Fashion and Textiles

RESEARCH Open Access

Developing an AI-based automated fashion design system: reflecting the work process of fashion designers

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Abstract

With the recent expansion of the applicability of artificial intelligence into the creative realm, attempts are being made to use AI (artificial intelligence) in the garment development system in various ways, both in academia and the fashion business. Several IT companies have developed and possess AI-based garment design technologies that utilize StyleGAN2 for image transformation. However, they are not widely utilized in the fashion business. Since fashion brands need to create numerous designs to launch new garment products for at least two seasons per year, the adoption of AI-based garment design generation technology can be one way to increase work efficiency. Therefore, this research aims to collect and analyze existing cases of AI-based garment design tools in order to identify the similarities and differences between the garment development processes of human designers and the existing AI-based garment design tools. Based on this analysis, the research aims to develop an AI-based garment development system that takes into consideration the garment development process of human designers, incorporating fashion domain knowledge.

Keywords: Artificial intelligence, AI driven garment development tool, Automated garment design generation tool, GAN (Generative Adversarial Networks), Fashion domain knowledge

Introduction

Artificial intelligence (AI) is one of the key drivers shaping the transformation of contemporary society alongside big data, virtual reality, and other technological advancements. The fashion industry is undergoing a transformation driven by technological innovations centered around AI (Carvalho et al., 2019; Jang & Ha, 2023; Market.US, 2023). For instance, advancements in AI technology have improved the ability to analyze big data, enabling online retailers to track consumer purchasing data and provide personalized services, thereby enhancing sales. Moreover, AI-based technologies allow for more accurate predictions of upcoming fashion trends, enabling efficient inventory management. Currently, "generative AI" technologies that generate diverse and customized outcomes are garnering significant attention. A notable example is Chat GPT; released by OpenAI,

it attracted the interest of over 100 million active users in only two months. Additionally, platforms such as DALL-E2 generate over four million images daily (Xu et al., 2023).

However, despite the fashion industry having a shorter product lifecycle than other industries, the field of fashion design has traditionally relied on designer intuition for decision-making (Dubreuil & Lu, 2020; Lin & Yang, 2019; Takagi et al., 2017). As a result, although the application of AI has evolved from analytical to generative AI, it has not been widely adopted in the field of fashion design. Experts in the fashion industry recognize the importance of AI-based garment development technology (Kim et al., 2022). Specifically, AI-based garment development technology, incorporating the design process of human designers and fashion domain knowledge, can reduce the workload of fashion designers and product planners, thus increasing work efficiency (Dubey et al., 2020).

This research aims to achieve two primary objectives. First, aims to collect and analyze existing cases of AI-based garment design tools in order to identify the similarities and differences between the garment development processes of human designers and the existing AI-based garment design tools. Second, based on this analysis, the research aims to develop an AI-based garment development system that takes into consideration the garment development process of human designers, incorporating fashion domain knowledge. By developing a system that supports fashion design generation based on an understanding of the work processes of fashion designers and the domain knowledge of the fashion industry, rather than focusing exclusively on technological development, this study will enable AI-based garment development tools to become more adaptable for practical use.

The structure of this research is as follows: First, an examination of previous cases related to AI-based fashion design is conducted. This research focuses on the cases that have emerged since the active development of conceptual studies related to deep learning-based image generation techniques. Second, the garment development processes of the collected cases are analyzed by comparing them to the garment development processes of human designers to thus propose an AI-based garment development system that incorporates fashion domain knowledge. Third, an AI-based garment development system is developed using StyleGAN2, and a pilot program is developed to evaluate its satisfaction among industry designers. Finally, the research findings are discussed, highlighting their implications for industry, and some recommendations for future research are provided.

Literature Review

Garment development process and fashion domain knowledge

The garment development process is a special problem-solving activity that comprises a series of small steps in which a designer explores a problem (Schoen, 1983). It is the process of designing, planning, and developing saleable products reflecting their brand identity and the relevant season's concept for the target consumers (Clodfelter, 2015; Kincade, 2010; Lee, 2004). Many studies have found that the garment development process of human designers sequentially and simultaneously undergoes several stages: analysis of the brand's internal data (i.e., sales review) and global fashion trends, concept

formation and design ideation, design generation and modification, and design finalization (Evans, 2014; Lamb & Kallal, 1992; Watkins, 1998).

