

Enabling Design and Business Innovation through New Textile Technologies

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Abstract

Textile production initiated the first industrial revolution, with James Hargreaves' invention of the Spinning Jenny in 1766 introducing the beginning of systems of mechanized mass production. More recently, the development of new forms of digital manufacturing has given rise to a "New Industrial Revolution". This paper considers the introduction of digital textile technologies in relation to this new "maker" economy and to traditional industrial textile and apparel design and production systems.

While factors such as high investment costs, technology limitations and the need for specialized technical knowledge initially restricted the uptake of new technologies by traditional textile and fashion design manufacturing companies, technology developments are overcoming many of these problems. However, a lack of access and usability has limited engagement and innovation by designers, makers and technology entrepreneurs. This paper discusses the achievements, opportunities, limitations and impacts of work conducted through a university-based research and development centre that provides access to advanced technologies and associated technical, research and design expertise in areas of digital textile printing and seamless knitting for product development, sampling and training.

Drawing on case studies developed from client and staff interviews, product and market analysis, recent theoretical writings and a contextual review, the paper will consider ways in which these technologies are helping designers and companies to do things differently and create value. More immediate and localized design development strategies can support on demand production of specialized, high value products locally and internationally. They have also provided more effective design

and production methods to other industries; for example, costume designers for film, theatre and television companies. This facility also provides support for new areas of application and new manufacturing processes, for example in the areas of shaped, seamless knit and e-textiles.

Through these studies, traditional fashion production and market problems such as remote global supply chains, the separate and highly specialized roles of designers and technicians in the knitwear industry, the production of pre and post-market textile waste and the minimizing of stock levels are reconsidered. Business concepts and strategies, enabled by new forms of digital manufacturing are related to approaches discussed in the case studies.

Keywords: Digital fabrication, textiles, technology, digital textile printing, 3D knitting, business

Introduction

Technology, as capability arising from the practical application of knowledge, includes the use of materials, tools, techniques, and systems to assist people to do things. While science is concerned with how and why things happen, technology focuses on making things happen. Technologies affect the way we design and make things and the economies that evolve from these systems of production. Industrial economies, developed over the nineteenth and twentieth centuries, based on mechanization, gave rise to standardization, mass production and globalization. Post-industrialization, emerging from the development of computing and the Internet in the late twentieth century into the digitalization of the physical world through digital fabrication and the Internet of Things in the twenty-first century (Gershenfeld, 2012), is challenging established industrial practices and enabling new economic strategies and business models.

This paper considers some of the effects and opportunities arising from the use of new digital fabrication technologies in the fields of textile printing and knitted textiles, with a focus on the New Zealand context. Critical writing about the history and theory

of technology (Norman, 1988; Feng & Feenburg, 2008; Wiburg & Robles, 2010) and new digital making, manufacturing and business strategies (Anderson, 2006, 2013; Gershensonfeld, 2012; Beuchely & Perner-Wilson, 2012; Ng 2014) have informed this inquiry. Some relevant international business initiatives that use digital fabrication are referenced. Case studies of industry-initiated and individual design projects conducted at the Auckland University of Technology's Textile and Design Laboratory (TDL) also inform this research into the limitations and potentials of these emergent systems for new design and business strategies.

Industrialization and Post-Industrialization

Textile production has been integral to both industrial and computational development. The first industrial revolution began in Britain in the late eighteenth century, heralded by James Hargreaves' invention of the Spinning Jenny in 1766 introducing the beginning of systems of mechanized mass production. Tasks previously done by hand in hundreds of weavers' cottages were brought together in a single cotton mill, giving rise to the "manufactory" system (Crouzet, 1996). The second industrial revolution came in the early twentieth century, when Henry Ford mastered the moving assembly line and ushered in the age of mass production (Piore & Sabel, 1984).

Textile technologies also informed the beginnings of computation, when the mathematician Charles Babbage, inspired by the punch cards of the Jacquard loom, began work on the first automated calculation machine, the steam powered "Difference Engine" in 1822 (Null & Labor, 2006). The development of computing and the Internet have radically changed established ways of producing and consuming. Anderson (2013b) has recognized we are now entering a "Third Industrial Revolution".

