# Optimization of Product Design and R&D in Apparel Enterprises through 3D Virtual Clothing Design: An Exploratory Analysis Based on Grounded Theory

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**Abstract:** This study delves into the attributes and edges of 3D virtual clothing design technology, capitalizing on the grounded theory in tandem with in-depth interviews to derive experiential insights from raw data. It establishes an optimization pathway model for product design as well as research and development (R&D) in apparel enterprises through 3D virtual clothing design. The objective is to scrutinize the influence of 3D virtual clothing design technology on apparel enterprises' design and R&D, formulate a theoretical framework, foster a virtuous cycle between new technology adoption and enterprise advancement, and furnish a theoretical underpinning for the intelligent evolution of clothing design. The findings unveil that the optimization of 3D virtual clothing design in apparel enterprise product design and development encompasses several dimensions, including "Reduced R&D Costs," "Elevated Collaboration Efficiency," "Improved R&D Efficiency," "Enhanced Design Outcomes," and "Shortened R&D Cycles." The interplay among these dimensions within the optimization pathway structure mutually reinforces, collectively propelling the optimization of apparel enterprises' design and R&D processes. Notably, "Reduced R&D Costs," "Elevated Collaboration Efficiency," and "Shortened R&D Cycles" directly contribute to augmented economic gains for enterprises. Meanwhile, "Enhanced Design Outcomes" and "Improved R&D Efficiency" can elevate the caliber and pace of clothing design, facilitating prompt product launches to meet market exigencies.

**Keywords:** 3D virtual clothing design; Grounded theory; Product R&D; Optimization pathway; Apparel enterprise

## 1 Introduction

As competition intensifies within the apparel industry, apparel enterprises face numerous challenges in product design as well as research and development (R&D). Enhancing design efficiency, reducing costs, and meeting consumer demands are pressing issues for these enterprises. In the traditional process of apparel design and R&D, from pattern design to material selection, sizing, sewing, and sampling, each step requires repeated modifications and approvals, consuming time and resources. This conventional approach is beset with lengthy cycles, low efficiency, and an inability to swiftly respond to market demands[1] . Alongside the advancement of virtual reality technology, 3D virtual clothing design achieves three-dimensional realistic simulations of styles, materials, and craftsmanship[2], effectively analyzing and determining clothing fit[3] , human body shapes, sizing, and dimensions of

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specific areas. Existing research indicates that 3D virtual clothing design can enhance the efficiency, quality, and creativity of clothing design[4] while also saving costs, time, and resources[5]. Compared to traditional design and R&D methods, it streamlines the process of clothing design. *Notice of the Ministry of Industry and Information Technology on Printing and Distributing the Development Plan of the Textile Industry*[6] emphasizes the utilization of technologies such as the internet, big data, 3D virtual fitting, and Computer-Aided Design (CAD) to advance the digitization of clothing and home textile design. *Digitalization Empowering the Action Plan for Consumer Goods Industry's "Three Improvements" (Increased Variety, Enhanced Quality, Brand Creation) (2022-2025)*[7] underscores support for the application of technologies like 3D modeling, simulation, virtual testing, etc., in industries including textile machinery, for product design, function development, process optimization, and testing scenario applications. Against this backdrop, it becomes imperative to gain a deep understanding of the characteristics of 3D virtual clothing design and how it optimizes the processes and outcomes of product design and R&D in apparel enterprises.