The purpose of this study is to develop an AI-aided design tool optimized for fashion brands owned by a producer or distributor. Based on previous research, the following five processes comprise the most optimized garment product development for fashion brands (Evans, 2014; Lamb & Kallal, 1992; Watkins, 1998): (1) analyzing internal/external data, (2) determining the concept to be the season's direction, (3) generating garment design according to the season's concept, (4) modifying the newly generated design, and (5) finalizing the garment design.

Fashion brands generally begin garment design development half a year or a year before the start of their product sales season (Blaazer, 2022; Lee, 2004). When developing garment products, fashion brands consider and analyze two main sources of information: internal brand data and global fashion trends (Clodfelter, 2015; Jackson & Shaw, 2017; Kincade, 2010). Internal brand data refer to past sales data, best-selling brand items, consumer data, or other relevant information (Testa & Karpova, 2022). The entire garment development team reviews the performance in previous seasons, including the previous year, to identify key trends that have contributed to profitability (Jackson & Shaw, 2017). Products that performed well in the previous season are likely to impact sales in the next season, making it crucial to review them (Ha-Brookshire, 2015; Jackson & Shaw, 2017; Kunz, 2010). Furthermore, for garment product development, global fashion trends are reviewed based on the runway collections of high-end brands. Runway collections are essential trend information and serve as significant factors in garment product development among mass fashion brands (Choi et al., 2021; Zhao & Min, 2019).

Next, it is necessary to plan the season's concepts. This stage involves determining the overall theme and mood of the whole garment design (Caniato et al., 2015; Clark, 2014). Since a fashion brand needs to create 20–30 pieces of garments per season, establishing a concept is crucial to ensure consistent designs across any season (Clark, 2014; Lee & Jirousek, 2015). Hence, garment design involves generating and modifying garment designs that reflect the brand's identity and seasonal concept (Caniato et al., 2015). This step focuses on generating a garment design and modifying the newly generated design to find an alternative design. Finally, through evaluations by merchandisers, shop managers, and other relevant stakeholders in the fashion brand, the finalization process entails selecting designs suitable for the brand's sales in the respective season (Evans, 2014).

Meanwhile, domain knowledge refers to the valid knowledge in a specialized field of study or industry (Choi, 2017). Although the development and introduction of new technologies are replacing many aspects of human factors, domain knowledge plays a critical role in setting the direction for any industry (Muralidhar et al., 2018). In the garment development process, this domain knowledge includes brand identity, past sales data, brand design characteristics, bestselling items and consumer information (Chen et al., 2012; Lee, 2004). In fields such as fashion, where human 'intuition' or 'sense' is highly involved, modeling domain knowledge based on human designers can enhance AI-based design processes.

AI-based garment design generation technology

Recently, AI in fashion garment design has evolved from image recognition and synthesis to image generation (Anantrasirichai & Bull, 2021). The beginning of research on the AI-based garment design process dates back to the early 2000s. Initially, garment design studies that incorporated AI used genetic algorithms (GA) that favor the evolution of the information of the previous generation, such as the genetic phenomenon of an organism, and pass this information on to the next generation. In other words, research was conducted to combine the design attributes of fashion products that have already been released and to suggest new styles (Khajeh et al., 2016; Kokol et al., 2006). The previous researches described garment design as a process that involves making various choices by combining different design attributes. Later, some studies found the location of fashion items in photographs using computer vision. This identification was made by improving machine learning performance (Hara et al., 2016; Lu et al., 2022), determining item categories and design attributes (Akata et al., 2013; An et al., 2023; Jang et al., 2022; Ji et al., 2018; Wang et al., 2018), and identifying similarities among designs (Ay et al., 2019; Ma et al., 2020; Tuinhof et al., 2018).

GAN has recently attracted attention in the research on AI-based garment design. The GAN model is an unsupervised deep learning method that generates or edits new fake images. A GAN is composed of two neural networks, namely, a generator and a discriminator, which compete against each other to improve the generation quality (Goodfellow et al., 2014). First proposed by Goodfellow et al. (2014), various derivative GAN models have since been introduced, enabling the editing and easy generation or synthesis of images. Hence, various research cases have emerged in the field of design (Raffiee & Sollami, 2021; Rostamzadeh et al., 2018).