While early rhetoric around the digital "Information Age" focused on a "weightless" dematerialized knowledge economy (Coyle, 1988), a third industrial revolution, associated with digital and personal manufacturing, located in the physical world rather than the virtual one, has been identified. This technology has taken over half a century to emerge, drawing from the development of mainframe computers in the

1950s, the personal computer in the 1970s, the Internet in the 1990s, and digital “making technologies” in the early twenty-first century. This is not the economy of bits, the trade in intangible information, services and intellectual property, envisaged by Coyle (1988), but of digital fabrication where the computational and the physical, bits and atoms, are combined. Converging with online systems, these new approaches are giving rise to not only new technologies of making, such as 3D printing, CNC routing and laser cutting, but also new design methods and new production and distribution systems, such as the online manufacturing service *Ponoko* (see <https://www.ponoko.com>)

Feng and Feenburg (2008) have recognized that past technologies and practices shape what we design and the way we design. Our “technical heritage” both informs and limits the way we design new technologies and the way we use them. A range of digital textile technologies has emerged over the past 20 years, including digital print, knit and weaving design and production platforms, as well as completely new forms of textile fabrication (such as laser cutting and 3D printing), and new technical textiles involving smart materials and /or the incorporation of electronics into textiles (e-textiles). While research and publication about the technical development of new textiles is increasing, the problems and potential of these technologies, including issues of convergence and integration, the new design methodologies they enable, and the new application areas and business strategies they can support, need further consideration.

Over the past 30 years there has been a shift in the way the economy operates, caused by the development of computers and the Internet. While the Internet began as a medium that connected existing products or messages with unserved markets, over time it has effected and changed the nature of the product or message. Scalability and cost effectiveness through product standardization that was the hallmark of industrial mass production is being challenged by new approaches, including product personalization by the customer and the ability for consumers to access highly specialized products online (through so called “long tail” markets), defying traditional manufacturing cost trade-offs between customization and scalability. With the advent of digital manufacturing systems, products are becoming

increasingly capable of dynamic reconfigurability beyond the factory floor. Ng (2013) recognizes that “progressive manufacturing firms will be redesigning their products’ physical and digital boundaries to create greater value both in its use and in its connectedness to other objects” (p. 5). This new connectivity of objects and systems is changing the relationship between a business, the market and its customers and the way value is being created. These changes in the way firms derive benefit are informing the development of new ways of doing business, leading to new business models.

A 2012 article in *The Economist* described the third industrial revolution as allowing: things to be made economically in much smaller numbers, more flexibly and with a much lower input of labor, thanks to new materials, completely new processes ... and new collaborative manufacturing services available online. The wheel is almost coming full circle, turning away from mass manufacturing and towards much more individualised production. (unpaged)

It is suggested that the economic potential of this on demand production technology is important to the growth of local economies, claiming it could help bring back jobs “to rich countries that long ago lost them to the emerging world” (*ibid.*). Anderson (2013) recognizes that this shift gives designers and innovators freedom to develop new ideas, prototypes, samples, small production runs and marketing strategies without depending on large companies for production and distribution.

New Approaches to Textile Production

Until very recently, in the field of textile and garment production and supply, we have been accustomed to a specialized workflow whereby the designer designs, the manufacturer makes, the distributor supplies, the retailer sells and the consumer buys. This production driven model has significant risks at each stage of the supply chain (Zsidisin & Ritchie, 2008). While the limited speed and relatively high cost of production with early digital textile technologies, such as digital textile printing, limited commercial uptake, the performance of these systems is rapidly improving (Provost, 2013). However, the significance of these new technologies is not how they

can be improved to meet the performance of traditional industrial textile technologies, but in terms of the new possibilities they present. These include:

- Consumer participation and collaboration in the design process
- The ability to easily change and modify designs (customization) to support product individualization and/or mass customization
- On demand production to ensure more agile and responsive supply chains, reducing time to market and eliminating costly stockholding and storage
- Local production hubs to reduce environmental impacts, supported by online sales to support long tail markets with their niche consumers (Anderson, 2006)
- New design and making approaches resulting in product innovation.

The opportunity for the consumer to decide what they want and to even become the designer or “prosumer” (Toffler, 1980) has emerged as:

tools that for years have been exclusively available to high-end professionals, or those who could afford them, are now getting democratised in price and ease of use, making them more affordable and accessible to much wider audiences ... Consumers and small players now have a chance to play with high-end technology and take a part in a game they didn't have a chance to play before. (Dzambazova, quoted in Stening, 2011)

This “democratisation of technology” has led to fears that “amateurs” will take over what were “professional” fields with a subsequent fall in design standards (Relph-Knight, 2007). However, as “Open Source” (Perrens, 1998) and “Maker” (Hatch, 2014) movements have developed and the value of shared knowledge, participation and creative collaboration becomes more evident, these approaches are increasingly being recognized as innovative, critical and productive (Holbrook, 2014).

