

# Generative AI in Clothes Design: A Scoping Review of Workflows, Challenges, and Future Pathways

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## ABSTRACT

The clothes design and development sector is under growing pressure to accelerate workflows as product lifecycles shrink. Generative AI (GenAI), driven by diffusion models, Generative Adversarial Networks (GANs), and Large Language Models (LLMs), is reshaping this process, yet existing studies often examine individual tools in isolation, overemphasise 2D visual outputs, and largely overlook real-world production. Following PRISMA-ScR, this scoping review examines 57 peer-reviewed articles on AI-assisted clothes design from Web of Science and Scopus (2021–2026), spanning computer science, HCI, textile engineering, and design. Studies cluster in early stages: ideation (29.8%) and sketch rendering (35.1%) make up nearly two-thirds, while physical-engineering stages combined (pattern-making and fabric visualization) account for only 24.5%, with pattern-making and structural design alone at 10.5%. This imbalance reveals a visual-engineering disconnect: AI still struggles to produce production-ready structures. To synthesize these insights, the review proposes a comprehensive diagram identifying four systemic challenges, future pathways, and stage-specific design implications.

**Keywords:** Generative AI, Clothes design, Scoping review, Human-AI Collaboration, Design workflow

## INTRODUCTION

Clothes design is undergoing a systemic transformation driven by Generative AI (GenAI). In 2023, the market size of AIGC applications in the clothing sector reached USD 1.27 billion and is expected to exceed USD 5 billion by 2028 (Market.US, 2023). AI has entered fashion workflows, from design briefs to 3D virtual garments and AI Fashion Week (Rizzi and Vandi, 2026).

Academic research has examined AI-assisted clothes design through creative generation, workflow integration, engineering verification, and cultural heritage. Systems such as HAIGEN, CoCoStyle, and CrossGAI support human-AI collaboration and designer intent preservation (Jiang et al., 2024; Kim et al., 2024; Deng et al., 2024), while LLMs, DrapeNet, and AIGC-based approaches have been applied to fit diagnosis, fabric drape simulation, and ethnic garment reconstruction (Kachbal and El Abdellaoui, 2026). However, these directions remain fragmented.

Existing reviews provide limited coverage of the full clothes design workflow. They often focus on isolated technical components and early-stage visual generation, while overlooking the transition from visual concepts to physical production. Because clothes design involves fabric drape, body deformation, and sewing construction constraints, a systematic review grounded in designers' practice and covering the complete workflow remains absent (Rizzi and Bertola 2025). Therefore, this study adopts a scoping review method to examine 57 articles published between 2021 and 2026, guided by two questions:

RQ1: What design tasks does AI perform at each stage of clothes design?

RQ2: What core challenges, future research opportunities, and practical implications currently exist in AI-driven clothes design?

To address these questions, this study maps AI technologies across clothes design stages, describes human-AI task allocation, and identifies the disconnect between visual aesthetics and physical engineering, providing a cross-stage synthesis diagram and practical recommendations for human-AI co-creation.

## **METHODOLOGY**

### **Research Design**

This study adopts a scoping review method to map the research distribution of AI-driven clothes design as an interdisciplinary field, rather than to quantitatively evaluate the effects of a specific intervention (Arksey and O'Malley, 2005; Peters et al., 2020). The reviewed literature spans computer science, human-computer interaction, design, and textile engineering. The review followed the PRISMA-ScR guidelines (Tricco et al., 2018), covering literature identification, screening, eligibility assessment, and final inclusion.

### **Search Strategy**

A systematic search was conducted in the Web of Science (WoS) Core Collection and Scopus. These databases cover major journals and conference proceedings in computer science, engineering, art and design, and textile and apparel studies. The search strings combined a "technology dimension" focused on artificial intelligence and representative generative technologies with a "design dimension" covering the main stages of the clothes design workflow, including ideation, sketching, pattern-making, and textile pattern design. Equivalent search strings were used in both databases, as shown in Table 1.

**Table 1:** Search strings and initial screening results.

| Database       | Search String   | Search Fields                 | Initial Results |
|----------------|---|-------------------------------|-----------------|
| Web of Science | TS=((“artificial intelligence” OR “generative AI” OR “generative artificial intelligence”) AND (“fashion design” OR “clothing design” OR “apparel design” OR “garment design” OR “costume design” OR “fashion ideation” OR “fashion sketch*” OR “garment development” OR “pattern design” OR “textile pattern design” OR “fashion creat*”))           | Title, abstract, and keywords | 138             |
| Scopus         | TITLE-ABS-KEY((“artificial intelligence” OR “generative AI” OR “generative artificial intelligence”) AND (“fashion design” OR “clothing design” OR “apparel design” OR “garment design” OR “costume design” OR “fashion ideation” OR “fashion sketch*” OR “garment development” OR “pattern design” OR “textile pattern design” OR “fashion creat*”)) | Title, abstract, and keywords | 341             |
| <b>Total</b>   |   |                               | <b>479</b>      |

Search Date and Scope. The search was completed on April 14, 2026. Only peer-reviewed journal articles and conference papers written in English were included. No publication-year restriction was applied in advance to retain the full developmental trajectory of the field.

