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Reconstruction and Practice of Sustainable Teaching Pathways for Garment Construction Courses Supported by 3D Virtual Simulation in the Era of Intelligent Digitalization

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Abstract: In the era of intelligent digitalization, technologies such as artificial intelligence, big data, and virtual simulation have profoundly reshaped the ecosystem of fashion design education. The textile and apparel industry's pursuit of green, low-carbon, and intelligent development continues to drive a systematic transformation in the knowledge structure, pedagogical approaches, and talent-training models of fashion design programs. Traditional fashion design education centered on skill training alone can no longer meet the future fashion industry's demand for digital-intelligence-driven, interdisciplinary, sustainability-oriented, innovative talent. Taking university-level courses in Garment Construction as a case study, this paper explores the reconstruction of sustainable teaching pathways and systemic reform of technical courses supported by 3D virtual simulation technology. Through literature review and pedagogical practice, the study elaborates on a three-dimensional framework of sustainable teaching objectives, encompassing knowledge, skills, and values, across the dimensions of curriculum philosophy, learning goals, and technological support. It further proposes a curriculum transformation strategy centered on the "logic of sustainable garment structure design for the future" and establishes a five-dimensional integrated teaching model as an implementation framework. The findings reveal that the integration of 3D virtual simulation technology not only optimizes material utilization and enhances process visualization in garment technology instruction but also fosters students' coordinated development in structural cognition, design innovation, and sustainability awareness. This study provides a systematic model and practical reference for the diversified and sustainable reform of Garment Construction courses, offering valuable insights into promoting the green transformation and digital-intelligent integration of fashion education.

Keywords: Intelligent digital era; 3D virtual simulation; Sustainable fashion education; Garment Construction course; Teaching pathway reconstruction

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1. Introduction

With the rapid development of the global economy, excessive resource consumption and environmental degradation have become serious threats to humanity, compelling society to re-examine the relationship between people and nature. In response, industries across the board have begun to adopt the principles of sustainable development in an effort to reduce energy consumption and carbon emissions. As a low-carbon, environmentally friendly, and circular design philosophy, sustainable fashion design has gradually evolved into a core direction for the future development of the fashion industry. In the 21st century, influenced by artificial intelligence, big data, virtual simulation, and the rise of sharing and circular economy models, sustainable fashion design has been endowed with new meanings and developmental orientations, exhibiting a dual-driving trend of "technological empowerment and ecological rationality." Against this backdrop, the sustainable transformation of China's textile and apparel industry remains at the stage of conceptual introduction and localized pilot implementation. The number of fashion designers equipped with systematic, sustainable design thinking and practical competence is still limited, and the existing fashion education system has yet to provide effective structural support. As a result, how to seamlessly and implicitly integrate sustainability concepts into the curriculum of fashion design programs has become a focal issue in both academia and education.

Taking university-level courses on Garment Construction as a case study, this research creatively integrates sustainability concepts into the teaching system, exploring new pedagogical pathways for green reconstruction of teaching content and sustainable cognitive transfer in the context of the intelligent digital era empowered by 3D virtual simulation technology. By developing a teaching model grounded in virtual–real integration, conceptual embedding, and reflective transfer, this study expands the scope and depth of sustainable fashion education. The proposed model serves as a reference framework for nurturing a new generation of interdisciplinary fashion designers in China who integrate ecological responsibility with creative and structural innovation.

2. Current status and challenges of sustainable teaching in fashion design courses in the era of intelligent digitalization

In recent years, with the advancement of the United Nations Sustainable Development Goals (SDGs) and the deepening of educational digitalization, sustainable fashion design education has emerged as a prominent research focus within the global academic community, exhibiting a dual-driving trend of technological integration and emotional engagement. According to a study conducted in Poland by Murzyn-Kupisz and Hołuj (2021), more than half of European fashion design institutions have incorporated topics such as environmental sustainability, ethical production processes, and resource conservation into their formal curricula, rather than limiting them to elective or extracurricular courses. In Portugal's Fashion Design Technician Course (FDTC) vocational education program, a survey of 40 local instructors revealed that 82.5% of respondents had integrated circular economy and sustainability issues into their classroom teaching activities [1]. Many researchers have since focused on transforming environmental awareness and ecological design responsibility into new pedagogical objectives, developing sustainability-oriented curriculum modules and knowledge frameworks to guide ongoing educational reforms [2].