## 2 Literature Review

The traditional design and R&D model in the apparel industry primarily grapples with hurdles such as long R&D cycles, high costs, low efficiency, and suboptimal market responsiveness[8]. MCQUILLAN(2020)[9] noted that traditional clothing production and R&D processes waste 15% to 25% of the fabric needed to make clothing. HSU et al(2019)[10] mentioned that in the conventional clothing design process, from pattern making to material selection, sizing, sewing, and sampling, each step requires repeated modifications and approvals, consuming time and effort. To achieve rapid industry advancement, an increasing number of enterprises are turning to 3D virtual clothing design. This technology transforms clothing design from two-dimensional planes to three-dimensional displays[11], allowing "virtual garments" to be directly integrated into R&D, production, and market sales. This connection between design and retail aims to realize the digital upgrade of the clothing industry. Leng(2014) [12] posited that 3D virtual clothing design could enhance the efficiency and quality of apparel enterprise product design and R&D, shorten product development cycles, reduce garment production costs, increase sample qualification rates, and improve market responsiveness. Nafz(2022)[13] suggested that 3D simulation of clothing can expedite product launches and confer competitive advantages to companies. Cheng(2017)[14] believed that 3D virtual clothing design could foster innovation and individuality in design and R&D, enhance the functionality and aesthetics of clothing, and cater to consumers' personalized demands. Papahristou et al(2016)[15] asserted that 3D virtual design offers the benefits of virtual sampling, enabling rapid testing of design concepts, streamlining processes, and enhancing visibility. Wang(2020)[16] proposed that 3D virtual design software can simulate real product effects, allowing users to immediately visualize the impact of pattern, color, texture, and detail modifications without creating actual garments. Anne et al(2012)[17] explored how 3D virtual design influences the quality and timing of collaboration and communication, confirming that 3D serves as a design communication tool that strengthens communication among collaborators. These studies shed light on the positive impact of 3D virtual clothing design on apparel enterprise product R&D. Leveraging the technological advantages of 3D virtual

clothing design in virtual design, fitting, and other aspects can propel the intelligent upgrade of the industry.

Albeit with the benefits of 3D virtual clothing design for enterprises' product design and R&D underscored by previous studies, there remains a dearth of theoretical framework and elucidation on the optimization pathway within design and R&D processes. This study adopts the grounded theory approach, complemented by in-depth interviews, to undertake empirical research. It delineates categories of advantages stemming from 3D virtual clothing technology in design and R&D across diverse dimensions and formulates an optimization pathway model tailored for apparel enterprises' design and R&D. This model endeavors to furnish apparel enterprises with a roadmap to amplify their design and R&D efficiency and innovation capabilities through the integration of novel technologies.

## 3 Research Methods

### 3.1 Grounded Theory

The characteristic of grounded theory lies in its commitment to a problem-oriented approach, deriving concepts directly from raw data and practical observations and establishing a theoretical framework in a bottom-up approach. It offers significant advantages in various aspects such as data collection, data analysis, exploration of relationships between social phenomena, and theory construction. It is noted for its "clear process, explicit steps, strong operability, and normativity and scientificity"[18]. This study adopts the research paradigm of Glaser and Strauss's grounded theory, encoding and summarizing literature data, constructing concepts, and exploring relationships between concepts. Based on comparisons of concepts and categories, supplementary data are added to achieve theoretical saturation, thereby building an optimized path for enterprise design and R&D in 3D virtual apparel design. The adoption of grounded theory as the research method in this paper stems from several compelling reasons. Firstly, the absence of established theoretical frameworks regarding the impact of 3D virtual apparel design on enterprises' design and R&D necessitates the creation of an optimization pathway for this technology within enterprise contexts. Given the exploratory nature of this endeavor, employing an approach that constructs theory in a bottom-up approach, grounded in raw data and empirical evidence without preconceived theoretical assumptions, aligns aptly with the research issue at hand. Secondly, conventional quantitative research methods may fall short of providing a comprehensive understanding of the intricate processes involved in the generation of optimization pathways. In contrast, grounded theory excels in uncovering dynamic processes, scopes of influence, and interrelations inherent in complex phenomena.

### 3.2 Sample Selection and Material Collection

This study primarily combines first-hand interview data with secondary data to obtain research materials. The collected secondary data includes: (1) Official websites of 3D virtual clothing design to understand its characteristics, effects, etc.; (2) Case information sourced from authoritative media's online news reports, official enterprise WeChat accounts, and other public channels, retaining content relevant to the research topic; (3) Literature retrieved from databases such as China National Knowledge Infrastructure (CNKI) and Google Scholar using

keywords like “3D virtual clothing design” and “apparel enterprises’ design and R&D.” A total of 47 textual materials were obtained, with 30 randomly selected for theoretical construction and the remaining 17 used for theoretical saturation testing.

