

## The Co-design Process in Mass Customization of Complete Garment Knitted Fashion Products

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### Abstract

Complete garment knitting technology is a method of producing products, generally fashion garments, ready-made directly in the knitting machine without operations such as cutting and sewing. This makes it possible to manufacture a fashion garment with fewer processes than with conventional methods. Mass customisation is a customer co-design process of products and that tries to meet the needs of an individual customer's demand. The customer can order a garment with a customised style, colour, size, and other personal preferences. Co-design is a collaborative process between the customer, the retailer, and the manufacturer by which a product is customised to fulfil the customer's requirements. This paper is based on the results of a doctoral thesis. The process of co-design and manufacture of a customised complete fashion product is examined. Research was conducted by a retail concept simulation and three case studies. A cross-case analysis was done to analyse the data. The main findings are a description of two kinds of retail concepts for knitted customized fashion products. A knitted garment can be customized, produced, and delivered to the customer in three to five hours. In the Co-design process two kinds of interactions are feasible between the company and the customer: manual or digital co-design. A manual process has advantages such as: high service level for customers, no requirement of advanced technical equipment. However, manual co-design is labour intensive, a shop assistant can only serve one client at a time. It is also only applicable to brick-and-mortar stores and not transferable to the Internet. Digital co-design, on the other hand, encourages customers to do the customisation on their own, without the aid of sales personnel and little risk of queues. Moreover, this technique is ideal for the Internet. Disadvantages to date have included limited design options and problem of taking body measurements.

**Keywords:** Knitting technology; Mass customization; Co-design; Complete garment; Supply chain management

### Introduction

This paper is the result of a PhD thesis at Tampere University of Technology, Finland and comprises studies in the area of knitting technology and mass customization (MC). The research objective was to investigate the possibility of combining complete garment knitting with MC. The term *mass production* was first introduced in the 1920s and is often associated with the factories of automobile manufacturer Henry Ford [1]. Since then, almost all manufacturing of textiles and garments worldwide has taken place in factories using the industrial concept of mass production. For a long time, textiles continued to be produced in Europe and elsewhere. In the 1960s labour costs increased in many countries of Western Europe, and so a great amount of domestic textile and garment production moved overseas, where manufacturing was cheaper [2]. Here we have a problem, production in low-cost countries in Asia results in long lead times from identified demand on the market to the moment the customer can buy the product. According to Hoover the supply chain needs to be time-based, customer-oriented, and agile in response to changes in demand [3].

In 1987 Stan Davis, a visionary business thinker and consultant coined the term *mass customization* for the first time. He described it as a system in which "the same large number of customers can be reached, as in mass markets of the industrial economy, but simultaneously can be treated individually, as in the era of customised markets in pre-industrial economies" [4]. This was developed further by [5], who defined it as a concept that provides such variety and individual customization that almost everyone can find what they want at prices comparable to mass-produced products. MC involves all aspects of development, manufacturing, sales, and delivery of the product [6,7]. It is a concept that comprises the whole chain from the designer's sketch to the final product received by the customer. MC allows buyers to modify

products according to their taste and requirements. It exists today in a variety of areas including automobiles, furniture, food, and clothing. One advantage for the retailer is that the product can typically be sold before the manufacturing takes place. Since the customer has already purchased the product, the risk for unsold goods is lower. Customers are not always satisfied with the products they have customised and bought. For such cases, it is important to have a return policy which allows returning with a full refund. [8].

*Complete garment technology (seamless garment technology)* was introduced on V-bed flat knitting machines in 1995, having evolved from developments in the 1980s. V-bed machines have two needle beds, in a position of an inverted V and equipped with needles [9]. This is considered as a new innovative technology for the future production of knitted garments [10]. The whole garment is made directly in the flat knitting machine without post cutting and sewing processes. This technology can make lead times shorter in the apparel industry [11].

While MC may not replace mass production of clothing, it may be a solution for certain products and niche markets. In some ways, the MC of clothing may be seen as a step back in time. We are reminded of the crafts era, when clothing was made to order as needed and produced

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near-by. Now this is being done again, but with modern technology - a return to clothing designed and manufactured in collaboration with the wearer. Here complete garment technology opens up new perspectives with its reduction of processes that allow a rapid response to customer demand, while the possibility of MC serves each customer individually. Fashion logistics, MC, and complete garment technology form an effective partnership. These three concepts are the focus of this study. They are relatively new and, while they have been considered separately, they have rarely or not at all been examined in combination.