### Inclusion and Exclusion Criteria

The inclusion and exclusion criteria were developed based on Arksey and O’Malley (2005). Three inclusion criteria (IC) and five exclusion criteria (EC) were established, as shown in Table 2.

**Table 2:** Inclusion and exclusion criteria.

| Code                      | Criterion   |
|---------------------------|---|
| <b>Inclusion Criteria</b> |   |
| IC1                       | Studies that explicitly examine the application of AI in one or more stages of clothes design, including ideation, sketching, pattern-making, textile design, and garment visualization.                          |
| IC2                       | Studies that not only address the technology itself, but also describe, test, or evaluate its impact on design tasks, design workflows, or designer-tool interaction.   |
| IC3                       | Peer-reviewed journal articles or high-quality conference papers written in English.  |
| <b>Exclusion Criteria</b> |   |
| EC1                       | Purely algorithmic studies that focus only on model architecture optimization, such as improving GAN loss functions or increasing image resolution, without discussing their application in designers’ workflows. |

(Continued)

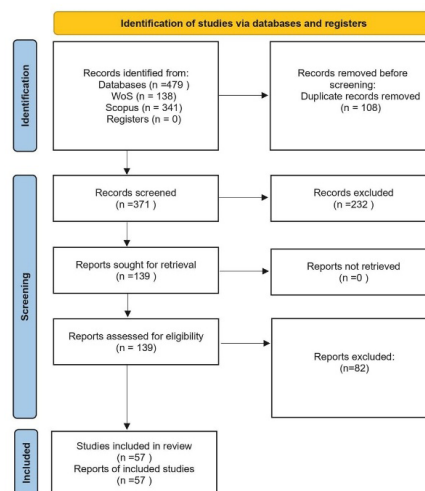
**Table 2:** Continued.

| Code | Criterion  |
|------|--|
| EC2  | Downstream business or consumer-side studies, such as intelligent recommendation systems, consumer virtual try-on, sales forecasting, inventory management, and fashion marketing. |
| EC3  | General art or design studies that broadly discuss “AI-generated art” or “AI industrial design” without focusing on clothes- or textile-specific contexts.                         |
| EC4  | End-stage production and manufacturing studies, such as sewing robot automation, fabric defect detection, and factory process optimization.  |
| EC5  | Duplicate publications of the same research output, for which only the most complete version was retained.   |

### Screening Process

The screening process followed the four-stage PRISMA-ScR procedure and was supported by Covidence. A total of 479 records were retrieved from WoS and Scopus. After 108 duplicates were removed, 371 records remained for title and abstract screening. At this stage, 232 records were excluded because they were unrelated to clothes design, were not empirical studies, or did not provide a systematic review of the field. The remaining 139 records were assessed in full text, and 82 were excluded because they lacked real design tasks, did not address workflows, or were not available in full text. Finally, 57 core articles were included, as shown in Figure 1.

The full 57-article corpus was retained as the coding dataset. The final corpus included 48 empirical studies, such as system development and user experiments, and 9 review-based studies, including 6 domain reviews and 3 theoretical frameworks. Review-based studies supported the analytical framework, while their contributions were distinguished from empirical studies in the statistical analysis.

**Figure 1:** PRISMA-ScR flow diagram of the review process.

## Data Extraction and Coding

Following the “data charting” strategy proposed by Arksey and O’Malley (2005), this study conducted structured feature extraction for the 57 included articles. The extracted items included basic metadata, AI models used, AI-involved design activities, research aims and methodological orientation, and human-AI task allocation.

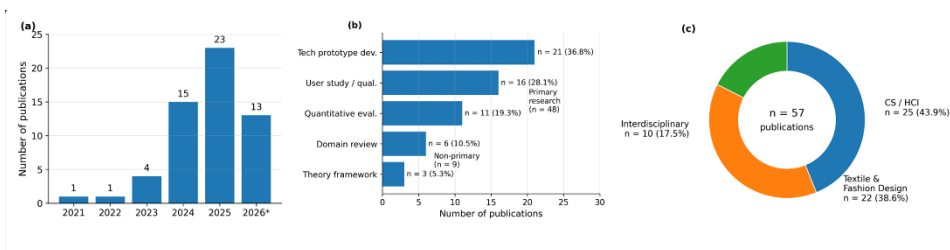
A multi-label coding scheme was adopted because the same article could involve multiple design activities or research aim types. Each article’s core contribution was used as the basis for primary classification, with secondary labels added where appropriate. The inductive process referred to Frich et al.’s (2019) classification of HCI creativity support tools. The coding results were summarized in Excel and analyzed through Python using Pandas and Matplotlib for descriptive statistics and visualization.