To collect primary data, semi-structured interviews were conducted with the theme of “The Impact of 3D Virtual Clothing Design on Apparel Enterprises’ Product Design and R&D.” A cumulative participation of 15 R&D personnel who have used or are familiar with 3D virtual clothing design software in the industry were selected as interviewees, including designers, pattern makers, and technologists. Efforts were made to ensure diversity in the operational nature of the interviewees’ respective enterprises. Each interview lasted between 20-30 minutes. The interview recordings were transcribed into textual materials, irrelevant statements were removed, resulting in 261 complete statements retained. Among these, 200 statements were used for theory construction, while the remaining 61 statements were used to test theoretical saturation. Subsequently, all textual materials underwent open coding, axial coding, and selective coding processes. After obtaining the conceptual model, theoretical saturation was tested, leading to the formation of the final theoretical model and its explanation. Figure 1 illustrates the research process.

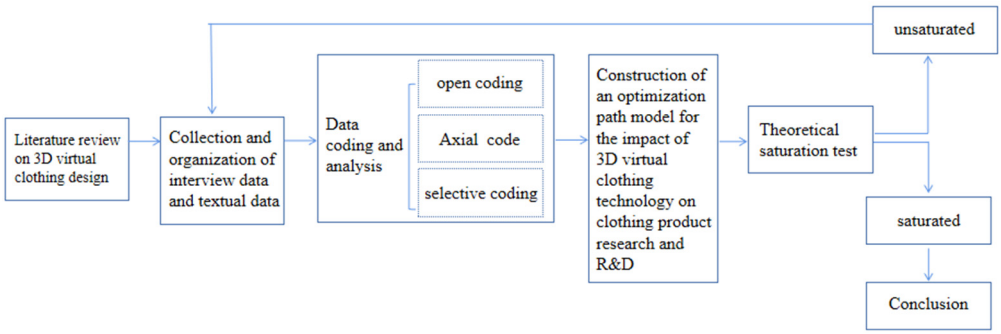


**Figure 1.** Research process

## 4 Category Distillation and Modeling

### 4.1 Open Coding

Open coding involves the collection and interpretation of raw data (text, images, data) to derive concepts. In this study, the initial coding of textual data yielded 30 concepts, which were further distilled into categories, forming 15 subcategories (as evidenced by Table 1).

**Table 1** Concepts and subcategories formed by open coding

| A subcategory | a concept | Original sentences from the text data |
|---|---|---|
| A1 Reduced material costs | a1 Reduction of sampling costs | In the first half of 2021, sampling costs decreased by 68.83% compared to 2020, dropping from 126,000 to 39,300... |
| | a2 Minimization of uncertain waste | For more expensive embroidery techniques, such simulations can reduce waste caused by uncertainty. |
| A2 Reduced error rates | a3 Error avoidance | Designers can send the digital prototype to suppliers, enabling manufacturers to respond to potential |

| | | |
|---|---|---|
| | | manufacturing errors more quickly and effectively. |
| | a4 Timely adjustment of design aesthetics | Intuitive discovery of structural template issues and adjustment of garment design aesthetics can be achieved through model fitting. |
| A3 Diversified utilization | a5 Selection through review meetings | The 3D garment renderings we ultimately produce are mainly used for the selection phase of designers' works, tailored for everyone's use during review meetings... |
| | a6 Electronic commerce display | Three-dimensional simulated clothing can be used in product development processes and for product displays in e-commerce. |
| A4 Enhanced selection efficiency | a7 Seamless conversion between 3D and 2D patterns | CLO can seamlessly convert between 3D and 2D pattern making. |
| | a8 Enhancement of clothing product precision | Especially for some printed/plaid fabrics, the use of such software produces very realistic effects, speeding up order processing... |
| A5 Intelligent operation | a9 Automatic matching of body data | Besides user-input dimensions, other relevant dimensions can also be automatically matched based on body data. |
| | a10 Multiple-use patterns | Using 3D digital garments, modeling needs to be done only once to see the effects in different colors... |
| | a28 Real-time communication | After modeling, there's no need to send parcels; instead, 3D models can be directly sent to clients,... enabling real-time communication... |
| A6…… | …… | …… |

