

Development of Outdoor Sports Protective Gear Using 3D Printing

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Abstract. In recent years, the sports protective gear market has expanded rapidly, while traditional products fail to meet personalized and comfort demands. Taking outdoor knee pads as the research object, this paper adopts the FEA model, combines market analysis and 888 consumer reviews, uses FDM 3D printing and TPU materials to design detachable and gradient-color personalized knee pads, providing a feasible solution for customized sports protective gear.

Keywords: 3D printing; outdoor sports protective gear; FEA model; online reviews

1. Introduction

In recent years, the global sports protective gear market has grown significantly, expected to reach 63.415 billion yuan in 2024 and 84.015 billion yuan by 2031 (CAGR 4.1%) [1], driven by enhanced health awareness, national fitness policies, and consumers' dual demands for function and aesthetics. As a key category, knee pads show diversified demands: lightweight styles are popular for outdoor scenes, and female users value comfort, flexibility and fashion. However, traditional knee pads have pain points such as poor size adaptability and single function, failing to meet young women's needs for personalization and sustainability [2].

3D printing, especially FDM technology, is widely used in sports protective gear due to its cost-effectiveness, environmental friendliness and high design freedom, enabling rapid prototyping and small-batch customization [3]. Its advantages include precise customization [4], functional modular design, and reduced costs.

Previous studies on 3D printed sports protective gear mainly focus on design and development, rarely considering consumer needs and market status [5, 6]. This study innovatively adopts the FEA theoretical model [7], analyzes Chinese consumers' online reviews and the design status of four major brands, and proposes more targeted solutions.

This study is expected to achieve multi-dimensional values: meeting consumer needs and cultural identity, providing industrial technical solutions for traditional craft transformation, and enhancing China's design soft power; it also aims to promote personalized protection, industrial customization transformation, and technological innovation in sports equipment.

Theoretical Background

2. Theoretical Background

2.1 Overview of 3D Printing

3D printing (additive manufacturing) constructs 3D entities by layer-by-layer material stacking, covering four core stages: digital modeling, layer-by-layer slicing, material deposition, and post-processing. Common 3D printing processes include SLA (widely used in functional parts), SLS (suitable for industrial parts with diverse materials), and LOM (applied in rapid prototyping and model making) [8]; due to dust and toxicity issues of SLS and SLA, FDM has become the most widely used technology for its simplicity and fast forming speed [9]. The main 3D printing materials include flexible PLA, TPU, ABS, polyamide, and photosensitive resin [10]: PLA is

environmentally friendly but brittle; ABS is suitable for decorative contours but inelastic; nylon and photosensitive resin are costly[11]; TPU is optimal for wear, with good wear resistance and ductility .

2.2 Overview of Outdoor Sports Protective Gear

2.2.1 Cases of 3D Printing and Outdoor Sports Protective Gear

Modhi and Alarifi [12] developed PETG/carbon fiber football shin guards via 3D printing, enhancing tensile/compressive performance and reducing weight. Croatian researchers created 3D printed hockey chest protectors for athlete safety. Jakob Schmied's team developed durable, lightweight SLS-manufactured shin guards with a Y-shaped impact-dispersing structure [13].

2.2.2 Types of Knee Pad Designs

Un scientific sports postures often cause injuries. Knee pads are functionally divided into protective, supportive, and rehabilitative . Supportive knee pads are widely used for intense sports to protect knees [14]. A survey shows 30.46% find knee pads inconvenient to move in, 22.34% feel tight, highlighting comfort and protection as key design factors.

3. Research Methods

3.1 Market and Design Analysis

Based on market share data, major sports protection brands have differentiated advantages: Li-Ning ranks first in all subdivisions; Bauerfeind is second overall, performing prominently in knee pads and other categories; LARA STAR ranks second in waist guards and fitness gloves; LP ranks third in knee pads and elbow guards with stable penetration. Li-Ning, Bauerfeind, LARA STAR, and LP were selected for their strong design strength and the largest Taobao fan bases. Taobao, a representative protective gear e-commerce platform, uses fan count as an indicator of seller credibility and service quality.