The principal objective of the present article is to examine the use of complete garment flat knitting technology in the production of mass customized fashion garments.

It poses the following overall research objective: *How can complete garment knitting technology be applied in a retail concept for customised garments?* The answer is pursued in four articles containing literature reviews, simulations, and case studies.

It poses the following research questions:

**Research Question One (RQ1):** *How does the co-design process function in the customisation of knitted fashion garments?*

**Research Question One (RQ2):** *What are the advantages and disadvantages with manual co-design compared to a digital co-design process?*

Co-design is a collaborative process between the customer, the retailer, and the manufacturer by which a product is customised to fulfil the customer's requirements. According to Franke and Piller, the success of a co-design system is defined by its technological aspects (generally software-based) and how well it works in the sales environment [12]. This research is a study of how the co-design process function in combination with knitted fashion products, and the effects of which co-design system is chosen.

## Methods and Materials

The Knit-on-Demand research project began as an attempt to develop a business concept utilizing complete garment knitting technology. This paper is based on the result of a doctoral dissertation with the title: Customisation of Fashion Products Using Complete Garment Technology [13]. The main methods used to compile research material for this article has been the qualitative multiple-case study defined by Yin, quantitative simulations by Banks, and action research by Näslund [14-16]. These three are the basis of the individual journal articles published in the PhD thesis.

### The research gap

The research gap was identified by a literature review. Complete garment knitting technology is a niche area in textile technology. It is difficult to find research literature on the subject, especially in combination with MC. The possibilities of using complete garment machines for the production of mass customised products are discussed by Choi and Powell and Choi [10,17]. There are a number of articles and some books describing and discussing integral knitting and complete garment technique, Spencer [9], Mowbray [18] and Hunter [19], all of which presents the history, technical aspects and an overview of the subject. However, none of these sources provide a deep picture of the complete garment technique in combination with MC of fashion garments. In MC, the importance of the co-design process between the company and the customer has been a major concern for more than thirty years [20-22]. However, if we are to argue that MC provides

a complement to mass production of knitted garments, it remains a matter of concern that there are no research-based studies for this type of co-design in combination with complete garment technology.

### Data analysis methods

The data analysis methods applied was cross-case synthesis. Two or more cases are performed and analysed separately but in the subsequent cross-case synthesis the results of the cases are compared and the research questions are answered [14]. A cross-case synthesis may be carried out whether the individual case studies were a predesigned part of the same study or if they were independent research studies: generalisations are sought across a number of studies.

In Articles 1, 2, 3, and 4, the case study method is applied by gathering data through simulations, interviews, and observations. Cross-case synthesis is used to analyse the data in those articles and form the basis for answering the research questions.

Article 1 [23], was the first attempt to develop a shop and production model for the Knit-on-Demand concept incorporating complete garment technology. The study was published in International Journal of Fashion Design, Technology and Education in July 2008.

Article 2 [24], was the case study of an existing MC concept for knitted products. The empirical data was collected on-site at Factory Boutique Shima in Wakayama, Japan and published in International Journal of Mass Customisation in January 2010.

Article 3 [25], was a case study comparing manual and digital co-design with most of the data supplied by Factory Boutique Shima. The study was presented at the MCP-AP Conference in Taipei, Taiwan, in December 2010 and published in Autex Research Journal in March 2011.

Article 4 [26], describes Knit-on-Demand case study from a supply chain perspective and considers design, technology, logistics, and performance and was published in Autex Research Journal in 2012.

## Results

### Mass customization in textiles

Before the industrial revolution, which began in the 18<sup>th</sup> century, manufacturing was largely a craft process. A product was custom made to fulfil the requirements of an individual person. It was often expensive and therefore available only to those who could afford it [27]. With the industrial revolution and the era of mass production, more goods could be obtained by more people. Today MC has emerged as a combination of craft and mass production. The textile and fashion industry was one of the first to adopt this concept. Tseng and Piller [28] refer to three aspects of textiles that must be fulfilled to apply in MC: design, function and fit. Maybe the most important of the three factors are garment fit.