## DESCRIPTIVE FINDINGS

### Temporal, Methodological, and Disciplinary Distribution

The included articles (2021–2026) show a two-stage pattern: only two articles were published before 2023 (Melnyk, 2021; Lee, 2022), after which output increased sharply. Using publisher-recommended citation years, 51 articles (89.5%) were published after 2023, including 38 articles in 2024–2025 and 13 in 2026. This rise aligns with Stable Diffusion, Midjourney v4, and ChatGPT.

Empirical studies accounted for 84.2% (n = 48), including technical prototypes (43.75% of empirical studies), user studies (33.33%), and quantitative evaluation (22.92%); 15.8% were review-based. Computer science contributed 43.8% (n = 25), textile engineering and design 38.6% (n = 22), and interdisciplinary areas (including HCI and cross-disciplinary design studies) 17.6%, showing growth toward workflow integration but limited dialogue between technical evaluation and design practice.



**Figure 2:** Distribution of publication year, research type, and disciplinary field.

## FINDINGS

### AI Applications Across Design Stages: Addressing RQ1

AI research is unevenly distributed across stages (Table 3). Sketching and style rendering (35.1%) and ideation and concept generation (29.8%) dominate

the corpus, while pattern making and structural design account for 10.5%. AI is therefore more mature in visual aesthetics than in physical engineering.

**Table 3:** Distribution of articles across clothes design stages.

| Design Stage                         | Articles (n) | Share (%) | Core Functional Role                           |
|--------------------------------------|--------------|-----------|--|
| Ideation and concept generation      | 17           | 29.8%     | Information processing; visual generation      |
| Sketching and style rendering        | 20           | 35.1%     | Visual generation; execution acceleration      |
| Pattern making and structural design | 6            | 10.5%     | Structural verification; inverse mapping       |
| Fabric and visualization             | 8            | 14.0%     | Visual rendering; physical simulation          |
| Cross-stage / Integrated studies     | 6            | 10.5%     | Systematic frameworks and workflow integration |

### Stage-wise AI Functions

In ideation, AI supports trend research, creative exploration, and semantic translation. CNNs cluster runway attributes, while text-to-image models and LLMs turn abstract or cultural ideas into prompts (Choi et al., 2023; Kim et al., 2024). Yet outputs often lack sewing logic, sizing constraints, and sustainability considerations, causing rework (Rizzi and Bertola, 2025; Schneider et al., 2026).

In sketching and style rendering, AI increasingly preserves designers' personal styles rather than only producing images. HAIGEN, StyleMe, ControlNet-based tools, and StyleWe support personalized lines, shape-texture control, sketch coloring, and privacy-aware style fusion (Jiang et al., 2024; Wu et al., 2023; Wu et al., 2024a). Designers retain structural intent and final judgment.

In pattern making and structural design, AI shifts to engineering support. LLM-based fit diagnosis can identify structural issues but still misreads wrinkles and requires manual adjustments (Knisely-Medina and Jo, 2026). DeepModelA supports fast base-pattern optimization for multiple body types (Chen et al., 2026b), while DrapeNet enables physics-based drape simulation yet still requires manual calibration (Kachbal and El Abdellaoui, 2026). AI remains a diagnostic aid, not a replacement for expert pattern-making.

In fabric physics and 3D visualization, AI supports textile presentation through simulation and neural rendering. Neural-accelerated simulation and 3D Gaussian Splatting improve wrinkles, frame rates, and virtual display fidelity (Kachbal and El Abdellaoui, 2026). However, realism still depends on manual tuning and sensory judgment, and special fabrics require physical validation (Kachbal and El Abdellaoui, 2026; Chen et al., 2026b).

### Challenges, Opportunities, and Design Implications: Addressing RQ2 Limitations and Challenges

The central limitation is the disconnect between visual generation and engineering structure. Current models produce 2D images that cannot directly become production-ready flat patterns or 3D structural data

(An and Park, 2026). LLMs also lack tacit pattern-making knowledge, while complex drape remains difficult to simulate (Knisely-Medina and Jo, 2026).

Collaboration is further limited by stochastic outputs, weak local editing, and data bias. AI content can be inconsistent or faster to redraw than repair (An and Park, 2026), while datasets may encode Western dominance, cultural misinterpretation, fabric taxonomy errors, and aesthetic convergence (Chen et al., 2025b; Chen et al., 2026a; Schneider et al., 2026). Resource, copyright, and privacy risks also restrict adoption (Kachbal and El Abdellaoui, 2026).