One of the best known facilitators of this Maker model in the textile design field is US based online digital textile printer, *Spoonflower*, established in 2008 to enable crafters and DIYers the opportunity to print their own personalized designs for home wares, apparel and accessories; see <<http://www.spoonflower.com/>>. The company has achieved phenomenal growth to become one of the largest digital printers in the

US, catering for a worldwide audience. Neither of the founding partners had a background in textiles before embarking on this venture. *Spoonflower* doesn't just support production but is also an online sales and distribution system, building a community of designers and textile buyers and developing global niche or "long tail" markets that were previously untenable due to their geographic spread (Anderson, 2006). These technologies are rebuilding the connection between the maker and products, empowering designers and artists to develop new markets and original designs that can't be found anywhere else.

The New Zealand Context

New Zealand's small population and distance from international markets create significant problems for small manufacturing companies and businesses wanting to expand into export markets. There are limitations associated with the uptake of new technologies, including high capital investment costs, a lack of access to trial new technologies and product development systems, limited staff know how and a lack of R&D capability to exploit new opportunities.

Local textile and apparel production in New Zealand was decimated with the global industry reforms of the 1980s, which resulted in the subsequent shift in garment and textile manufacturing offshore (Joseph & Cie, 2009; Smith, 2013). In 2006, recognizing the potential that new digital design and textile production systems offered the New Zealand textile industry, funding was granted by the New Zealand Government's Tertiary Education Commission, under its Growth and Innovation Pilot Initiative scheme, to establish the Textile and Design Laboratory (TDL) at Auckland University of Technology. The TDL invested in technology and expertise in digital textile printing and seamless knitting, which were identified as being relevant to the future of New Zealand's fashion and textiles sectors.

The TDL's aims were to:

- Build capability and support knowledge sharing with students and local industry

- Work with industry to support design innovation through product development, prototyping, sampling and small-scale production
- Develop and lead textile research with postgraduate students, university researchers and commercial research partners.

The TDL has opened up numerous opportunities for individual designers, small and large-scale businesses. Access to technologies and expertise has enabled products to be developed without the incurrence of high set up costs. Inventory levels can be minimized through on demand production. Opportunities have been created for students and designers to experiment with new materials and new design methods. Local, more sustainable production systems have been established - a claim that is supported by increased investment in 3D knit technology by New Zealand companies (TDL Case Study, 05/2010).

The case studies discussed in this paper have been developed from interviews conducted with partners, researchers and TDL staff and secondary reference material. Published annually on the TDL website, they document ways in which the TDL has worked with industry, designers, researchers and students in areas of digital print design, costume production, seamless knitwear, homewares and e-textiles, to develop innovative new products, design methodologies and business opportunities.

Local knitwear designer Kylee Davis recognized the benefits of being able to locally produce short runs of high value knitwear through the TDL. She initially took a direct sales approach, arranging viewings of her collections at venues around New Zealand and Australia, from which sales were then made to order. She has subsequently set up her own online retail store (see <http://www.kyleedavis.com/>) followed by a “pop-up” shop in Auckland. Access to local knitting and digital printing technology has been a key factor in her business development planning (see Figure 1). This business model requires significantly lower investment costs for individual designers wanting to build high-end niche brands, with the ability to respond to high consumer demand as required.



Figure 1. Intarsia knit design by Kylee Davis, developed and produced at the Textile and Design Lab, 2012-13. Image courtesy of Kylee Davis.

Costume Design for Film and Television

Digital textile technologies have introduced new costume design methods to the film and television design environment where one off or limited edition production and customization are required. The TDL's technologies and expertise have been utilized in various ways by a number of designers and companies, supporting the New Zealand film industry with novel and cost efficient solutions for costume design (see Figure 2).

Historically accurate textile prints and garment details are critical for veracity in film. Traditionally this need was met by sourcing vintage fabrics or hand crafting prints. These established methods could be costly and time consuming. Award winning New Zealand costume designer, Barbara Darragh, approached the TDL for help with the development of specific items of clothing from Sir Edmond Hillary's historic Everest expedition, for the film *Beyond the Edge* (Pooley, 2013). The weathered

striped hat fabric and woolen mitts were subsequently produced to match criteria for the 1950s era. Another production that required costumes to fit a specific period in time, *The Lovely Bones* (Jackson, 2009), was set in the 1970s. Textile prints, based on vintage samples, required a purple and mustard colour range with a faded appearance. The TDL was able to print several variations of the same design using different opacity levels for the designers to select those with the most desirable degree of fading.