The author's review indicates that current research in this field primarily concentrates on four key areas: (1) The construction of emotionally driven models for teaching circular design; (2) The practical application of 3D virtual simulation technologies in sustainable design education; (3) The development of multidimensional evaluation systems for effectively assessing students' learning outcomes and motivational engagement; (4) The exploration of culturally and ethically oriented pathways for sustainable instructional design. Korean scholar Lee Hyewon (2025) proposed an emotionally driven model for sustainable design education, suggesting that textile waste can be transformed into a combination of “digital emotion + physical entity” to foster students’ emotional connection with discarded clothing materials [3]. Wang Mengyuan (2023) from the University of Surrey in the United Kingdom redefined the role of virtual fashion experiences in sustainable education, emphasizing students’ learning processes as they relate to social structures, cultural values, and identity formation within the context of sustainability. Chinese scholar Jiang Dongdong (2023) advocated for the systematic integration of sustainable development principles into the learning objectives of creative fashion design courses, proposing an organic fusion of creativity and functionality, and of environmental awareness and aesthetics—thereby challenging the traditional design paradigm that prioritizes aesthetics above all else. Although research on sustainable fashion design education continues to deepen both domestically and internationally, the field still faces a range of theoretical and practical challenges.

At present, the core challenge lies in achieving a deep integration among concepts, technologies, and pedagogical logic. In Chinese higher education, reforms toward sustainability in fashion design curricula largely remain at the stage of conceptual introduction or localized experimentation. The structural optimization of teaching systems and the holistic integration of sustainability into curriculum design are still insufficient. Sustainability is often treated as “supplementary knowledge” rather than as the core value driving the reconstruction of pedagogical logic. Furthermore, scholars widely acknowledge that sustainable fashion education constitutes an inherently interdisciplinary and systemic endeavor—one that requires not only instructors with solid professional backgrounds in fashion design, but also educators who possess a thorough understanding of sustainability principles and digital-intelligence technologies. However, in many Chinese fashion colleges, faculty members still exhibit relatively narrow knowledge structures and rely on traditional teaching methods—limitations that significantly constrain the innovative implementation of sustainable pedagogical practices [4].

3. Advantages of applying 3D virtual simulation technology in the sustainable transformation of garment construction education

3D Virtual Simulation technology represents an innovative educational approach that integrates artificial intelligence, big data, and immersive interaction. Its core advantages—high visualization, strong interactivity, instant feedback, and reproducibility—make it particularly well suited to the evolving demands of fashion design education. Platforms such as Style3D and CLO3D exemplify how virtual garment modeling technologies enable real-time multimodal linkage and dynamic mapping among 2D garment patterns, 3D virtual forms, and technical processes. This allows students to comprehend garment structural principles through an experiential learning process characterized by “seeing, modifying, and verifying.” Sustainability has long centered on the principles of resource efficiency and circularity, and 3D virtual simulation technology provides a powerful means to realize these goals within fashion education [5]. It enables the quantifiable assessment of material consumption throughout the learning process. Within a virtual environment, students can use parametric tools to simulate various structural schemes, compare material utilization rates, and evaluate the complexity of different production workflows—thus verifying the sustainability and adaptability of their structural solutions in advance. This cyclical experimental mechanism of “virtual experimentation – data feedback – structural refinement” greatly enhances the environmental responsibility embedded in garment technology teaching. Moreover, it provides both technical support and a digital visualization pathway for integrating sustainability into curriculum design, fostering a teaching model that unites ecological awareness with technological innovation and advances the sustainable transformation of fashion education [6].

