it pursues form simplicity, often using transparent or semi - transparent materials to downplay packaging's visual impact. In visual presentation, Muji minimizes decorative elements, presenting products via uniform labels, simple color schemes, streamlined text and real pictures. This directly stimulates consumers' visual senses for better product understanding and reduces ink pollution from printing [23]. Muji's extreme pursuit of green materials thus makes it a prime example of the green design concept.



Fig. 3 Muji Packaging (Image Source: Baidu Images)

In April 2020, the domestic oral - care brand usmile launched a half - price trade - in service, mainly targeting users who had purchased electric toothbrushes over a year ago. By returning old or unused electric toothbrush handles, users could get brand - new ones at half price. After collecting the old toothbrushes, usmile sent them to a recycling company certified by the State Environmental Protection Administration. There, the toothbrushes were disassembled into plastic shells, motors, circuit boards, and lithium batteries. The plastics were recycled into industrial - grade plastics, metal electronic components were crushed and smelted into valuable metals, and lithium batteries were discharged and then smelted for metal recovery. This unique trade - in model, an active exploration based on life - cycle - oriented design, offers consumers a cost - effective and eco - friendly product - renewal option. It also showcases usmile's environmental responsibility as a domestic brand, setting a good example for the industry's sustainable development [24].



Fig. 4 Usetool toothbrush (Photo credit: Designer Jiyoun Kim)

The Chinese - made Cat Workshop Stacking Cat Cardboard Boxes, designed like Lego, can be freely stacked and combined in various non - fixed ways to fit different home corners. With a unique modular design, this cat cardboard box allows for flexible application in multiple scenarios through diverse combinations of different - function modules. It effectively integrates product application functions, successfully merging modular design with pet furniture design. This not only better satisfies pet owners' personalized needs, enabling them to create unique pet living spaces based on their preferences and home environments, but also brings practical advantages. It significantly shortens the design - to - production cycle, cuts down on duplicate supplies, and reduces resource waste. This design concept fully reflects ecological values, adheres to the sustainable - development - oriented green design and environmental - protection concept, injects

new vitality into pet furniture design, and stands as an outstanding example of China's smart manufacturing [25].



Fig. 5 Cat Workshop Stacking Cat Carton (Image source: Cat Workshop Taobao store)

Italian designers Simone Caronni, Paolo Stefano Gentile, and Pietro Gaeli have ingeniously recycled discarded potato skins (see Figure 2 for details). They use potato skins, a mixture rich in starch and cellulose. By soaking and drying, they combine and solidify these skins into bags for street food. After use, these bags can be effectively repurposed as animal feed or plant fertilizer. This design not only adds new value to potato peels and lessens waste's environmental impact but also embodies the resource - recycling concept, offering an innovative idea and practical case for green design [6].



Fig. 6 Eco-French Fries Packaging (Image Source: Baidu Images)

Under the green design concept, numerous brands contribute to environmental protection with innovative designs and practices. These cases show the broad application and positive influence of green design throughout product life - cycles, from design to use and recycling. This approach not only meets consumer needs but also spurs industry sustainability, enhances enterprise competitiveness, and strongly supports the creation of a more eco - friendly and harmonious social environment.

6. Summary

Currently, in product design research, the green design concept is garnering increasing attention. Green design has become a crucial element in product design, driving product innovation and industrial upgrading. By applying green design methods like optimizing the product life cycle, choosing green materials, using modular design, and emphasizing the circular economy throughout product design, we can mitigate environmental impact, boost product competitiveness, and foster industry sustainability. Yet, green design implementation faces hurdles in technology, cost, and consumer awareness. In the future, as technology advances and environmental awareness grows, green design will increasingly blend with intelligence and personalization, draw on cross - disciplinary knowledge, and play a more significant role in promoting sustainable economic growth and enhancing quality of life.