Figure 2. Costume pieces for *The Lovely Bones* (left) and *Beyond the Edge* (right)
Images courtesy of Paramount Pictures and General Film Corporation.

The aging of garments and props over a television series is a continuity issue that can cause problems for the designer. The ability to control the appearance of the wear and tear of leather armour, scrolls and maps that could be reproduced through digital printing was utilized by prop designers for the third season of the television series *Spartacus* (DeKnight, 2010 – 2013), which was filmed in Auckland.



Figure 3. Digitally printed leather map for the Spartacus TV production
Image courtesy of Starz.

Digital textile technologies have introduced new, timely, cost effective methods for costume designers. Exact colour matches, vintage designs and fabric wear effects can be produced quickly from samples and original artwork. The production scale does not affect costs, with one off prints for unique costumes being produced from digital files.

Digital Knitting

Seamless knitting technology, developed for the production of three dimensional knitted garments, has introduced an on demand, 3D printing-like technology to knitwear manufacturing. While open source developments like Gerard Rubio's Open Knit Project (Mok, 2014) are beginning to make aspects of this technology more accessible to makers, the most sophisticated and versatile 3D knitting technology, developed for the knitwear industry, is complex, expensive and proprietary. The simultaneous construction of an intricate, structured textile into the 3D shape of a seamless garment, with all the variables introduced through yarn types and combinations, stitch structures for textile dynamics and form building, along with aesthetic and functional considerations, make 3D knit design and production highly

specialized fields. The software and machines themselves are complex. However, the design interface has been influenced by the system of industrial knitted garment production, with the library of garment shapes accessible to knit designers based on earlier fully-fashioned garment forms (Kalyanji, 2012; Smith, 2013). As most 3D knit production machines in industry are in use 24 hours a day, seven days a week, there is little time for designers to develop a deeper understanding of the technology, or to experiment and push applications beyond industry norms. Exploration of the potential to develop new areas of textile application using knitted shape has been limited. While there has been strong recognition of the potential of this technology, with its lower labour requirements and costs, to reinvigorate local knitwear production, such initiatives – like the US based *Kotoba* initiative - have focused on knitwear rather than new areas of knit application.

Shima Seiki, one of the top two manufacturers of seamless flatbed knitting technology (and provider of the knit technology at the TDL), launched the *Kotoba* brand with an inaugural Spring 2013 collection introduced at New York Fashion Week. *Kotoba* is a collective brand of knitwear intended to focus consumer attention on the benefits of the company's *WholeGarment* knitting technology. The *Kotoba* website states:

Due to the lack of seams, *Kotoba* fashion is knitted as a whole, producing minimal waste during the production process. Its pieces are soft, light and comfortable with superior draping characteristics. In addition, because the entire production process relies on minimal labour, it is economically feasible to source and produce the collection within the United States. *Kotoba* manages to produce unique and comfortable knitwear that is environmentally and socially responsible as well. (<http://kotoba.us/our-mission>)

While the brand produces beautiful, fine knitwear, it tends to more conventional knitted garment shapes, reflecting Feng and Feenburg's (2008) theory of "technical heritage" that recognizes the limitations of the ways we tend to design with and use new technologies, in light of older forms and practices.

Sportswear companies *Adidas* and *Nike* have been researching more innovative uses of seamless knit technology to create running shoes and football boots that offer a glove like fit, unparalleled lightness and waste free production. The technical innovation in these new knitted applications, in terms of form, yarn development and stitch structure (using a combination of flechage or short row knitting, intarsia, jacquard, tuck stitches and stitch transfer techniques) is remarkable, as is their reduced environmental impact (Aston, 2012). Both companies have supported extensive research and development programs with large cross-disciplinary teams working over many years leading to this design innovation.

Two individual research projects, conducted through the TDL by Mandy Smith (2013) and Jyoti Kalyanji (2012), have also investigated ways of using and extending seamless knitting technology. Kalyanji's adaptation of the technology for homeware applications included shaped cushion covers, upholstery and beanbags. Along with the techniques of shaping corners and curves, the designs produced were notable for their aesthetic qualities. Most seamless knitwear uses single block colours, or traditional patterns like stripes. The mix of coloured yarns, producing subtle, mossy patterns, resulted in a distinctive textile better suited to furnishing applications. These are areas that Kalyanji is developing further in her current PhD research, working with furniture designers to develop new knit shapes and exploring textile aesthetics using seamless knit technologies.