4. Course orientation and teaching objectives of garment construction under the guidance of sustainable design concepts

The Garment Construction course is a core component of fashion design programs in higher education. It serves as a crucial bridge guiding students from perceptual modeling in design toward rational structural construction, as well as a key transitional stage linking design concepts to technical realization. Under the guidance of sustainability-oriented design thinking, the teaching objectives of this course go beyond the conventional transmission of technical skills such as pattern drafting, cutting, and sewing techniques. Instead, the course emphasizes cultivating students' spatial reasoning and problem-solving abilities through the logical framework of sustainable design. This course is primarily designed for fashion design students who have already completed foundational courses such as fashion modeling design, color composition, draping, and basic design principles [7]. It aims to help them integrate structural logic, ecological awareness, and technological application into a unified learning system that supports innovative and sustainable approaches to fashion creation.

4.1. Three-dimensional framework of teaching objectives: Synergistic construction of knowledge, skills, and values

In general, the teaching objectives of garment technology courses in higher education are to help students develop a systematic understanding of the structural principles and technical logic underlying garment design. Through structured training in construction theory and production processes, students learn the underlying rules governing garment form, material properties, and manufacturing procedures, thereby establishing a comprehensive cognitive framework of garment technology. With the integration of sustainability concepts, the course embeds green design awareness and resource conservation into every stage of the teaching process. It emphasizes structural rationality as a driving force for creative design, cultivating versatile fashion designers who possess structural analytical ability, technical implementation skills, and innovative application competence. This is achieved through progressive learning that interconnects technical reasoning, design innovation, and sustainable value creation.

Overall, the sustainability-oriented Garment Construction course is guided by a three-dimensional framework centered on the synergistic development of "knowledge, skills, and values."

(1) Knowledge Objective

To master the fundamental principles of Garment Construction; understand pattern construction rules and the complete process of garment production; and comprehend the logical relationships among structure, form, and material.

(2) Skill Objective

To develop the ability to independently draft women's wear prototypes and perform fundamental sewing operations, as well as to verify structural accuracy and optimize technical processes in both virtual and physical environments.

(3) Value Objective

To cultivate forward-looking and sustainability-oriented thinking in garment structure design; to internalize the understanding that "sustainability is an inherent design responsibility"; and to build the comprehensive capability to transform creative concepts into technical and practical design expressions.

4.2. Green reconstruction of course content: A resource-efficient path integrating materials, structure, and technology

In traditional fashion design education, Garment Construction courses have often emphasized technical metrics such as accuracy, speed, and process precision while neglecting ecological dimensions such as material waste, energy consumption, and structural efficiency. Guided by the principles of sustainability, the Garment Construction course now shifts its focus from purely technical skill training to a dual emphasis on resource efficiency and ecological rationality. The green reconstruction of course content not only involves adjusting individual teaching modules but also reconfiguring the underlying logic of the knowledge system itself. This transformation replaces the traditional linear sequence of "design–pattern making–production" with an integrated and resource-conscious framework of "materials–structure–technology" [8]. The core value of this green restructuring lies in making the course content itself a carrier of sustainability concepts. In this way, students can build cognitive connections between structural rationality and ecological efficiency, cultivating an awareness of resource conservation and developing sustainable judgment rooted in rational design thinking.

