DESIGNER'S PERSPECTIVE OF DIGITAL KNITTING: from fashion design to wearable technology

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Abstract

This paper recommends that digital knitting as an integrated textile-based design and development process not only reforms the framework of conventional fashion and textile design but also offers an alternative pathway towards the innovative construction of advancedwearable technology. From a designer's perspective, the transitional role of digital knitting in these two fields is illustrated, analysed, and compared. A practice-based methodology is indicated for the development of both fashion design and wearable technology through the digital knitting process, in which the positive character of a designer is especially highlighted.

First, the concept of digital knitting is described. The general work procedure and the advantage of digital knitting are explained. Second, the relevant research regarding digital knitting design is reviewed. The examined cases are generally grouped as fashion design through the application of digital knitting and wearable technology using the digital knitting process. The design proposes, work process, and outcome of each reviewed case are compared. The general frameworks of each group are additionally shown and concluded.

Third, the original practice-based research work is presented. A technical-led fashion design practice utilizing digital knitting as an integrated process for the creation of both textile and garment is exhibited. Then, a design-led wearable technology exploration using digital knitting as digital fabrication and additive manufacturing method is also demonstrated as preliminary research work.

This paper introduces brand-new thinking of utilization of digital knitting as a transitional bridge for both techno-led fashion design and design-led wearable technology development. The recent and classic research cases are examined from a comparative viewpoint. The empirical experience of two practice-based projects with completely different orientations offers innovative and reasonable insights for future relevant research and practice, especially for a practitioner with design backgrounds.

Introduction

The topic of this paper is that digital knitting makes a positive contribution to both design creation and technology innovation through playing different roles in the research process. There is also interaction and relationship between techno-led fashion and textile design and design-led wearable technology development. They have reciprocal impacts on each other.

It is known that design cannot be separated from techniques or technology and designer are required to be occupied with techniques or technology to realise their design ideas (Matković, 2010). However, with the progress of society and the refinement of disciplines, the gap between art design and engineering technology is increasing larger. The high precision of machines and the high complexity of technology make it very difficult for designers to master and manage technology. The technical skills gaps prevent the ideal of a designer-maker. At the same time, knitting as one traditional textile manufacturing method has attracted more and more attention in recent decades. It is because of its cross-border applications in other scientific research fields, especially in the direction of wearable technology. Therefore, knitting now spans the traditional textile and clothing industry and modern electronic devices. However, this advanced research area is often dominated by scientists due to its technical complexity, and the proportion of design is very limited. How to make designers find another pathway to carry out innovative research in this field is a focus worthy of discussion. The emergence of a digital knitting design system seems to bring hope to this dilemma to a certain extent. From the designer's point of view, a digital knitting system links the design content and engineering content in a visualised method, so that the designer can easily carry out technological design and has the opportunity to understand the technology in the design process (Eckert, 2001).

This paper gives a brief understanding of digital knitting and its roles in the different research areas. First, the general explication of the concept of digital knitting is presented. Second, a literary review regarding digital knitting applications is presented. Finally, some original practice-led studies are introduced. It aims to generate a possible method based on a designer’s viewpoint for developing both fashion design and wearable technology using the digital knitting process.

Knitting and digital knitting

(1) General information on knitting

Knitting is a conversion system in which yarn loops are intermeshed to form a fabric (Raz, 1993). A continuous length of yarn structures the basis of knitting, and a knitted loop is the basic unit of each knit. Commonly, there are three construction types of knitted loops, including weft knitting, warp knitting and crocheting. The first two are widely used in industrial mass-production for various textiles and clothing, while the latter type is normally handmade. Among various knitting technologies, V-bed flat knitting has the most superior design flexibility and creative possibility.

(2) Concept and feature of digital knitting

Digital knitting generally refers to the knitting technology that seamlessly connects knitting design and production process through comprehensive digitisation. In comparison with the common concept of computerized knitting, one of the most significant features of digital knitting is its super-powerful and friendly knitting design program. Developing from a designer's perspective, the digital knitting design system is highly embedded in the entire knitting process. The generated design file from the knitting system not only provides comprehensive design information, such as pattern and colour combination but also enclosures essential setting data for various digital-controlled devices in the machine, such as knitting bed racking and take-down method. A perfect design document equals successful cooperation of design ideas and engineering data. Therefore, the digital knitting process is gradually altering the leadership of knitting development from engineering thinking to design thinking. This lays a foundation for the difference between digital knitting and other knitting technologies. Therefore, it also can be said that digital knitting marks that the evolution of knitting is about to enter a brand-new stage. Different types of knitting are involved in the trend of digitalization through different pathways. The digital knitting system for V-bed flat knitting is the distinctive one among all of them. Since the design-led nature of the digital knitting system is well suited to the variable attribute of V-bed knitting, the enormous design opportunities and creativities are possible to be stirred up infinitely. The digital knitting discussed in this paper is mainly concentrated on digitalized V-bed flat knitting.