### 4.2 Axial Coding

Axial coding entails the identification and establishment of logical connections between concepts and categories, discerning the main categories for in-depth analysis through axial coding. 3D virtual design augments operational efficiency fosters interdepartmental coordination, and conserves workforce and material resources, enabling companies to allocate more resources towards product design, thereby enhancing design outcomes. Concurrently, the reduction of the R&D cycle expedites product launches, catering to consumer needs, thus nurturing a virtuous cycle. Through an examination of the inherent and logical relationships among the 15 subcategories detailed in Table 1, five main categories have been delineated, as illustrated in Table 2.

**Table 2** Main categories formed by axial coding

| Main category | Subcategory | Category connotation |
|---|---|---|
| Reduced R&D Costs | Reduced material costs | It reduces research and development costs by lowering raw material consumption rates and the probability of repeated revisions. |
| | Reduced error rates | It decreases rework and error rates, avoiding unnecessary waste. |
| | Diversified utilization | It directly uses "virtual clothing" for promotion, exhibition, etc., reducing costs in the original stages. |
| Improved R&D Efficiency | Enhanced selection efficiency | Virtual clothing can present realistic design effects, increasing the probability of style selection |

| | | |
|---|---|---|
| | Intelligent operation<br>Optimized design quality | during the development phase.<br>It assists designers in quickly and accurately completing design tasks, improving the quality and precision of product design.<br>3D clothing design technology enhances the quality of clothing design, reducing modifications with a high success rate. |
| Shortened R&D Cycles | Streamlined physical production processes<br>Time-saving measures<br>Optimized design processes | It can instantly view real design effects, avoiding repeated revisions to produce physical samples.<br>It reduces the time spent on design and production processes, lowers the modification phase, and shortens the R&D cycle.<br>Precise and rapid design optimization streamlines the design process, enhancing design efficiency. |
| Enhanced Design Outcomes | Virtual reality simulation<br>Fulfilled design requirements<br>Diversified design approaches | It reproduces actual clothing realistically in virtual space and simulates real physical samples in real-time.<br>Designers can better grasp their design effects and creativity, better meeting design requirements.<br>Designers can quickly experiment with various design ideas, enhancing design innovation. |
| Elevated Collaboration Efficiency | Facilitated communication<br>Rapid communication<br>Effective communication | It assists departmental personnel in communication, significantly improving team collaboration efficiency.<br>It facilitates data sharing and communication, allowing departmental personnel to view and provide feedback anytime, anywhere.<br>It provides a more intuitive and effective tool for communication among departmental personnel. |

### 4.3 Selective Coding and Modeling

Selective coding is the process of further exploring the core categories within established concept categories, clarifying the hierarchy of existing categories, and describing the text data around the "core category." Leveraging well-developed main categories aids in delineating the entire "storyline." The core category must occupy a central position among all categories and boats the ability to integrate other categories. Following the research paradigm of grounded theory, this study identifies "Optimization of Apparel Enterprises' Product Design and R&D" as the core category of selective coding. The storyline around this core category can be summarized as follows: Using 3D virtual clothing design can reduce R&D costs, enhance R&D efficiency, and elevate collaboration efficiency among departmental personnel while enhancing design outcomes and shortening the entire R&D cycle. From these five dimensions, the optimization of product design and R&D for apparel enterprises is achieved, as illustrated in the theoretical framework depicted in Figure 2.