GAN is used in the fashion industry to generate new designs or modify specific parts of the design (Liu et al., 2019), create graphics printed on clothing (Kim et al., 2017; Raffiee & Sollami, 2021; Rostamzadeh et al., 2018), and achieve a fusion of mixed semantic styles (Zhu et al., 2020). In addition, Disco GAN technology has been developed and advanced such that AI identifies the characteristics between different object groups and learns the relationship between the two to modify the design (Kim et al., 2017). For Disco GAN, if the image of a handbag is designated as the input value and the image of a shoe is designated as the output value, a new shoe design can be generated by identifying the image characteristics of the handbag and applying them to the shoe (Kim et al., 2017). StyleGAN and StyleGAN2 are algorithms optimized for fashion image generation. They consider image composition as a combination of styles and synthesize images by applying style information to each layer of the generative model. Models utilizing StyleGAN or StyleGAN2 can control network architecture and styles while generating clothing images, thus enabling the editing of garments for specific attributes (Lewis et al., 2021).

Methods

This research analyzes existing AI-based garment design tools and develops a new AI-based garment development system specifically designed for the fashion industry. As shown in Table 1, the entire process of the research was divided into three stages:

Table 1 Stages in the development of AI-based garment design tool

Stage	Content	Method
Requirement analysis and system design	– Compare the garment development process between existing AI-based design tools and human designers based on the literature review – Identify problems *Suggest an AI-based garment development system*	Case study
System development and Implementation	*Development of AI-aided design process* – Data Collection for Training (Yoox, Net-A-Porte, Vogue, Tagwalk) – Algorithm design – Training of an image generation model based on StyleGAN2 – Front-end Development	Fashion image generation model development based on StyleGAN2 – iteration: 200,000 (=4 epochs) parameters: 28.27 M
Pilot test	– Survey on image and system quality satisfaction	Survey

Requirement analysis and system design

We conducted a case study by collecting examples of AI-based fashion design tools that have been utilized in practical applications. As garment design plays a significant role in the process of garment developing, we determined the need to gather and analyze cases of AI-based garment design tools to build an AI-based garment development system. Therefore, we compared the cases with the garment development process of human designers as a benchmark and derived commonalities and differences. On the basis of the analysis results, we proposed a new system that fashion designers can use in their practical work. Currently, AI-based fashion design processes are not widely used in the industry, the evaluation of the level of development varies (Kim et al., 2022). Thus, we concluded that qualitative research on the current state of technological development must be conducted. The research procedure for the case study is as follows.

Data collection

We explored articles and papers to extract information on IT companies with AI-based technologies for garment design generation. We collected articles published since 2018 by searching keywords, including "AI-based fashion design," "AI fashion design tool," and "AI fashion design process," on the web portal 'Google (www.google.com)' in English and 'Naver (www.naver.com)' in Korean. Naver, the largest local search engine in South Korea, is optimized for retrieving information in Korean. We used Korean keywords for searching on Naver and English keywords for searching on Google. Additionally, we searched Google Scholar using the same keywords in both Korean and English to collect papers published since 2018 that included cases of AI-based garment design tools. As a result, we collected 13 cases from a total of 28 relevant articles and two papers, excluding duplicate articles.

Next, we excluded AI-based garment design tools that are still in the development stage or have not been commercialized. Ultimately, nine AI-based garment design tools with a history of commercial utilization were selected for analysis. The selected companies (tool names) include ETRI (AI Fashion Market Platform); Designovel (style AI), LG (AI artist Tilda); Google and Zalando (Project Muze); Amazon (Lab126); Google, H&M,

and Ivyrevel (Coded Couture); Stitch Fix (Hybrid Design); YNAP (8 by Yoox); and OpenAI (Dall-E2).

Coding and data analysis

Each case was analyzed using the collected data. Four doctoral-level researchers in the field of fashion examined the original texts of the collected articles and conducted a constant comparison analysis. The five-step garment development process of human fashion designers presented in previous studies was used as a comparative criterion. Through this criterion, the commonalities and differences between AI-based design processes and human designers were explored. The researchers coded and classified the design processes of nine AI-based garment design tools. In cases where the researchers' opinions did not align, additional search processes were conducted by setting the respective tool as a search keyword, followed by coding.

System proposal

On the basis of the analysis of the case studies, a new AI-based design system was designed. The system design involved the participation of four fashion researchers and three computer engineering researchers. Through approximately six months of continuous discussions, a user-centered (designer-centered) workflow, which could be integrated with the garment development process of human fashion designers, was designed. Then, a system consisting of four modules was proposed.