The typical digital knitting system for V-bed knitting includes APEX from Japanese company SHIMA SEIKI and M1 plus from Germany company Stoll. Both companies are the major manufacturers in the world for flat knitting machines. And they have developed their design system for their machines. Although the specific software development logic is comparatively different, the general components of these two systems are the same. If using APEX as an example, it can be noticed that there are various design platforms with different functions combined in one system. Among them, the KNIT program is used for knitting development, including designing a variety of stitches and patterns, while the DESIGN program is used to assist the design procedure, such as picture preparation. It is worthy to point out that, in this design system, various coloured squared incorporate special knit notations that denotes both the knit stitch structure and the mechanical operation. This fundamental programming philosophy originated the design-led attribute of digital knitting, using a visual and easy method to represent complex engineering contents.

The conventional workflow of such a digital knitting system consists of two main takes, including (1) creating and exporting a knit file by using the provided apparel designs system, and (2) executing the generated file and producing a knit on the digital knitting machine (Yan, 2021). This synthesise empowers a seamless dialogue to occur between design programming and technical engineering. All knitting information is integrated into a data file and conveniently transferred to the knitting machine.

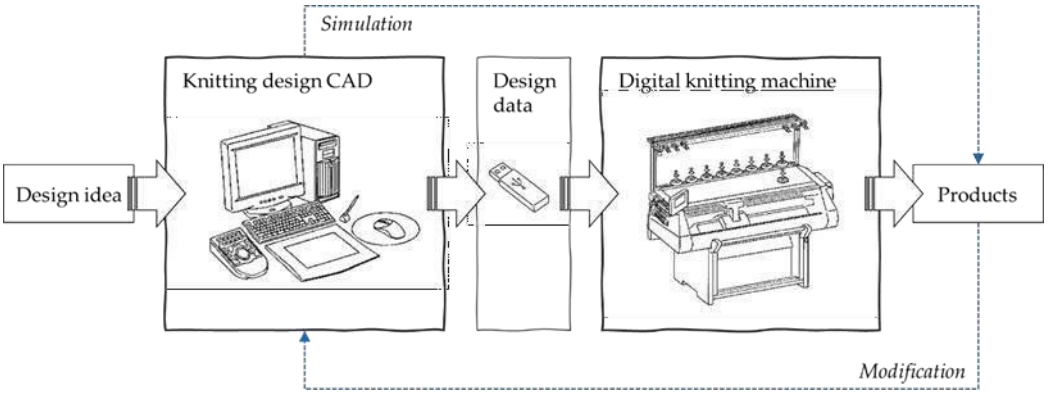

Figure 1. The conventional workflow of a digital knitting system

Moreover, another critical highlight of the workflow that involves a digital knitting system is that the visual simulation programming, which can offer highly accurate virtual samples and digitise interaction. This function completely alters the conventional development process of knitting. It can automatically check and simulate the entire knitting process on the machine before real production avoiding a vast amount of waste material, time, and human resources. At the same time, this digitalised function provides an efficient way for designers to understand certain mechanical principles and procedures that can greatly help for improving design effects and generating new design ideas. Therefore, it paves the way to designer-led creations and innovations through the application of advanced technologies.

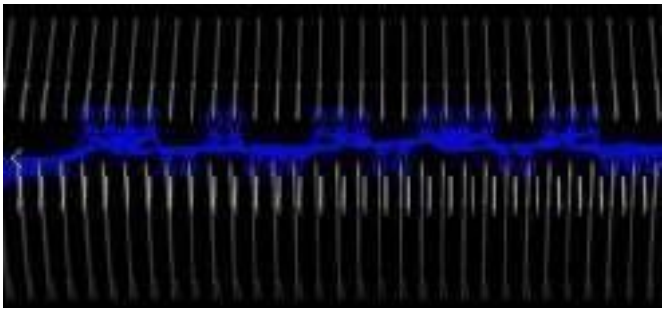

Figure 2. An example picture of knitting simulation using APEX 3 knitting design system

Due to these features examined above, digital knitting addresses many researchers' attention, not only from the arena of textile and clothing but also from other different disciplines, such as computer science, electronic engineering, and health care. The relevant research and applications precisely prove the huge potential of digital knitting in emerging novel technologies and building future lifestyles.