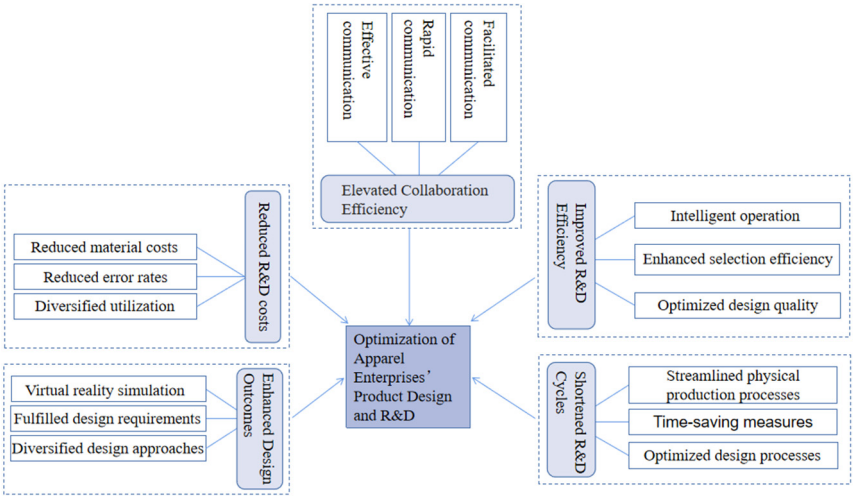


**Figure 2.** Optimization pathway model of 3D virtual clothing design for apparel enterprises' product design and R&D

### 4.4 Theoretical Saturation Test

This study conducted coding analysis on 17 randomly selected secondary data sets and 61 textual statements to examine the research conclusions. During the coding process, no new categories were discovered, and there were no new associations between categories. The main categories formed during theory construction remained consistent. It can be considered that the categories deduced from the data have developed relatively comprehensively. Therefore, the theoretical model constructed in this study is relatively saturated.

## 5 Elucidation of the Optimization Pathway Model of 3D Virtual Clothing Design for Apparel Enterprises' Product Design and R&D

Deriving from the aforementioned storyline, a logical deduction through the pathway of "Optimization of 3D Virtual Clothing Design for Apparel Enterprises' Product Design and R&D" integrates main categories and subcategories, thus laying the groundwork for a preliminary framework encompassing all categories and concepts. Specifically, "Reduced R&D Costs" primarily refers to the replacement of physical garment samples with virtual counterparts, thereby circumventing material consumption and waste while reducing the frequency of iterative sampling adjustments. Furthermore, virtual clothing finds utility in brand promotion, virtual fashion shows, and online retailing, consequently economizing corresponding expenditures. "Improved R&D Efficiency" underscores the intelligent features of 3D virtual clothing design, fostering heightened quality and precision in product design and augmenting the proportion of effective styles. "Shortened R&D Cycle" delineates the intuitive presentation of garment effects, streamlining designers' processes from initial design to subsequent modifications, thus elevating accuracy and obviating the need for physical

prototypes, ultimately saving time. “Enhanced Design Outcomes” accentuates the swift and seamless presentation of garment materials, colors, and details from design to showcase stages, thereby catering to diverse design innovations. “Elevated Collaboration Efficiency” highlights the facilitation of swift and effective communication among departments, enterprises, and their clients. Subsequent elucidation will delve into each dimension.

### 5.1 Reduced R&D Costs

“Reduced R&D Costs” refers to the capability of 3D virtual clothing design technology to assist enterprises in saving various expenses incurred during the design and R&D process, thereby enhancing resource utilization and return on investment. This is manifested in the reduction of material costs and error rates, alongside the diversified application of virtual clothing in different commercial environments.

Throughout the entire process, from design and pattern making to sampling and production, a significant amount of material and labor costs may be expended[19]. However, leveraging 3D virtual design technology can reduce material consumption rates, defect rates, and costs associated with maintenance and management. With just a computer and specialized 3D software, the entire process from design to presentation can be completed, eliminating the need for designers to repeatedly modify design drawings, thus improving design efficiency and quality while reducing error rates.

Enterprises can integrate these “virtual garments” into their R&D, production, and market sales processes, determining production quantities based on sales figures to reduce inventory. Alternatively, they can directly replace traditional methods such as catalog shoots and promotional displays, thereby reducing the costs associated with the production and transportation of physical garments, alongside establishing a seamless connection from the design stage to the retail stage. Reduced material costs save development costs from the source, while the diversified utilization saves costs in the enterprise’s terminal processes, and reduced error rates indirectly save workforce and material costs for the enterprise.