System development and implementation

An AI-based garment development system based on StyleGAN2 was developed by computer engineering researchers. The StyleGAN2 algorithm has demonstrated superior diversity and image quality in the generated outputs. In view of these findings, the researchers chose to employ the StyleGAN2 algorithm as the cornerstone for their AI-based garment development system. In particular, the system model was trained using dress and skirt images, which are well suited for exploring various silhouette variations. To train the model, a dataset of 52,000 images was collected from 168 leading fashion brands obtained from international fashion retail platforms, such as Yoox (www.yoox.com), Net-A-Porte (www.net-a-porte.com), Vogue (www.vogue.com) and Tagwalk (www.tag-walk.com). Subsequently, a model was developed to learn the distribution of the training images and generate new fashion images by adding noise and generating image variations. The trained model enabled coarse style variations in silhouette elements, such as full length, sleeve length, and neckline, in the early stages and fine style variations, such as color, pattern, and print, in the later stages.

Pilot test

To evaluate the developed service, a pilot test was conducted with a diverse group of 8 designers in South Korea, including women's clothing designers from small and medium-sized enterprises (SMEs) and large corporations, as well as designers from apparel vendor companies. Prior to the pilot test, a snowball sampling method was used to select designers who wished to review the service. Taking into account their expertise and company size, a final group of 8 users was chosen. They used the service for a period

Table 2 Case study results of AI design generation model versus human design process

AI design generation model	Human design process					
	Data analysis		Determination of the season's concept	Design generation (method)	Design modification	Design finalization
	Internal data (brand internal data)	External data (global fashion trends)				
AI Fashion Market Platform	X	◯	X	◯ (GAN)	X	X
style AI	X	◯	X	◯ (GAN)	◯ (GAN)	X
Tilda	X	X	◯	◯ (GAN)	X	X
Project Muse	◯	X	X	◯ (Trained neural network)	X	X
Lab 126	X	X	X	◯ (GAN)	◯ (GAN)	X
Coded Couture	◯	X	X	◯ N/A (not applicable)	X	X
Hybrid Design	◯	◯	X	◯ (GAN)	X	X
8 by Yoox	◯	◯	X	◯ (N/A)	X	X
Dall-E	X	X	X	◯ (Diffusion model)	◯	X

N/A not applicable

of 10 days in mid-December 2022. Then, the researchers conducted interviews and brief postservice surveys. The measurement items included the participants' perception of the service quality before and after usage, evaluation of the design outcomes, and intention for continuous usage. Respondents indicated the degree to which they agreed with the statements using a five-point Likert scale (1 = "strongly disagree" to 5 = "strongly agree").

Results and Discussion

The result of case study

The nine AI-based garment design generation tools selected in this study are summarized in comparison with the human designers' development process (Table 2). An "X" mark indicates that the tool does not include the stage of the human garment development process, and an "O" mark indicates that it includes the stage. Specific commonalities and differences are described later.

Garment designers spend extensive time in internal and external data research (Clodfelter, 2015; Jackson & Shaw, 2017; Kincade, 2010). The internal data analysis stage appeared in four out of nine cases. To support efficient design generation in a mass production preplanning system, the brand's internal data must be incorporated. Most of these profiling data pertain to customers and are primarily utilized in the form of recommendation services to enhance consumer experiences. This aspect constitutes only a portion of the personalization service that "recommends" designs to consumers, thus causing difficulty in claiming that it is primarily aimed at "generating" designs for mass production. For instance, Stitch Fix's Hybrid Design and YNAP's 8 by Yoox analyze and incorporate customer data, such as user lifestyles, to generate personalized designs for users.

Some AI-generated design tools also provide external data research and analysis. Global fashion week data, social media fashion data, and social media influencer data can be included in external data. The AI Fashion Market Platform (ETRI), Style AI (Designovel), 8 by Yoox (YNAP), and Hybrid Design (Stitch Fix) support design generation based on external data (i.e., social media influencers` fashion data) research and analysis. The AI Fashion Market Platform (ETRI) generates garment designs in light of domestic trends reflected on social media, while YNAP's 8 by Yoox reflects the trends by analyzing and showing clothes that social media influencers prefer (Melton, 2018). However, they have limitations in that they analyze and provide trends without considering the brand identity or brand concept for the season in the external data analysis.

Second, many AI-based design tools lack the stage of concept formation. The development of season concepts is reflected only in the case of Tilda. Tilda generated approximately 3000 inspiration images for the design theme presented by the human designer (LG AI Research, 2022). As the development of the designs is led by technology without design development knowledge, such as brand profiling, season trend analysis, and concept decisions, which affect the direction of learning and design, users may conclude that AI's design ideation is less brand specific.