Research regarding digital knitting

The reviewed research concerning digital knitting and its applications are generally classified by (1) fashion and textile design and (2) wearable technology. Because the subject categories are fairly different, even if they are all associated with digital knitting, the viewpoint of these studies is also fairly different. A general review will be presented according to the two aspects, respectively.

(1) Fashion and textile design

Knitting as a traditional textile manufacturing method is constantly one essential research emphasis in the scope of the fashion and textile industry. Different from weaving, in the knitting process, especially the flat knitting process, the knitted fabric structure and knitted garment structure can be constructed simultaneously. This feature merges the definite boundary of garment and fabric making and provides great potential for knitting innovation. On the other hand, with the rapid development of science and technology, the problem of the separation of technical design and artistic design has become increasingly prominent. The increasing technical threshold makes it difficult for designers to take charge of the entire knitting development process. Various researchers have been conducted different studies around these features and problems.

Underwood (2009) conducted a study about the construction of three-dimensional preforms using the digital knitting process. The research employed flat knitting as an additive fabrication method for generating various three-dimensional objectives for a wider range of product types, not just textile and clothing. Besides, many studies have focused on seamless knitting in flat knitting machines, which is one of the most popular textile technologies recently. They investigated the complex digital system for seamless knitting from a designer's prepositives around serval key questions, including the conflict between fashion design process and technical development process using digital knitting design system (Yang, 2010), the technical skills gap between designers and industrial knitting technology (Taylor, 2015), and digital seamless knitting as a design innovation method for three-dimensional assemblages' development (Smith, 2013). Furthermore, due to the comfort and inclusiveness of seamless knitwear, there is also a study on designing clothes that can accommodate the physical problems of the disabled using digital seamless knitting technology (Radvan, 2013).

Overall, studies in the fashion and textile arena regarding digital knitting generally consist of two major objectives. First, it is understanding the technical matrix of digital knitting technology to bridge the gap and build a new design workflow. Second, it is using the established perception and technology to create a new design for different proposes.

(2) Wearable technology

Wearable technology, or known as smart clothing, has been attracted a dramatic increase in attention from both academics and industry. The digital knitting process has been widely used in the research and development of various wearable devices due to the outstanding structural flexibility and the forming possibility of a knitted construction. However, as a highly interdisciplinary research field, the research attributes of different wearable technologies are

very different. In addition to textile and clothing engineering as an important scope, the research regarding wearable technology normally requires many different bits of knowledge, such as computer sciences, information science, electronic engineering, and human engineering. Therefore, the role and proportion of digital knitting in different research are verydifferent.

Relatively simple wearable devices often use textiles as the carrier of electronic devices, smaller devices are embedded in clothing using pocket or other direct methods (Van Langenhove, 2007). On the other hand, some scholars have utilized the flexibility and elasticity of knitting to develop a series of textile sensors through the digital process (Ou et al., 2019, Fan et al., 2020, Luo et al., 2021). These flexible sensors have been integrated into the various knitted structure to investigate different properties, improving the comfort of smart clothing as well as reducing additional devices. Furthermore, these sensors have been investigated as an essential wearable platform for applications in various interfaces. MIT Media Lab has introduced a smart jacket that embedded a touch-sensitive keypad connected by conductive yarns, which is the beginning of exploring textile-based wearable devices in human-computer interaction (Orth et al., 1998). Moreover, a knitted smart keyboard has been developed, highlighting advantages of the digital knitting process, such as intarsia knitting and attractive colour effect by thermochromic and composite yarns (Wicaksono and Paradiso, 2020). Additionally, Song and team members developed a design framework for producing a seamless smart glove sensor system using digital knitting technology, various design components, including electrical conductivity and reasonable comfort, were achieved (Song et al., 2021).

Overall, studies using the digital knitting process for wearable devices development are usually including three main kinds. The first is the basic type, knitted textile is used as a reasonable media to carry electric devices to achieve a certain function. This method is a very efficient way to provide some single functional requirements. The second type is assembling textile sensors using knitting construction. In this way, the electronic equipment is directly integrated with the textile itself, so as to provide stronger functionality. The last type is to develop a completed and multifunctional product or objective. This method highly integrates different disciplines, realising both complex functions and precise control.