### **Future Research Opportunities**

Future work should bridge visual concepts and manufacturing through stronger 2D-to-3D transformation, physics-based fabric simulation, and controllable multimodal interfaces for adjusting materials, silhouettes, and details while preserving personal style (Utami et al., 2026). Inclusive datasets and specialized models should reduce bias, while ethical and copyright mechanisms should support privacy, originality tracing, and adoption (Rizzi and Casciani, 2025; Schneider et al., 2026).

### **Design Implications**

For ideation and concept generation, AI should support trend clustering, image screening, and conceptual expansion while designers retain final evaluative judgment, as overreliance may narrow creative directions too early (Chen et al., 2025c; Jang, 2026). For sketching and style rendering, systems should prioritize personal-style preservation and local editability to reduce rework and protect designers' authorship (Jiang et al., 2024; Wu et al., 2023). For pattern making and structural design, AI should be positioned as a preliminary diagnostic aid rather than a substitute for expert pattern-making, because senior makers remain skeptical of LLM-based fit guidance (Knisely-Medina and Jo, 2026). For fabric and 3D visualization, digital prototypes can reduce part of physical sampling, but complex or special materials still require physical validation (Chen et al., 2026b).

## **DISCUSSION AND CONCLUSION**

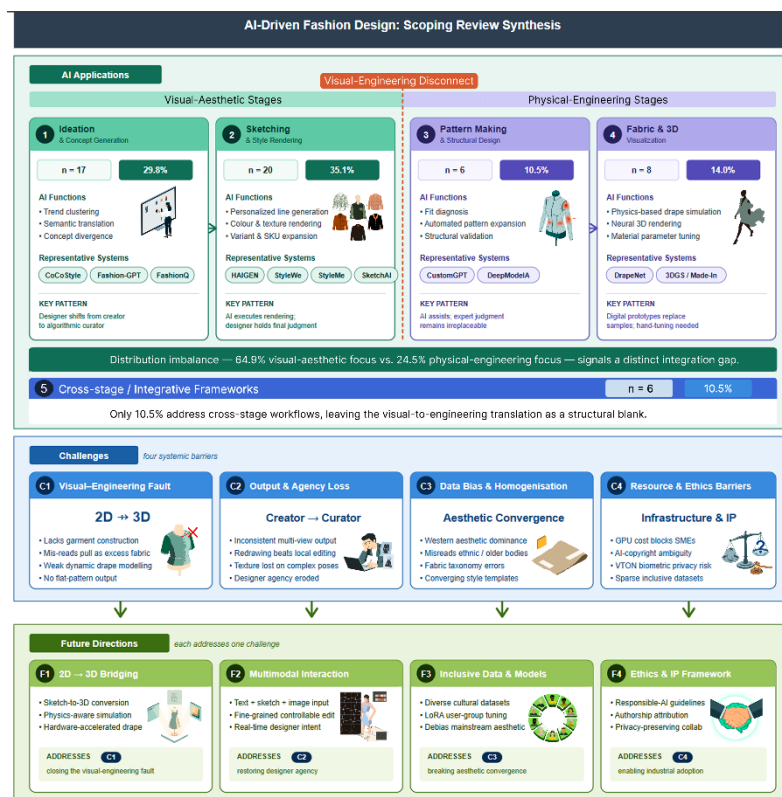
AI shows an uneven pattern of penetration in clothes design. Generative technologies demonstrate strong capacity for ideation and sketch rendering, but their involvement remains limited in pattern making, structural design, and 3D simulation, where manufacturing knowledge is required. This gap reflects a deeper technical challenge: existing models map 2D visual space effectively but lack a foundational understanding of 3D geometric topology, fabric mechanics, and sewing construction.

Figure 3 synthesizes the core findings: 64.9% of studies concentrate in visual-aesthetic stages, while physical-engineering stages account for 24.5% and cross-stage integration for 10.5%. It also links four systemic challenges to future directions, showing how technical gaps increase rework, data bias reduces designer agency, and computational, copyright, and ethical barriers

restrict industrial adoption (Kachbal and El Abdellaoui 2026; Rizzi and Bertola 2025).

As a scoping review, this study focuses on distribution and themes rather than levels of evidence or meta-analytic effectiveness. The English-language, peer-reviewed search scope may underestimate progress in industry practice, ethnic garments, and local design workflows.

Overall, the reviewed articles point to a structural mismatch between the capability boundaries of AI tools and the engineering requirements of clothes design. AI currently functions more as an uneven set of tools than as a collaborative system connecting the full workflow. Future research must move beyond screen-based visual generation and address the specific engineering details needed to support physical production.



**Figure 3:** Comprehensive synthesis diagram of stage-wise distribution, challenges, and future research directions.

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