4.3. Digital-intelligent integration of teaching strategies: Synergizing implicit conceptual embedding and technological scaffolding

Complementing the greening of course content, innovation in teaching strategies lies in shifting the transmission of sustainability concepts from explicit instruction to implicit construction. 3D virtual simulation technology provides a digital-intelligent scaffold for this transformation, enabling educators to naturally integrate awareness of conservation and ecological reasoning into students' learning experiences through a cyclical model of "context–task–feedback–reflection." The instructional design is characterized by task orientation and data-driven learning. As students engage in virtual garment structure design and process optimization, the system provides real-time feedback on quantifiable indicators such as fabric utilization rate, production time, and fabric waste ratio. Teachers then use these data, together with peer evaluation mechanisms, to guide students in reflectively assessing the sustainability of their design solutions—transforming green awareness into structural design logic. Through this process, digital-intelligent integration achieves a two-way fusion of technology and sustainability concepts, reshaping learners' cognitive patterns and making sustainable design education a genuinely internalized process—one that becomes embodied in both thought and practice.[9]

5. A five-dimensional integrated sustainable teaching model for Garment Construction courses based on 3D virtual simulation and its practice

This study proposes a five-dimensional integrated sustainable teaching model for Garment Construction courses, grounded in 3D virtual simulation technology. The model aims to advance the sustainable development of fashion design education through the deep integration of digital and virtual simulation technologies. Its core concept is to cultivate students' sustainable design thinking and strengthen their green values—from conceptual design to technical implementation—through five progressive teaching modules. Each module builds upon the previous one, emphasizing energy conservation, eco-friendly craftsmanship, and structural innovation.

5.1. Module A: Garment structure experimentation and the cultivation of resource-conservation awareness

As the starting point of the course, Module A focuses on garment structure experimentation and the cultivation of awareness regarding material and process efficiency. The goal is to help students understand, through 3D virtual simulation, the causal relationship between structural decisions and material conservation, thereby forming an initial perception of sustainability [10].

At the beginning of the module, instructors guide students to research literature and design cases related to zero-waste and sustainable structural design, encouraging autonomous learning and conceptual familiarity. In class, guided by the core task of "identical forms, different structures," students use a 3D virtual platform to compare how various garment structural compositions and production process schemes affect factors such as fabric utilization rate and manufacturing time. Through this comparative experimentation, students gradually develop sustainability-oriented design thinking in garment structuring. After class, they analyze material and energy-saving effects and record their findings in experimental reports. In this stage of structural experimentation and comparative learning, students gain a practical understanding of the logic of resource-efficient design, laying a solid cognitive foundation for creative exploration and sustainable innovation in the subsequent modules.

5.2. Module B: Integrating creative structural design with sustainable thinking

Cultivating innovative thinking in garment structural design has always been one of the core objectives of fashion technology courses in higher education. A designer who focuses solely on sketching stylistic designs, without understanding pattern communication or effectively translating design intentions into structural solutions, cannot achieve true creative realization. Observations reveal that many fashion design students in universities lack innovative thinking centered on structure. A prevalent misconception among students is that design innovation stems primarily from fabric manipulation or surface pattern design, which reflects a significant gap in professional understanding [11]. Module B focuses on developing students' capacity for structural design innovation and serves as a pedagogical bridge from resource-efficiency experimentation to structural creativity. Its core objective is to foster the ability to balance structural rationality, creative expression, and sustainability. In the instructional design, the module follows the main learning pathway of "structural variation and form recombination." Using 3D virtual garment modeling systems, students conduct experiments in virtual environments involving seamline transfers, pleat reconstructions, and cutting recombinations. By applying single-variable controls to structural parameters, students explore how sustainability principles can be structurally embodied, evaluating their designs based on two key dimensions: material utilization efficiency and form innovation.

At the same time, the module incorporates learning activities such as parametric form reconstruction, ecological form-language analysis, and comparative studies of international fashion brands' green structural innovations. These experiences guide students to deepen their understanding of the relationship between structural innovation and sustainable value through cycles of analysis, experimentation, and reflection. The core intent of this module is to integrate structural experimentation with virtual validation, encouraging students to internalize resource conservation as the starting point of creative thinking. Ultimately, this enables the formation of a sustainability-driven logic of structural creativity, achieving a cognitive shift from "awareness of green design" to "expression of structural innovation."