Customization can be defined as a strategy that creates value by some form of interaction between the company and the client at the manufacturing stage [29]. Lampel and Mintzberg describe this as "tailored customization" [30]. This means that a company offers a prototype to the client and then change it to the demands of the customer. This is defined as a collaborative approach by Gilmore and Pine [31]. This process is cooperation between client and company in order to achieve a suitable product for the customer.

The collaborative process between the company and the customer is defined as the "co-design process" [32-34]. A client selects options in a configurator or a co-design system of some kind and then they

become a co-producer or “prosumer” according to Toffler [35]. Co-design is described and defined in literature as an interaction between the company and an individual customer in order to configure a desired product [36-39].

According to Fralix [27] MC is a future direction of the fashion and textile industry but garment fit and colour selection can be a problem. It is important that the fit of the garment is accurate and this can be done by taking the body measurements in store or an on-line solution where the customer gives the measurements directly in the computer [38].

Body scanning has often been mentioned as a solution to the problem of perfect fit. Its disadvantages are three-fold: 1) an investment in specialised equipment is required, 2) not all people wish to be scanned, and 3) certain types of clothing require taking a customer’s measurements manually. However, the impact can also be that some customers find body scanning exciting and like the experience of the process and that they also like to get the advantage of having accurate measurements. A manual procedure also enables a dialogue between the purchaser and the salesperson about the preferred fit of the garment, i.e., tight or roomy, an aspect often overlooked in promoting body scanning. On the negative side, taking measurements manually can be more time consuming and may raise issues of personal privacy. Catering to individual customer sizes becomes an even bigger problem in e-commerce.

There are many examples of businesses that combine manufacturing technologies with MC as shown in Table 1. The Finnish Left Shoe Company (formerly known as The Leftfoot Company), is one example of this concept. Each customer’s feet are scanned by sales personnel and the collected information is then used to produce customized shoes that can be delivered to the customer within three weeks [39]. Spreadshirt, an Internet based firm sells t-shirts whose design are individually done by customers and then printed on standard t-shirt’s [40].

Brooks Brothers, an upscale American apparel company founded in 1818, now offers mass customised, made-to-measure suits and shirts based on individual body sizes and preferences in partnership with Pietrafesa Corp., a private label suit manufacturing company from Liverpool based in New York [41,42]. Information technology and manufacturing processes were developed and a system called eMeasure introduced in 17 Brooks Brothers stores. The customer’s dimensions are taken by a body scanner in the shop and those measurements are used to produce suits and shirts with a perfect fit. The eMeasure system also can store measurement profiles and quickly recall information

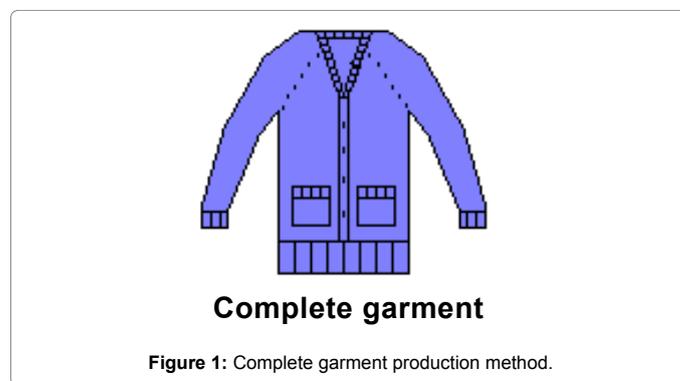
for repeat customers. Many examples of MC now exist in the fashion industry, and the Internet continues to open up more possibilities for the future.

In MC the business process must be changed, from a linear to a concurrent or parallel process [43,44]. This process often starts with the co-design process and then selling the product to the customer before manufacturing starts.

### Complete garment knitting

In complete garment manufacturing, the garment is ready-made in the knitting machine. The panels of the product are knitted in the right shape and knitted together with the trimmings, pockets, and other decorative elements in place as presented in Figure 1 [10]. The advantage of this technique is no waste of material (cut-loss) and no expensive post-knit operations (sewing or cutting) (Legner, 2003). Depending on the style of the garment, some minor cutting and sewing of labels or trim may still be necessary. In addition, while panels sewn together using other manufacturing techniques run the risk of having variations in colour shades between the panels because they were knitted with yarn from various dye lots, in complete garment technique, all the yarn comes from the same cones, enabling higher quality and reducing problems of colour mismatch. With seamless technology, the garment can be made to fit perfectly and be comfortable to wear. In summary, manufacturing processes are reduced and knitting is done on-demand, which can shorten production lead time considerably [11].