3.2 Consumer Analysis

To explore consumers' knee pad purchase needs, this study collected 888 valid online reviews (March 20-23, 2025) from the four brands' Taobao flagship stores. Online reviews, with high credibility [15], reflect both product functions and consumer emotions. Using Textom 5.0 and NetDraw (UCINET 6.780), the study analyzed keyword frequency and semantic associations after data cleaning. Based on Lamb and Kallal's FEA model (functional, expressive, aesthetic dimensions), two researchers double-blind labeled reviews to capture consumer demands and preferences.

3.3 Design and Development

The FEA model, widely applied in fashion product development [16], is suitable for this study as it integrates functional, expressive, and aesthetic demands. The FEA-based design process (Figure 1) includes: (a) problem identification; (b) preliminary conception; (c) design optimization; (d) prototype construction; (e) effect evaluation.

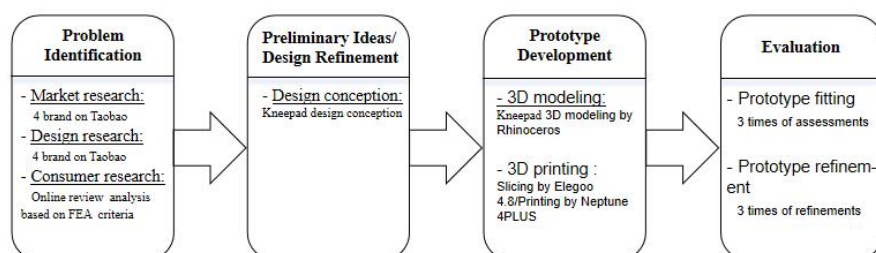


Fig. 1 Design and Development Flowchart Based on FEA Model

4. Research Results

4.1 Market Analysis

Li-Ning, a leading domestic brand, ranks first in sports protective gear market share with diversified products and event cooperation. Bauerfeind, a pioneer brand, ranks second in knee pads and other categories, using medical-grade materials for protective and comfortable products. LARA STAR focuses on fitness protection and has developed rapidly, while LP, a professional brand, ranks third in knee pads and elbow pads with international certification.

Outdoor sports protective gear mainly includes knee pads, wrist guards, waist guards, etc. [17]. Knee pads account for the largest proportion among the four brands: Li-Ning (59.02%), Bauerfeind (45.45%), LARA STAR (41.43%), and LP (69.62%), indicating high usage during sports.

In terms of knee pad types, supportive knee pads account for the largest proportion across all four brands: Li-Ning (50%), Bauerfeind (60%), LARA STAR (29.6%), and LP (48.9%) (Table 3). This reflects that supportive knee pads meet mainstream market demand, as consumers prefer products that provide stable knee support and reduce injury risk [18].

4.2 Visualization Analysis of Taobao Sports Brand Knee Pad Product Reviews

4.2.1 Visualization Analysis of Review Research Hotspots

From 888 valid Taobao reviews, 50 high-frequency keywords were extracted using Excel. Ucinet software was used to analyze keyword network structure, centrality, and other indicators to identify consumer focus and research hotspots.

4.2.2 Keyword Network Relationship Graph

Keyword network analysis (Figure 2) shows that core hotspots include "replaceable", "customized", "environmental protection", and "degradability", while edge keywords have fewer connections due to late demand mining. This reflects consumers' core demands for multi-function, personalization, and green attributes.