### 5.2 Improved R&D Efficiency

“Improved R&D Efficiency” denotes the capability of 3D virtual clothing design technology to assist enterprises in enhancing the speed and quality of work during the design and R&D process, thereby reducing time to market and increasing product competitiveness. This is demonstrated by the intelligent operation, optimized design quality, and enhanced selection efficiency through the 3D virtual design technology.

In the traditional process of clothing design and production, the realization of a garment entails a prolonged sequence commencing from the designer’s sketch of the style, continual pattern modifications until the style is finalized, followed by pattern making by pattern makers, and then the creation of samples by garment makers. Subsequent adjustments and corrections based on these samples are iteratively made until satisfaction is achieved. This iterative process requires a significant amount of time and is characterized by relatively low efficiency[20]. Hinging on the intelligent advantages of 3D virtual design technology, designers can gain real-time insights into intricate design textures, colors, and other details, as well as simulate the realistic presentation of clothing design effects[21]. This facilitates timely problem identification, modification, and optimization by designers during the design phase.

Various simulation tests, such as material simulation, lighting simulation, and dynamic simulation, can be conducted during this phase to predict and optimize the performance and effects of virtual clothing, effectively enhancing design quality and precision, increasing the proportion of effective styles, and mitigating potential issues and risks in later stages. Modular design can also be employed, where a garment is dissected into components such as the collar, sleeve, and body for individual modeling, and then these components are assembled into a complete garment. This approach accelerates the pace of style updates and comprehensively enhances the efficiency of design and R&D processes from design inception to production procedures.

### 5.3 Elevated Collaboration Efficiency

"Elevated Collaboration Efficiency" embodies the capacity of 3D virtual clothing design technology to enrich communication and coordination among teams throughout the design and R&D process, facilitating seamless data sharing and exchange to enhance work effectiveness and quality. This is primarily achieved through internal and external collaboration mechanisms, fostering swift and efficient communication channels between intra-enterprise personnel and external stakeholders.

With regard to internal collaboration, 3D virtual clothing design technology facilitates seamless integration among diverse departments within the enterprise. Leveraging online platforms, data can be swiftly uploaded, downloaded, modified, and subjected to feedback, thereby minimizing information transmission time and errors. For instance, designers can directly transmit virtual clothing models and parameters to the production department, where automated cutting, layout, and stitching processes are executed based on the virtual clothing data, obviating the necessity for manual measurements and adjustments. Concurrently, designers can monitor real-time progress and feedback from the production department, enabling prompt modifications and optimizations[22]. This intuitive communication approach consolidates the roles of designers, pattern makers, and garment makers into a unified position during the developmental phase, mitigating the likelihood of rework and errors.

In light of external collaboration, efficient interaction between enterprises and external collaborators or clients is facilitated via online platforms designed for data display, communication, evaluation, and transactions, thereby augmenting the efficacy and satisfaction of collaborations. For example, post-modeling completion, enterprises can showcase the virtual clothing's effects through videos or images with no need for delivery, enabling partners or clients to experience the performance and effects of virtual clothing online and provide timely feedback and suggestions. This circumvents the need for multiple rounds of sample modifications, as partners or clients can confirm samples, colors, and fabrics sans the complexities associated with traditional physical samples, thereby conserving time and effort.

### 5.4 Enhanced Design Outcomes

"Enhanced Design Outcomes" represents the enhancement of design quality and effects, manifested through various aspects such as virtual realistic simulation of physical garments, fulfillment of diverse design requirements of designers, and diversified design approaches.

3D virtual clothing design technology allows enterprises to achieve high-quality rendering and presentation of virtual garments during the design phase. The software provides designers with

more opportunities for innovation and unleashing creativity through realistic simulations of concepts, colors, materials, patterns, and styles. Designers can immediately visualize the effects of modifications to garment patterns, colors, textures, and details[23], facilitating real-time checks on garment styling and fit. They can also make online adjustments to garment sizes, patterns, and materials, providing robust technical support for design creativity.