Third, models for design generation and modification were provided with a focus on image composition and text-to-image composition using GAN in half of the cases. Some technologies (e.g., Coded Couture; Dall-E2) are image-generation technologies that simply convert text into images rather than AI technologies that creatively generate garment designs (Lee, 2018; Oh, 2021). In addition, although designs that are generated on the basis of the serendipity of AI-based fashion design look creative, they remain limited because they require modification by human designers to be used as commercial designs. However, only three cases allowed modifications after the generation of garment design images. Last, not all cases included the finalization process.

In summary, compared with the garment design development of human designers, the biggest drawback of existing AI-based garment design development tools is the difficulty in accurately reflecting the designer's intentions. Such tools that are currently being developed and used focus only on trend analysis and image generation. This limitation has led to a nonholistic view of AI-based garment design tools developed in the fashion domain and has raised the need to generate a tool that reflects knowledge in the fashion domain.

Suggestion of AI-aided design process

Garment design is a complex and cyclical process in which various thinking methods are continuously and simultaneously applied in each stage of the design process (Evans, 2014). However, through analyzing the cases, researchers have found that the AI-based garment design tools commercialized thus far do not cover the comprehensive process from the perspective of human designers. Therefore, this study proposes an AI-based garment development system that reflects fashion domain knowledge. We advance an AI-based garment development system that integrates the human-based design process as follows (Fig. 1). The system consists of four modules, integrating five stages of the garment design process. Detailed explanations for each module are provided in the following section on system development and implementation.

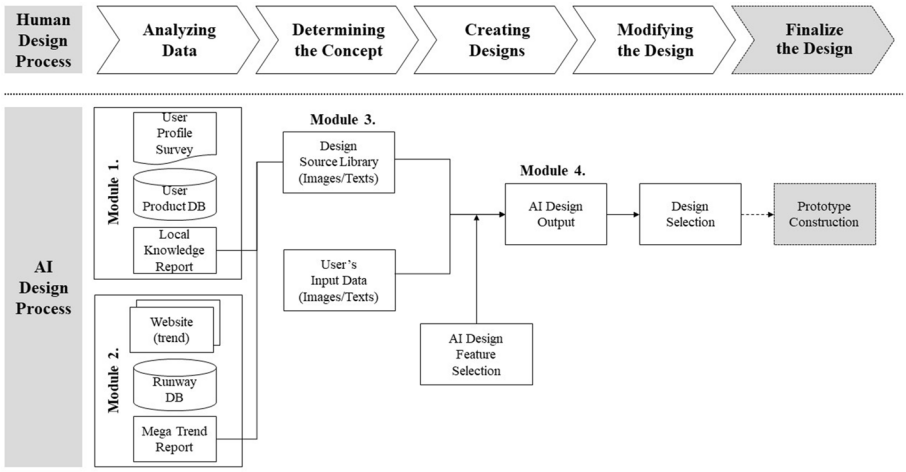

Fig. 1 AI–human collaborative garment development system

Development of AI-aided design process

Module 1 and Module 2 involve the collection and analysis of internal and external data, respectively. Module 1 builds a dataset based on the brand's internal data, while Module 2 extracts external information. In addition, Module 3 functions as a design source database, serving as a repository where users can store necessary keywords and images during the garment design process. Module 4 generates garment designs and modifies the garment designs. Considering that the garment design process is simultaneous and repetitive, the process was designed for users to organize the process freely depending on the purpose, such as changing the order of the module with key functions according to the user's needs or removing an unnecessary module.

Module 1: building a database of the company's internal environment

A system was designed to analyze and integrate the brand's internal data, thus enabling the inference of brand concepts and designing intentions from the brand's own product data. Users are prompted to upload brand-related data directly when they first start using the system. Then, users upload images related to the brand and reference images used during garment development. These images can be uploaded manually by users or automatically collected through a crawling robot by entering the website address of the shopping mall or social media platforms managed by the company. Upon uploading a product image, an automated tagging system labels the design features and automatically generates and stores product information in the database. In addition, a brief profiling survey is conducted in which users are asked to select brands similar to their own brand from domestic and global fashion brand lists. All of these processes are optional, thus allowing users to skip them without any hindrance in utilizing other modules. The collected information is utilized as a weighting factor during the generation of garment designs for user brands. Once the input of basic information regarding the brand's internal environment is completed, the system extracts the typical design factors associated with the brand's design and incorporates them into the garment generation process.