Shima Seiki developed the complete garment concept in 1995 and launched it under the brand name WholeGarment. Knit & Wear is the



Companies	Products	Descriptions
Tailor Store	Shirts	<ul style="list-style-type: none"> <li>- Swedish on-line retailer</li> <li>- on-line configurator</li> <li>- customers take their own measurements</li> <li>- manufacturing in Sri Lanka</li> <li>- delivery to customer in 10 to 15 days</li> </ul>
The Left Shoe Company	shoes	<ul style="list-style-type: none"> <li>- Finnish on-line retailer</li> <li>- customers feet’s are scanned in the store</li> <li>- delivery to customer in three weeks</li> </ul>
Spreadshirt	t-shirts	<ul style="list-style-type: none"> <li>- German on-line retailer</li> <li>- graphics individually designed by customers</li> <li>- digital printing technology is used</li> <li>- customers can sell their designs to other customers in Spreadshirt’s on-line shopping system</li> </ul>
Brooks Brothers	suits	<ul style="list-style-type: none"> <li>- American apparel company</li> <li>- made-to-measure suits</li> <li>- eMeasure system for measurements in 17 Brooks brothers stores</li> <li>- body scanner in the shop</li> <li>- customer measurement profiles are stored and used for repeat orders</li> </ul>

Table 1: Descriptions of MC examples.

German firm Stoll’s name of the concept of complete garment [9,10].

Complete garment technology in combination with MC in a supply chain for fashion products may result in measurable benefits such as: *manufacturing lead times reduction, close to point-of-sale production, fast deliveries and a positive shopping experience for the customer.*

There are a lot of advantages with the complete garment knitting technology but the supply chain in the production of knitted garments must be adopted to this technology to gain the benefits.

## Summary of the Results

The results of four peer-reviewed published articles are used to answer the research questions stated at the beginning of this concluding article.

### Article 1

**Purpose and overview:** Article 1 describes a design and manufacturing concept “Knit-on-Demand”. This is a research project with the aim to show how the complete garment technology can be combined with MC. The manufacturing equipment is located in the retail store and the customer designs the garment in a collaborative process with store personnel. The research method for this study is the case study method combined with lead time simulations. A literature survey and information gathering from suppliers of knitting machinery are performed. The input data for the simulations were tested on both design equipment and textile machinery involved. The study involved a simulation of both the co-design process between the company and the customer and the actual manufacturing process.

**Principal findings:** Article 1 described the benefits achieved by combining complete garment technology with MC in a business and production system for the Knit-on-Demand concept.

We have endeavoured to show that a high fashion, customised garment may be designed, sold, and manufactured to order in two to five hours. Our findings agree with Choi and Powell [10] that complete garment technology can be effectively employed in conjunction with MC to produce knitted garments. The Knit-on-Demand concept shows an alternative way for European knit fashion producers to shift from mass production to MC, rather than outsourcing their manufacturing to low-income countries.

The present multiple-choice co-design system must be refined and expanded, and manufacturing processes have to be optimised. Products may be delivered quickly if there are no queues caused by many customers wanting to configure a self-designed product at the same time. Ideally, actual customer demand would be fulfilled on location. Where this is impossible, postal mail or express delivery may be the second best option, as is common practice in mail-order or Internet sales. Whether a delay of a few days or weeks would affect a customer’s attitude towards the Knit-on-Demand concept has not been ascertained. A key success factor appears to be the quality of the shop personnel and the kind of customer service they provide. The financial aspects of the concept also need to be studied.

### Article 2

**Purpose and overview:** Article 2 is a case study of the Japanese company Factory Boutique Shima in Wakayama. Factory Boutique Shima is a firm that combines the complete garment technology with the concept of MC. A customer can design a garment in a collaborative co-design process guided by staff in the shop. Options of styles, materials, yarns and colours are presented to the customer to support the design

of the own designed product. The shop assistant collects and writes the information down to support the manufacturing of the garment when the co-design process is finished. The customer approves the design and pays for the garment before the actual production starts. By this concept the percentage of garments sold at full price (sell-through) is much higher than for a business model where garments are produced in advance of being sold [45]. The case study had an inductive approach based on company visits and interviews with shop personnel. Quantitative data were collected and a Strengths–Weaknesses–Opportunities–Threats (SWOT) analysis performed using qualitative data to identify critical success factors in fashion retailing.