(3) Discussion

The general frameworks of the two research categories regarding digital knitting systems are presented and compared in Table 1. Corresponding to the nature of research, various studies regarding digital knitting can be roughly divided into techno-led design research and design-led techno research. Techno-led design research refers to the research that investigates certain technology from a design perspective and uses this technology as an innovative base for new design creations. On the contrary, design-led technology research refers to the research that examines certain design-related approaches from a science perspective and uses this approach as an imaginative foundation for novel technology or engineering innovations.

Categories	**Fashion and textile design**	**Wearable technology**
	Techno-led design research	*Design-led techno research*
Major researchers	Designer	Scientist
Research scopes	• Digital knitting • Certain design concept	• Digital knitting • Other science and technology • Certain design concept
Objectives & The role of digital knitting	Digital knitting as a practical technology for new design creations	Digital knitting as a design approach for novel technology or engineering innovations

Table 1. The general frameworks of digital knitting research from the two categories: (1) fashion and textile design, and (2) Wearable technology

The essential difference between the two types of research comes from their varying research proposes and the perspectives of major researchers. Some research stands in the between or known as transitional area. This kind of research is, in general, highly interdisciplinary and required a researcher and team with comprehensive discipline development. Generally speaking, the research proportion of digital knitting in a research project is directly proportional to the proportion of design in this research. That is, the more attention is paid to design, the more emphasis is positioned on digital knitting.

Original practice-led studies of digital knitting

From a viewpoint of a fashion and textile design specialised in knitting, two practice-led explorations around digital knitting systems will be presented. One is using digital knitting as a practical technology for generating modern fashion design based on the transitional concept. Another is using digital knitting as a design approach for developing novel personal wearable devices.

(1) Transitional fashion via digital knitting

Transitional fashion via digital knitting (TFDK) is a design approach that aims to develop a systematic process for creating a new form of knitted fashion with improved adaptability by using digitalized V-bed knitting technology (Yan, 2021). In this research project, the design concept of transitional fashion is the leading force, while digital knitting is a technological means. The advantages of digital knitting and the integrated attributes of fashion knitwear design together present new opportunities for the realisation of TFDK. Firstly, based on the proposed design concept, a theoretical model is established. According to the model, two practical explorations, “3D stretchable fabrics” and “adaptable forms”, are conducted.

Finally, design applications based on the obtained direction from both theoretical and practical studies are demonstrated. Figure 3 and Figure 4 show a series of fashion and textile design that generates from the presented research.

(a) (b)

Figure 3. The design collection of TFDK in Fashion Shenzhen Show

(a) (b)

Figure 4. An exhibition showing TFDK design results in Fashion Gallery, The Hong Kong Polytechnic University

In this research project, the knitting structure mainly studied is very basic, but due to the complex physical and mechanical properties of both yarn and fabric structure, there has been no systematic research to explain and summarise this basic law. The digital knitting design system provides excellent convenience for this research. A special knitted template is developed, including three main parts: waste, main body, and binding-off. In addition to the change in the number of stitches in the basic stitch structure, all other parameters that may affect the final fabric effect, including yarn feed amount and take-down tension, are all accurately controlled (Yan et al., 2021). This founded the base of this design research. After understanding the basic law of the change of stitch structures, the pattern drawing function of the digital knitting design system offers a flexible but logical method to the general various stitch pattern, which is highly stimulating and expands the innovative possibility of basic stitch structures. Combined with different stitches and rows, several elementary patterns can be knitted and transformed into fabrics required by different fashion styles.

(2) Integrated knitting for personal wearable device

A personal wearable device is proposed to offer a reasonable control of both temperature and humidity for individuals wearing protective clothing. The basic principle of the entire equipment is generally similar to an air conditioner, which is containing many components, such as the main apparatus, fans, pipes, batteries, and controllers. The basic design requirement is that this garment can bear the weight of all equipment, place various components in a reasonable position with a suitable method and can be disassembled. It also needs to be lightweight and comfortable wearing while ensuring the firmness and durability of the fabric. In addition, the basic beauty of clothing is also necessary.