To implement Module 1, technology is needed to identify the design features of garment products in images and label them in text format. To accomplish this step, computer vision and natural language processing (NLP) techniques are employed to preprocess and structure internal data, encompassing extensive unstructured image and text data. Generally, internal databases contain various, large-scale, and unnormalized data, which can be obstacles to utilizing AI techniques. Before applying advanced image/text content analysis techniques, building a database can be helpful. For example, auto labeling (Cheng et al., 2018) techniques can extract style keywords (e.g., "casual," "modern") and objective attributes (e.g., "turtleneck," "puff sleeves") from fashion images. NLP techniques can also be utilized to process unstructured text data to reduce the incompleteness of the database.

Module 2: global runway trend extraction

Module 2 was designed to analyze fashion trends based on runway collections and provide trend keywords associated with specific seasons or design attributes. This module visualizes prominent design keywords in ready-to-wear (RTW) and haute couture based on runway shows held twice a year: Spring/Summer (S/S) and Fall/Winter (F/W). The design features of a particular runway brand serve as important design references for mass-market fashion brands (Jang et al., 2022). Therefore, rankings must be derived on the basis of seasons and major keywords.

Runway data can be automatically collected using the brand name on TAGWALK (www.tag-walk.com) or the official US website of Vogue (www.vogue.com). Then, the data can be saved on the trend database. The saved images are turned into labeled data with major design features through the computer vision technology mentioned in Module 1. In addition to the frequency of extracted keywords, comparisons with the same season in the previous year and the last season are provided. Keywords with high interest can be moved to the design source of Module 3. Again, global runway trend keywords are stored together with relevant images.

Module 3: design source database

The design source database is a function that can save and manage keywords and images selected by users. All keywords and images directly entered by the user in Module 1 are also stored in Module 3. Then, users can use them as needed. The users can freely organize the dashboard by season, item, or design features depending on the purpose. Moreover, the users' convenience can be increased by separately storing the sources required for future design generation. Module 3 must further implement a feature to search associated images by selecting one or more design keywords. In addition, a user interface must be implemented to facilitate the retrieval of information (keyword or image) stored by the user according to the user's purpose. This module allows users to gather keywords and images stored in the database on the basis of their needs. As a result, the module serves as a mood board in the garment design process and facilitates the establishment of season concepts.

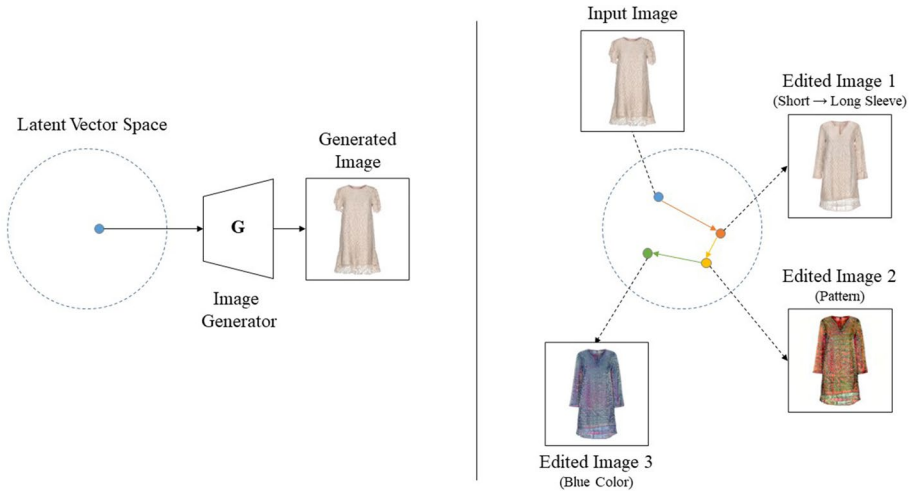

Fig. 2 AI techniques for image generation and editing (all images are generated by artificial intelligence)

Module 4: design feature combination and GAN-based garment design generation

In Module 4, users can not only upload or retrieve new images from the design source library (Module 3) to generate a new garment design but also modify their own designs or the generated designs within the available options presented by the system. Users can modify various design features, such as color, silhouette (fit, length), pattern and prints, and detail features.

Furthermore, users can repeat this process as many times as they want until they are satisfied. Then, they can obtain new inspiration from the AI-generated images. They can also use the design as it is or transform the details or colors for a better design. Moreover, users can generate or transform images by uploading their own brand in Module 1 to ensure that they obtain results that reflect their input. Among the generated images, an image selected by the user can be included in Module 3. Even when the image is not selected, the system can ask users why they did not store the image, thereby recording enhanced personalized preference results. The accumulated personalized data may be associated with the elaboration of the image generation result. The images finally generated can be shared with users and people with registered accounts related to the brands for evaluation. This step corresponds to the finalization stage of the human design process.