**Principal findings:** The SWOT analyses in Table 2 indicate one strength, a positive shopping experience for the customer. The Factory Boutique Shima concept suggests how their WholeGarment technology, as the process is called by that company, can be used for MC in the future. The current system, in which one or two staff members devote their full attention to a customer during the co-design process, pleases customers. However, attending to one customer at a time is costly for the company, and so Factory Boutique Shima seeks to develop its co-design system to the point where customers do more of the customization themselves.

The SWOT analysis suggests that Internet sales may present an opportunity for the future. With an efficient co-design system on a company’s web page, a vast number of customers could be served at one time. Obtaining accurate customer measurements remains a challenge. One solution is to let customers take and enter their own measurements into the co-design system, as many companies already do. The analysis showed two main areas in which Factory Boutique Shima may improve their business concept: 1) adapting MC to products that can be manufactured with complete garment technology, and 2) developing the customization concept.

### Article 3

**Purpose and overview:** The aim of article 3 was to study and compare two different customization systems. The systems to investigate are one digital configurator and the other is a manual co-design system. Knitting technology is combined with MC in a retail store. In the fashion store the customer can look at swatches, yarn samples and different fashion styles to support the co-design process for the customer. The co-design process is supported by skilled personnel in the store. The products that can be customized are of the types cut and sew fully fashioned and complete garment. The items can be customized to correspond to each technology.

Customisation processes were studied in manual co-design and the digital ordermade WholeGarment. Both were evaluated and appropriated as models for simulation in AutoMod in order to compare their performance. Qualitative interviews with factory representatives at Shima Seiki and retail staff at Factory Boutique Shima provided additional understanding of two procedures. The data gathered from the three sources – Shima Seiki, Factory Boutique

Strengths	Weaknesses
Positive shopping experience	Risk of long queue of customer in the shop Time-consuming co-design process Little reuse of customer information
Opportunities	Threats
Internet sales	Limited design options available in WholeGarment Limited interest among consumers

Table 2: Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis.

Shima, and SOMConcept – were used for the simulations. The results are presented in Article 4.

**Principal findings:** The first simulation compared customised garments made by the manual WholeGarment co-design process with products created using Ordermade WholeGarment digital co-design system. The simulation represented 200 hours and was repeated 15 times. The result for the manual WholeGarment, varied from 146 to 409 products. The variation of the result was depending on the number of shop assistants available to help the client with the co-design. For the digital alternative, Ordermade WholeGarment co-design system, the number of customised products ranged from 259 to 794, depending on the availability of one, two, or three computers for customer use.

Another simulation was done to show the difference between manual- and digital co-design. 1000 digital co-design systems were compared with the alternative with five shop assistants. The aim was to study the effect if a digital Co-design system can be accessed over the Internet. The result showed that over 8000 items can be designed in 200 hours compared to less than 1000 garments using the manual co-design alternative. This illustrates the vast possibility for the digital configurator if it can be applied over the Internet.

There are two main benefits with a configurator system: 1) customers can do a considerable amount of customisation unaided, and 2) the customization options in the co-design tool are pre-programmed to provide information to the knitting machine: when the customization process is done, knitting can begin without the need for time-consuming programming. A configurator brings the entire process a step closer to mass-production efficiency, while maintaining all the distinctive features of customization.

#### Article 4

**Purpose and overview:** The aim of Article 4 was to show the supply chain of the Knit-on-Demand concept. It examines the results of the customisation process, technology, systems, and logistics. A case study method and data from two cases were used. The purpose of the first case study was to map the Knit-on-Demand supply chain.

The method applied in this study was value-stream mapping. A technique used to identify waste in the production chain. It begins with a client entering the retail store and purchasing a garment, then follows the order back to the customer order decoupling point (CODP). The purpose of the second case study, conducted during spring 2010, was to analyse the customisation of measurements for each purchase. These measurements were then compared with the standard size tables used in Sweden. The project ended in December 2010 due to the knitting capacity constraints of the manufacturer, Ivanhoe AB.