Based on the needs, a knitted vest is designed and produced. One of its primary features is the unique channel constructed with a special knitting structure. This channel is completely hidden between the fabrics, at the same time, providing enough volume that can be propped up by pipeline. While ensuring that the pipeline passes through the specific envisaged position, this design improves the aesthetics of the entire clothing. In addition to fabric structure, garment structure is also considered in the process of designing the knitting procedures. The one-piece, fully formed garment structure is devised to make the subsequent processing steps extremely simple and ensure the durability of the garment. The realization of these complex structural designs highly depends on the suitable application of the digital knitting design system. Figure 5 shows an initial sample for the proposed knitting vest design. Figure 6 exhibits a part of the knitting design program in the SHIMA SEIKI digital design system.

Figure 6. An initial sample for the proposed knitting vest design

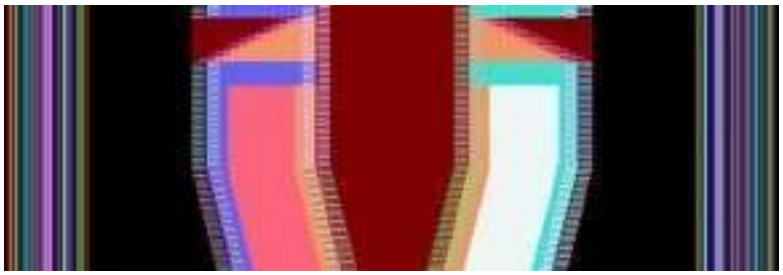

Figure 5. A part of the knitting design program in the SHIMA SEIKI digital design system

It is worth mentioning that, unlike the wearable designs reviewed earlier, the functional device in this project is relatively heavyweight and requires to be disassembled, so more attempts are made to construct a reasonable knitted structure to arrange, bear, and protect all components in the device system, so that makes it wearable and functional garment.

Therefore, the focus of design has shifted from the construction of circuits or sensor structures in the knitted fabric to the construction of the knitted garment itself. It indicates another route for developing clothing for wearable technology that is in between. As a preliminary research work, there are many matters considered to be explored in the future. One of the next research goals is to integrate all equipment into clothing smoothly and provide an integrative disassembly scheme.

(3) Discussion

From a designer's perspective, the digital knitting process is an integrated media that connects both art design and techno engineering. On the one end of the spectrum, digital knitting is an advanced platform for transforming design ideas to real objectives, as an additive manufacturing method for digital fabrication. On the other end of the spectrum, the process of digital knitting is a precious deposit containing a vast number of creative ideas. In other words, some surprising creativities and innovations could be born during the designing process for a specific purpose in digital knitting workflow. This potential part benefits from the training of design thinking for a designer, and also thanks to the unique working model of digital knitting system integrating design and engineering. Therefore, for a designer who would like to practice digital knitting in design innovation, it is necessary to build a clear insight about the general engineering of digital knitting, at the same time, to master the thinking mode of creative design.

According to the requirements of different types of projects, different design strategies can be proposed and further implemented on the basis of the appropriate deployment of the two fundamental knowledge mentioned above. The collision of the subjective initiative of designers and the objective initiative of digitalised design tools is the major source of the originality and novelty of this practice-led design research for future fabrication. Comparing these two types of design practices, it should be noted that, with obvious different orientations, how to grasp and balance the role of designers in the research process is one significant topic. Because this directly affects the final landing place of the research and the way forward for future

development. Especially for wearable technology, as multiple scientific knowledge is often involved and leading the way, the design of digital knitting should assist the achievement of essential functions, meanwhile, developing unique aesthetics and practicality understand certain constraints. When talking about creative fashion and textile design, the use of digital knitting is relatively flexible. However, it also means that the design innovation requires a deeper understanding of knitting technology.

Overall, the transition from designing for fashion and textile to designing for wearable technology is a flowing process, in which the two categories could promote each other harmoniously. The practice-led research conducted for both sides could be beneficial for the advancement of digital fabrication as well as the development of a moving design paradigm.

Conclusion

This paper introduces a novel design thinking regarding the digital knitting process. From a designer's viewpoint, it is believed that digital knitting can be acted as a transitional bridge for developing both techno-led fashion and textile design and design-led wearable technology development. The concept, advantages, and general workflow of the digital flat knitting system are presented. The recent and classic studies concerning digital knitting are examined from both design and technology viewpoints. The comparative analysation is revealed that, according to different research objectives and needs, digital knitting could alter its role in the research process and this transformation process is circular and interactive. Additionally, two practice-led projects using the digital knitting process further prove the huge possibilities of digital knitting, especially when design and designer are the dominant force.

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