References

- [1] Zhang Jun, Li Chengbo. Green design: a new quality of productivity to lead the green transformation of China's economic and social development[J]. *Art and Design*, 2024, 1(12): 24-29.
- [2] Mao Liuya. Analysis of the application of green design concept in Xinyang Maojian packaging design[J]. *China Packaging*, 2024, 44(10): 79-81.
- [3] Zhao Yakun. Green design drives change in the apparel industry: a comprehensive discussion from sustainable materials to circular economy[J]. *Textile & Clothing Weekly*, 2024, (42): 24.

- [4] Xu Xiao. Research on the application of green design concept in gift box packaging design[J]. Green Packaging, 2024, (11): 126-129.
- [5] Duan Jiahao, Jin Lutong. Exploration of agricultural packaging design under green design concept[J]. China Packaging, 2024, 44(05): 98-100.
- [6] Ma Zihan. Application of food packaging design under green design concept[J]. Shanghai Packaging, 2024, (06): 13-15.
- [7] [Ma Xiaozhan. Discussion on the application of green design concept in indoor leather products design[J]. China leather, 1-5.
- [8] Zhao Shan. Research on intelligent toilet styling design based on green design concept[D]. Supervisor: Xu Xiaoman; Xie Hongtong. Changchun University of Technology, 2020.
- [9] YANG Bing, GAO Bo. Exploring the design of furniture for the old and young sharing under the concept of green design--Taking the design of indoor sofa as an example[J]. Toy World, 2024, (09): 111-115.
- [10] Xiao You. Research on ecological design of cultural and creative products based on life cycle assessment[J]. Art Education Research, 2023, (23): 103-105.
- [11] CHENG Xianfu, ZHOU Jian, XIAO Renbin, et al. A review of research on product modularization design for green manufacturing[J]. China Mechanical Engineering, 2020, 31(21): 2612-2625.
- [12] FU Xiaoyun, HUANG Zongzhong, LU Qiaozhen, WANG Yinghao. Research on sustainable design strategy of educational furniture based on LCA method [J]. Packaging Engineering, 2024, 45 (20): 183-191.
- [13] Xing Jinfan. Application and development trend of green design concept in product packaging design[J]. Shanghai Packaging, 2023, (10): 16-18.
- [14] Liu Yu. Research and development of sustainable materials in product design[J]. China Resource Comprehensive Utilization, 2024, 42(09): 167-169.
- [15] Ji Dunduan. Research on the application of product improvement design under the concept of green design[J]. Green Packaging, 2024, (07): 171-174.
- [16] WU Jie, WANG Chenchen, YU Baiji. Research on the application of modularization design in footwear and boots product design[J]. Fashion Designer, 2022, (06): 94-98.
- [17] YU Linlin, YE Lindong. Modularized sports footwear design under the sustainable perspective[J]. Silk, 2024, 61(02): 31-43.
- [18] WANG Yu, XU Yifei. Exploration on the utilization of green design concept in product packaging[J]. China Packaging, 2024, 44(06): 110-114.
- [19] Yu Xiaoying. The application of modular design concept in the design of daily-use ceramics[D]. Supervisor: Zhang Yalin. Jingdezhen Ceramic University, 2024.
- [20] Luo Yunhui. Application of green design concept in product design[J]. Communication power research, 2019, 3(34): 189.
- [21] Liu Jiping, Li Yi. The application of green design concept in stroller product design[J]. China Bicycle, 2019, (06): 78-81.
- [22] Chen Meilin, Zhang Yun. Research on the application of green design concept in modern furniture design[J]. Shanghai Fashion, 2023, (01): 97-100.
- [23] Gao Tongchang, Guan Ying. Application of green design concept in packaging design[J]. Shanghai Packaging, 2024, (09): 22-24. DOI: 10.19446/j.cnki.1005-9423.2024.09.007.
- [24] YK Fu. Research on the Design Application of Green Design Concepts in Oral Cleaning Products [D]. Supervisor: Tang Chongxi. Jingdezhen Ceramic University, 2022.
- [25] Hu Yinghui. Research on furniture design based on green design concept[J]. Packaging Engineering, 2020, 41 (10): 345-.