**Principal findings:** The original purpose of the Knit-on-Demand project was to test and evaluate complete garment technology. However, the investment required by the participating manufacturer was rejected as being too risky. We then considered using fully-fashioned or cut & sew production methods. Those technologies involved different set-ups and placement of the CODP in the production line. Cut & sew has the fastest order-to-delivery time, since panels can be knitted and kept in stock until a customer's order is received. Value adding time in the production process was 126 minutes for a fully-fashioned product. However, when the cost of the garment is figured, the total time allotted to each operation is calculated using standard allowed minutes (SAM). This differs from actual lead time, depending on how much set-up time a process is allowed to have. In the knitting production step, the allowance is 100% due to downtime, set-up time, and problems that

might occur in manufacturing a garment. Using SAM, the total lead time equalled 179.7 minutes.

The delivery time is one or two days to the store but the product can also be delivered directly to the customer by post. Total lead time from customer order to delivery of the product varies from one to three weeks. The analysis of the co-design process viewed that most clients make minor size changes to products, supporting the market need for MC knitwear.

## Discussion

### Analysis of Research question 1

**Research Question One (RQ1):** *How does the co-design process function in the customisation of knitted fashion garments?*

In order to analyse the RQ1 a cross-case analysis method was performed. The case study method is used in Articles 1-4. Data was collected along with simulations, interviews, and observations. The result of using manual or digital co-design is illustrated in Table 3.

Crucial factors for the interaction process between a customer and the company were identified as *risk of having to wait on line (queuing), efficiency, service, co-design tools, programming of the knitting machine after point-of-sale, and internet access*. The factors are rated according to whether they affect the co-design process positively, or negatively.

The analysis shows that the positive factors in the manual co-design alternative are a high level of service provided to the customer and no need for a co-design tool. On the negative side, however, are the risk of queues, a low-efficiency level, no Internet ordering possibility, and the need for time-consuming programming of the knitting machine after the point-of-sale.

Positive aspects		
Article	Manual co-design	Digital co-design
1	High service level	
2	High service level No need for co-design tool	
3		Low risk of queues High efficiency No knitting machine programming required after POS Internet sales possible
4	High service level No need for co-design tool	
Negative aspects		
Article	Manual co-design	Digital co-design
1	Risk of queues Low efficiency Need for co-design tool Knitting machine programming required after POS No internet sales	
2	Risk of queues Low efficiency Knitting machine programming required after POS No Internet sales	
3		Low service level Co-design tool needed
4	Risk of queues Low efficiency Knitting machine programming required after POS Internet access; no	

**Table 3:** Cross-case synthesis of data in analysis of Research Question One (RQ 1).

The positive aspects of the digital co-design process are efficiency in serving multiple customers at once, no knitting machine programming needed after point-of-sale, and the possibility of Internet ordering. Conversely, the customer is given no personal service and the retailer must invest in a sophisticated co-design tool (or several).

## Analysis of Research question 2

Research Question One (RQ2): *What are the advantages and disadvantages with manual co-design compared to a digital co-design process?*

### Manual co-design

Manual co-design is defined as an interaction between the client and a shop assistant in designing a garment without the aid of a digital tool. Manual co-design offers advantages, as has been shown in the study of Factory Boutique Shima, described in Article 3. Body measurements are taken to achieve a perfect fit, and colours, patterns, structures, and attachments are selected with support of staff in the store. This collaboration between customer and store personnel is a process that customers often find positive. Lampel and Mintzberg [30] define this as “tailored customization”: the company shows the buyer a prototype and then modifies it to the customer’s preferences. A similar dialogue with the customer is termed the “collaborative” approach by Gilmore and Pine [31].

The simulations presented in Articles 2 and 4 indicate the problem inherent in manual co-design is the limited number of customers who can be served at any one time. Perhaps this can be remedied by scheduling appointments, as people are in the habit of doing with their hairdresser or tailor. If the co-design process can be planned in advance, client frustration while waiting to be served can be minimised.

The Knit-on-Demand concept uses a manual co-design process in which the customer is allowed to change four of the garments parameters: model, fit, colour, and details (Article 4). Larsson, who has studied this approach, found that store personnel and customers both wished they had a tool that visualised the customer’s choices [46].