Mandy Smith looked to exploit the properties afforded by seamless knitting technology to create a collection of merino wool garments. Using flechage knitting techniques, she was able to generate designs with unique draping properties that could not have been produced using traditional, two dimensional, cut and sew or fully fashioned techniques (Smith, 2013).



Figure 4. Home ware applications by Jyoti Kalyanji (left) and seamless knitwear by Mandy Smith (right).

There is significant potential to develop new applications using the unique shaping of seamless 3D knit technologies and new yarns. Critical to this is both shape and aesthetic development. Commercially, some large cross-disciplinary research teams are pushing the boundaries of this technology, but the knowledge associated with their breakthroughs is proprietary. It is still difficult for textile designers to access and use this technology experimentally. As advances are made in knit technology interface design and deeper knowledge about 3D knit technology is gathered and taught, individual designers are pioneering new approaches and innovative designs.

Smart Textiles

Our final area in this study looks at the development of new electronic or e- textiles using special yarns and digital intarsia knitting. The global market revenue for smart textiles is expected to grow to reach over \$2 billion by 2018, growing at an estimated rate of 21.54% a year from 2013 (MarketandMarkets, 2013). The special structural qualities of textiles, including lightness, drape, porosity, strength and durability, along

with their human uses for protection, support, comfort and wearability, are being integrated with sensing, communication and response capability, as electronic or e-textiles. Globally the potential of this emerging, multidisciplinary field is being recognized, with significant research investment, leading to higher levels of integration of textiles and electronics and new areas of textile application, particularly for military, sports, health and medical areas, resulting in the reinvigoration of local, high-value, textile production.

Knitted textiles present unique opportunities as they involve multilayered construction methods, which can be made as single continuous sheets of fabric (Jost, Dion, & Gogotsi, 2014). Within a knitted structure, dynamic textile and yarn properties such as stretch, tension, texture and garment fit can be used to enhance signal output and hence electronic performance; sections, layers or structures made of nonconductive yarn can be used to contain or enhance the electrical properties within conductive sections, allowing the development of reliable and repeatable knitted sensors and more precise placement of sensors.

Over the past five years the TDL has been involved in the development of smart knitted textiles. These investigations have included collaborative methods using “maker” approaches (Joseph, 2013), specialist in-house teams (Joseph & Heslop, 2014) and commercial R&D projects with industry partners. TDL staff have worked extensively with smart textile company *Footfalls and Heartbeats* (FHL) to create intricate knit designs with conductive yarn which are in turn used for a variety of bio-monitoring applications for the sports, medical and healthcare sectors. These developments allow the textile to sense and communicate.

An early application for FHL’s technology is compression bandages for use on chronic leg ulcers. With a large corporate partner, FHL is developing the design for a bandage that can potentially measure its own tightness and convey information to medical staff by colour change, sound or an alternative method of alert. There are also a number of other potential applications in aged-care and injury monitoring in high risk environments such as the military. There are opportunities for these

designs to be adapted for monitoring mechanical stress in composite structures such as aircraft wings and turbine blades.

In the future, FHL intends for their textiles to be sufficiently sensitive to detect the bioelectrical signals of active and passive skeletal muscles. Applications may include injury rehabilitation, neurological trauma reconditioning, real-time stress testing or a human interface for robotics. This is ongoing research, which the company is beginning to commercialize with local and overseas partners.

The partnership with FHL has encouraged the TDL to build greater expertise and extend its research into smart knit structures and applications, through collaborations with AUT's Schools of Engineering, Computer Science, Podiatry and Physiotherapy, building wider, cross-disciplinary capability across the University. The successful commercialization of e-textile products is still limited by the enormous gap between textile and electronic knowledge and associated manufacturing systems. The technologies and expertise required to produce yarns and fabrics and to make electronic components and assemble hardware, needs to be brought together to support this integration and enable the development of this new field.

Conclusion

Digital technologies have brought significant change to the textile field. More democratic, accessible means of design and manufacturing allow small players and amateur crafters to explore and develop products using digital textile printing. New on demand production that can be easily customized to support individualization or mass customized strategies, supported by online interest based networks and distribution systems, are enabling new business models and opportunities for niche brands. The integration of electronics into textiles has opened up new areas of health, sports and medical applications. However the complexity and lack of access to technologies like 3D knitting has limited opportunities for individual designers to explore and push their full potential. The area of e-textiles has significant commercial potential but the divide between textile and electronic knowledge and associated manufacturing systems limits this realization and can only be addressed through

cross-disciplinary engagement. The Textile and Design Laboratory is able to provide expertise, teaching and access to help designers, researchers, students and companies to develop greater understanding of new textile technologies and support innovation.

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