5.3. Module C: Green substitution and cognitive reconstruction in garment manufacturing processes

Sewing technology is a crucial link in transforming creative design into tangible garments. Traditionally, sewing courses in fashion programs have relied heavily on industrial flat sewing machines for hands-on process training, while paying little attention to the future significance of these skills or the technological advancements shaping contemporary manufacturing. Module C centers on optimizing garment manufacturing processes. Its instructional focus lies in using 3D virtual garment modeling and simulation technologies to help students recognize differences in energy consumption and environmental impact among various process pathways, thereby reshaping their understanding of traditional production concepts. The course also introduces cutting-edge sustainable garment-making methods currently adopted or emerging in the industry, such as heat bonding, seamless joining, and detachable construction [12]. Through virtual experiments comparing conventional sewing workflows with streamlined or alternative methods, students gain a deeper understanding of how digital production management contributes to sustainable manufacturing practices. The objective of this module is to cultivate students' ability to make scientifically grounded technical judgments through experimentation and case analysis. It challenges the conventional notion that "refinement equals complexity" and instead emphasizes that "simplicity, recyclability, and low energy consumption" constitute the fundamental logic of modern sustainable garment craftsmanship. Through green process substitution and virtual cognitive training, students progressively develop a process-oriented mindset guided by energy-efficiency optimization, thereby laying the groundwork for subsequent modules focused on structural integration and innovative design development.

5.4. Module D: Structural logic construction and sustainable cognitive transfer

In Garment Construction education, structural logic capability serves as the core foundation connecting creative fashion expression with technical implementation. Module D aims to establish a systematic structural reasoning framework through structural deduction and digital visualization technologies, enabling students to develop transferable structural logic that spans across materials, styles, and contexts. The emphasis is on helping students understand that all fashion design expressions must ultimately be realized through structural logic—structure is not subordinate to garment silhouette, but rather the prerequisite for silhouette formation [13].

(1) Constructing a "Dynamic Structural Logic" System Using 3D Virtual Simulation as Cognitive Scaffolding

Module D employs 3D virtual simulation technology as cognitive scaffolding, utilizing CLO 3D and Style3D to construct a visualized "dynamic structural logic" system. This enables students to understand the causal relationship between pattern structure and garment form within a real-time mapping environment. Through 2D-3D interactive demonstrations of subtle pattern adjustments, instructors guide students to conduct quantitative analysis of material consumption, fabric waste rates, and manufacturability across different structural solutions. This approach helps students develop systematic design decision-making capabilities that integrate structural reasoning, silhouette assessment, and sustainability optimization.

(2) Problem-Driven Structural Logic Training: Reasoning-Based Learning from Sketch to Structure

The module introduces various interactive teaching scenarios that use "problems" as drivers to strengthen students' ability to analyze form from a structural perspective. Real assessment tasks and AIGC comparative analysis are employed to establish structural logic awareness. The instruction begins with the guiding question: "Which fashion illustrations cannot be structurally realized?" Students are presented with design sketches or AI-generated images to identify structural impossibilities, thereby recognizing that visual forms do not equate to structural manufacturability [14]. Subsequently, students engage in "Abstract Sketch to Structural Solution Reasoning" tasks, using generative AI software to convert random sketches into garment realization proposals. Through comparing human-generated and AI-generated results, students understand AI limitations and the irreplaceable nature of structural thinking during this comparative process. This task-based training helps students recognize the importance of structural learning while enhancing their ability to assess design feasibility from a structural perspective.

(3) Building Cross-Contextual Sustainable Structural Awareness Through "Cutting-Edge Design Cases"

The curriculum incorporates cutting-edge fashion master cases to cultivate sustainable structural design awareness. Through analyzing Rei Kawakubo's anti-structural experiments, Iris van Herpen's structure-material integration strategies, and Issey Miyake's origami garment creative systems, students learn that complex silhouettes do not rely on decorative accumulation but stem from functional innovation in structural cutting methods, body curves, and material properties. The course engages students in deconstructing classic international silhouette structures, simulating morphological differences created by structural line variations, and ultimately understanding that structural innovation is not only the essence of silhouette breakthroughs but also an important pathway for sustainable design.