To implement Module 4, an image generation model, namely the GAN model called StyleGAN2, was employed (Karras et al., 2019, 2020, 2021). Once the image generation model is trained with a large set of training images, the model can generate a wide range of synthetic but photorealistic fashion images. Furthermore, the design features of the generated garment images can be finely modified, including the silhouette, color, patterns, and prints (Patashnik et al., 2021; Shen et al., 2020; Wu et al., 2021). Figure 2 presents an overview of the AI-based garment design framework, which utilizes the StyleGan2 model. As shown in Fig. 2, the recent image editing technique can support various user-specified cues, such as silhouette (length), pattern, and colors. Furthermore, Fig. 3 shows an example of images generated using the AI techniques mentioned in Fig. 2.

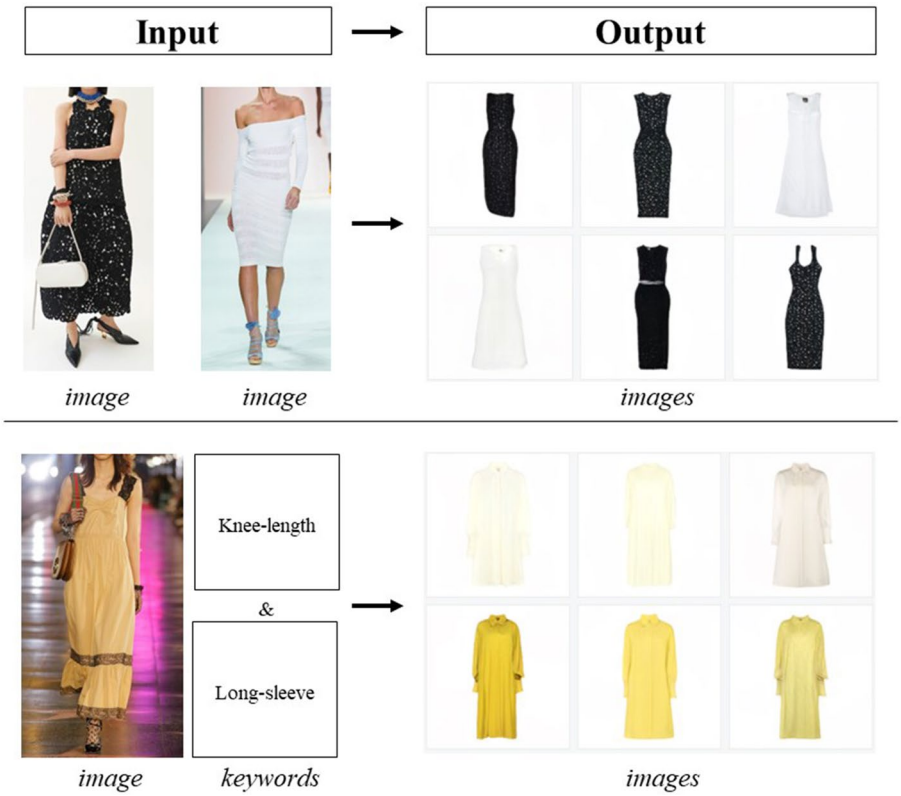

Fig. 3 The example of fashion image generation and editing Note. top-left image: From Look 3 [Photography], by Jil Sander, 2022, Vogue (https://www.vogue.com/fashion-shows/resort-2022/jil-sander/slideshow/collection#3). Note. top-left image: From Look 48 [Photography], by Daniele Oberrauch, 2022, Vogue (https://www.vogue.com/fashion-shows/spring-2022-ready-to-wear/sergio-hudson/slideshow/collection#48). Note. bottom-left image: From Look 44 [Photography], by Gucci, 2022, Vogue (https://www.vogue.com/fashion-shows/spring-2022-ready-to-wear/gucci/slideshow/collection#44. Accessed 2 August 2022)

Pilot test of AI-based garment development system

The research team created a front-end program to enable fashion designers to evaluate both quantitative and qualitative performance through access to the AI-based garment development system. As a result of the quantitative performance indicators of the design generation system, the inception score (IS) was 7.40, image reality score was 3.76, response time of the design generation was 1.02 s/req, and processing rate of the design generation was 58.4 req/min. Next, following Nielsen's usability test guidelines (Nielsen, 2012), a pilot test was qualitatively conducted with 8 fashion designers in this study. The results showed that the participants' expectations for the quality of the AI-generated garment design images were rated at 2.44 before using the AI-based garment development system. However, after using the system, the satisfaction with the AI-generated outcomes increased to 3.81, thus indicating that the final design results demonstrated high completeness and exceeded the participants' expectations.