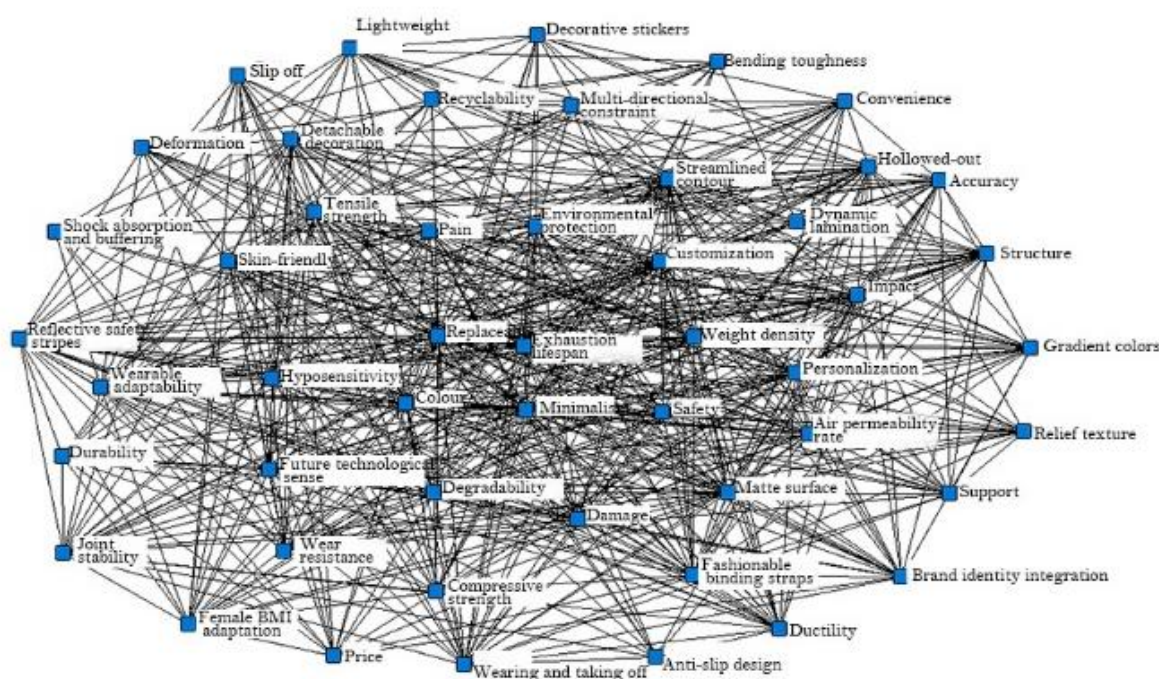


Fig. 2 Network relationship map of knee pad brand keywords

Keywords were classified by product characteristics and user needs: functional keywords (e.g., "impact", "support", "dynamic fit") highlight core protective demands; material/environmental

keywords (e.g., "environmental protection", "lightweight") reflect comfort and green awareness; aesthetic keywords (e.g., "streamlined outline", "minimalism") show fashion pursuit; personalization keywords (e.g., "replaceable", "customized") reflect diverse needs. Overall, consumer needs combine "function + expression + aesthetics".

5. Design Section

5.1 Design Scheme

Functional Structure Design: Focusing on detachable needs, the design achieves precision through disassembly and replacement. Key stress areas adopt wider and thicker specifications, and replaceable accessory interfaces use Velcro and strap wrapping for convenience and stability.

Expressive Form Design: Adopting a minimalist style that fits ergonomics and modern aesthetics, the knee pad has a streamlined outline to reduce movement obstruction. 3D printing multi-color nozzle technology realizes blue-purple gradient color matching, creating a sense of technology and high-end texture.

Aesthetic Composition Design: Based on gender preference surveys (Zhou, 2019), females prefer blue and purple. The knee pad adopts "interstellar blue-purple gradient", with blue as the base and gradient to light purple, fitting female aesthetic preferences.

5.2 2D Plan Design

2D design drawing (Figure 3).



Fig. 3 2D design drawing

5.3 3D Stereogram Design

3D design drawing (Figure 4), with a bending angle of 0°-140° to suit different leg types.



Fig. 4 3D design drawing

5.4 3D Printing Process and Finished Product

TPU material is selected, with a printing temperature of 200-220°C (Figure 5: finished product display).



Fig. 5 Finished product display picture of knee pads

6. Conclusion

Research has confirmed that 3D printing can effectively solve the problems of poor fit and limited functionality of traditional protective gear. Based on the FEA model, integrating functions, expressing and aesthetic requirements, lightweight, replaceable and environmentally friendly knee pads have been developed to meet the preferences of female users, and can provide a reference for personalized research and development of outdoor protective gear.

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