5.5. Module E: Comprehensive implementation of sustainability-themed garment construction design teaching

The systematization of structural logic and the transfer of sustainable cognition constitute a vital bridge between fundamental garment construction skills and holistic innovative design. The central aim of this module is to guide students in systematically integrating the fragmented knowledge acquired in previous modules, such as structural efficiency, green craftsmanship, and creative expansion, into a coherent and unified knowledge framework that interconnects structure, process, and sustainability. Students are further encouraged to apply this integrated framework to the deconstruction and analysis of classic designs and complex silhouettes, thereby progressing from passive reception to active analysis and innovation. In its instructional design, the module introduces product life-cycle thinking as a key conceptual foundation. This approach urges students to extend their perspective beyond garment design and construction to include the entire life span of a garment—its use, maintenance, and end-of-life recycling or disposal. A major strategy for facilitating cognitive transfer in this module is the "Deconstruction and Reconstruction" workshop. In these sessions, instructors lead students in digitally deconstructing representative works from leading international fashion houses, examining their underlying structural logic and craftsmanship decisions. Guided by the principle of sustainable optimization, students then re-envision these garments through structural simplification or green process substitution, and test the feasibility of their redesigned versions within a 3D virtual simulation environment. Chinese traditional culture has long embraced the philosophies of "cherishing materials" and "making the best use of things," which offer profound inspiration for contemporary sustainable design. Through comparative case studies under the theme "From Tradition to Sustainability," instructors guide students to explore how cultural heritage and sustainable logic can be organically integrated. This process enables students to achieve a deep cognitive transfer—transforming sustainability from an abstract ideal into an internalized design philosophy that informs creative practice. The pedagogical design of Module E seeks to complete the closed-loop structure of the entire teaching model, enabling students to achieve a comprehensive transformation from conceptual understanding to innovative application through experiential practice. Ultimately, it cultivates an integrated competency framework that unites "structure-driven design, process-supported execution, and sustainable expression." Through this holistic learning process, students not only strengthen their capacity for creative implementation but also develop the professional competence and social responsibility necessary to contribute meaningfully to the sustainable transformation of the future fashion industry.

6. Conclusion

Anchored in the context of the intelligent digital era, this study has explored how 3D virtual simulation technology can serve as a foundation for reconstructing the teaching pathways of Garment Construction courses through the integration of sustainability concepts. A five-dimensional integrated sustainable teaching model was developed to provide both theoretical guidance and practical application. Through literature review and pedagogical practice, the study found that Garment Construction education can, within a virtual environment, achieve more efficient resource utilization and process optimization. This not only enhances students' understanding of garment structure and process logic but also promotes the coordinated development of structural cognition, design innovation, and sustainability awareness. During course implementation, instructors employed a modular teaching framework to progressively cultivate students' cognitive transition from structural decision-making to sustainable design thinking [15]. This approach effectively strengthened students' innovative capacity, awareness of resource conservation, and ability to integrate systems knowledge across design and production processes.

Looking toward the future, teaching in Garment Construction will enter a new stage characterized by the deep integration of technology and sustainability concepts, giving rise to more diversified and flexible modes of exploration. The boundaries between professional courses will become increasingly fluid, with a greater emphasis on "application and evaluation" rather than merely "learning and doing." As virtual simulation, artificial intelligence, and big data technologies continue to advance in synergy, the key question for future fashion designers will be how to effectively utilize environmental and digital tools to enhance their own capabilities. Interdisciplinary and collaborative educational models will foster a new generation of designers equipped with both innovative thinking and ecological responsibility, thereby driving the sustainable transformation and long-term evolution of the fashion industry.

Disclosure statement

The author declares no conflict of interest.

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