Through 3D virtual design technology, the techniques for garment styling variations can become more diverse. Designers can approach design from holistic and detailed perspectives as well as from detailed design to overall styling, fully showcasing their design ideas. By combining and varying garment styles, colors, and materials, innovative styles can be achieved, promoting stylistic innovation[24]. Additionally, the creation of component libraries, virtual accessories, and parameterized human models enables customers to quickly and easily find fashion items that match their tastes and requirements, facilitating diversified and innovative designs.

### 5.5 Shortened R&D Cycle

"Shortened R&D Cycle" signifies the reduction of unnecessary steps and processes to expedite product time-to-market, thereby gaining a competitive edge in the market. This is exemplified by the streamlined garment production processes, time-saving measures in overall product development, and optimized design process.

3D virtual garment design technology enables direct modeling, modification, and display of virtual garments on computers, obviating the necessity for physical garment production. This alters the traditional design process sequence, resulting in time and resource savings. Furthermore, it offers diverse functionalities and tools, such as automatic cutting and sewing, facilitating swift and precise adjustments to virtual garments, mitigating human errors and redundancies, and curtailing the physical sample production process[25]. For instance, in a particular apparel company, during one season's product development, a total of 198 garment styles were devised. Nonetheless, virtual garment production was accomplished within three days of receiving the samples. This approach notably diminishes designers' time spent on drafting plans and communicating with pattern makers, sample producers, and clients, thereby abbreviating the entire season's product development cycle[26].

Apparel enterprises can promptly materialize design intentions by establishing a fundamental pattern library. For instance, they can effortlessly interchange between various fabrics and colors for the same style, modify garment particulars, or adjust lace pattern positions, thereby minimizing the likelihood of remaking samples in the traditional process. Through this optimized process, the R&D cycle for the entire season's products is truncated, enabling companies to better cater to market demand expeditiously, thereby augmenting market competitiveness.

## 6 Conclusion

Through iterative cycles of open coding and selective coding in tandem with theoretical coding based on in-depth interview data, this study effectively applied the grounded theory to construct an "Optimization Path of 3D Virtual Clothing Design for Apparel Enterprises'

Design and R&D." The outcome is ideal, as it identified and formulated a theoretical model for the optimization path, as illustrated in Figure 2. According to the optimization path model, it becomes apparent that the five dimensions of the optimization path — "Reduced R&D Costs," "Improved R&D Efficiency," "Elevated Collaboration Efficiency," "Enhanced Design Outcomes," and "Shortened R&D Cycle" — collectively contribute to the overarching goal of "Optimization of Apparel Enterprises' Product Design and Development."

(1) By exploring the characteristics of 3D virtual clothing design and its impact mechanism on apparel enterprises' design and R&D, the constructed optimization path model in this paper demonstrates the three-level coding of the grounded theory. It reflects the impact mechanism and optimization strategies of 3D virtual clothing design on apparel enterprises' product design and R&D across various levels. Additionally, the theoretical model developed in this study has contributed to advancing relevant theories in the field of "3D virtual clothing design," laying a theoretical foundation for subsequent empirical research.

(2) 3D virtual design technology, as a novel clothing design method grounded in digital technology and innovative concepts, serves as a collaborative tool capable of consolidating the fragmented and intricate processes inherent in traditional clothing R&D design into an intuitive 3D digital workflow. This technology transcends the confines of conventional clothing design methods, fostering enhanced quality and efficiency in clothing design, characterized by accelerated design speed and reduced costs. By digitally linking the fashion industry's upstream and downstream sectors, it engenders efficient collaborative management and generates economic benefits for enterprises.

(3) Through three-level coding, it was discerned that R&D efficiency, product innovation, cost control, time efficiency, and teamwork emerge as pivotal factors influencing the optimization of apparel enterprises' design and R&D. This shed light on the impact mechanism of 3D virtual clothing design on apparel enterprises' product R&D, offering a reference framework for technological innovation for small and medium-sized apparel enterprises reliant on traditional design and R&D methods. Furthermore, it presents a fresh perspective for apparel enterprises seeking to optimize their design and R&D processes.

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