Conclusions

Garment design undergoes the comprehensive process of building the season concept by considering both global fashion trends and brand merchandising knowledge, going through design ideation based on the above, concretizing, and ultimately creating the design (Evans, 2014; Lamb & Kallar, 1992). If even one of these processes is omitted, a design with commerciality and brand identity can be difficult to develop. Although nine AI-based design generation solutions have been advanced thus far, they have focused only on the advancement of fashion trend analysis and automatic fashion image generation technology. The lack of intermediate stages in the garment development process leads to the absence of a holistic view of garment design (Kim et al., 2022). Thus, this study attempted to develop and propose an ideal AI-based garment development system by comparing the design process of human designers with the AI design process. The research on developing an AI design system that reflects the perspective of fashion designers is particularly relevant and timely, given the rapidly growing importance placed on advancing generative AI technologies (Market.US, 2023). Furthermore, by surveying the satisfaction of fashion designers, the potential usability of the proposed system has been confirmed. On this basis, the academic and practical implications of this study are as follows.

First, in this study, computer science and fashion fields were efficiently integrated, thus leading to the implementation of an AI-based garment development system that can yield highly effective results. To ensure the practical application of technology in the industry, the technology must be closely aligned with industry-standard processes (Caruelle et al., 2022; Jarek et al., 2019). While AI cannot fully comprehend the intuition of human designers, AI design tools can assist human designers by learning domain knowledge and being designed according to the design processes commonly followed by human designers (Dubey et al., 2020; Song et al., 2022). In this way, AI systems can be incorporated into the work environment and support human designers effectively. In this sense, this study holds academic and practical significance because it analyzed existing cases of AI-based garment design tools and developed an AI-based garment development system that incorporates fashion domain knowledge. Most research in the fashion field related to AI technology has remained at the stage of case analysis. However, the current study stands out by collaborating with computer science researchers to design a new system and implement it at a practical level, thus demonstrating its academic importance. Furthermore, generative AI has currently gained significant attention. Generative AI can produce images or music that reflects the user's intent with simple prompts (Hsu & Ching, 2023; McCormack et al., 2023). The significance of the developed system in this study lies in its ability to generate results that incorporate the user's intent. Finally, by allowing real fashion designers to use the system and evaluating its usability, this study confirms the practical significance of the developed system and its potential for practical application.

The following limitations exist in this study, and we would like to suggest further research to supplement them. First, we developed an AI-based fashion design system using Style GAN2 as the main algorithm. However, since we did not compare and analyze image generation performance because we focused on the algorithm development process, subsequent studies need to supplement this. Second, while GAN model is a

crucial technology for image generation and has been actively used in garment design generation, Rostamzadeh et al. (2018) explained that the quality of the dataset affects design image generation when creating garment designs using GAN. Therefore, the data source must be obtained in such a way that designs of various conditions can be learned. Third, the AI-based garment development system developed in this study has a limited image resolution. This limitation poses challenges for fashion designers in manipulating and utilizing the images. However, recent advancements in diffusion models have significantly improved (Li et al., 2022), enabling the transformation of low-resolution images into high-resolution images. By incorporating such neural networks, the system's utility can be enhanced. Fourth, the current system focuses only on dresses and skirts. In the future, expanding the training set to include a wider range of item categories (e.g., outer, pants, etc.) will allow for the broader application of the AI-based garment development system.

Acknowledgements
Not applicable.

Authors' contributions
WJC, SJ, and HYK designed the study and developed the theoretical framework, collected and analyzed the cases of Ai driven design tools, designed the module, and wrote the manuscript. YL guided the development of the theoretical background, results, and conclusion, and revised the manuscript. SP, S-GL and HL gave advise on designed module. All authors read and approved the final manuscript.

Funding
This work was supported by the Institute of Information & Communications Technology Planning & Evaluation (IITP) full name funded by the Korean Government (2021-0-00302, AI Fashion Designer: Mega-Trend and Merchandizing Knowledge Aware AI Fashion Designer Solution).

Availability of data and materials
The datasets used and analyzed during the current study are available from the first author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Received: 20 December 2022 Accepted: 14 September 2023
Published online: 25 October 2023

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