Huffman and Kahn [47], concluded that customers prefer a limited number of *attribute-based* options that are presented by a shop assistant, rather than an *alternative-based* system in which customers are confronted with numerous possibilities to choose from on their own. Both in Factory Boutique Shima and in the Knit-on-Demand case, a manual co-design process was used with an attribute-based selection of alternatives along with the guidance of store personnel.

### Digital co-design

Digital co-design incorporates a digital tool in the interaction between the client and a shop assistant in designing a garment. The interface between the company and the customer is a crucial process in MC. Customer satisfaction depends on obtaining accurate body measurements and getting the computer screen to display the true colour of the finished garment.

The MC of complete knitted garments is made more efficient through the use of a co-design configurator. Analysis of the manual and digital customization concepts and the simulations in Article 3 show the strength of such a tool, which is IT-based [48-50]. More customers can be served via computer co-design than by a manual process, reducing the number of store personnel involved and potentially lowering costs. In addition, a configuration tool enables customization over the Internet, allowing a retailer to engage in e-marketing.

The digital system examined in Article 3 offered the following advantages:

- Most customization can be done by a client working unaided with a configurator
- Limited programming of a knitting machine is required after point-of-sale
- A configuration tool makes retailing of customised garments on-line possible

The drawbacks include obtaining a client’s measurements and the limited number of design options that current knitting machine technology offers. The Swedish company Tailor Store shows customers how to take their measurements on their website. Offering an increased selection of styles, colours, and materials might encourage more customers to purchase customised garments on-line.

### Findings

The co-design process can take place at a shop, through an on-line configurator, or use a combination of both concepts, as described by Reichwald, Piller and Mueller [50]. Thus, a customer can be personally guided through the customization by a shop assistant, a process the authors find advantageous because of the reassuring direct interaction it allows. The same customer can later access an online tool to place a reorder. Such manual co-design is preferred by many customers for the personal service it affords, especially for clothing in the higher price range. Stores that already have an established staff may consider adopting such an MC concept if they wish to expand their business strategy.

Manual co-design does not require a great investment and do not require a digital configuration tool. Such an expense may be too much for a small company, as we found in the Knit-on-Demand project (Article 4). Larsson [26] concluded that most customers were not concerned about lead-times or price. On the other hand, offering to deliver a customised garment in 3 to 5 hours (see Article 1) might it be a considerable advantage for a retailer.

A great benefit of the digital co-design system was the pre-programmed options in the configurator. These eliminated or greatly reduced manual reprogramming of the knitting machine, thereby expediting the manufacture and delivery of the finished product. This corresponds to that all known mass customisers use systems that are to some extent IT-based as mentioned in the Frame of Reference of this thesis.

The future of mass customisation of knitted garments looks bright for co-design systems of the kind we have considered. Perhaps shops like Factory Boutique Shima or Knit-on-Demand will one day offer their clients the opportunity to design a product that is knitted in the shop and delivered to them within hours. We may also see collaborations between retailers with an insight into fashion trends and efficient knitwear manufacturers for the development and production of co-designed products. Soon the technology will be available that can facilitate the growth of stores devoted to the MC of fashion products with a minimum of help from shop staff.

### Conclusions

The overall research objective of this article stated in the beginning was: *How can complete garment knitting technology be applied in a retail concept for customised garments?* A strategy for mass customised knitted garments using a manual co-design process was developed

in collaboration with SOMconcept AB and Ivanhoe AB and tested in the SOMconcept store in Stockholm. Manual co-design was also examined in a case study at Factory Boutique Shima in Japan, where an analysis between this system and Shima Seiki's Ordermade system was conducted.

MC of knitted products requires specialised production facilities located in the retail store, at a near-by facility, or at a remote location linked by good shipping facilities. If production takes place in the store, it is possible to customise and deliver a garment to the customer in 3 to 5 hours. If the garment is manufactured at another location, the total lead time from customer order to delivery can range from 1 to 3 weeks. Both systems operate within a relatively short lead time compared with mass-produced products sold at ordinary fashion retailers. In the MC process itself, two kinds of interactions are feasible between the company and the customer: manual or digital co-design. A manual process, in which the customer is actively involved in the design, but guided by a shop assistant, is the basis of concepts like Knit-on-Demand and Factory Boutique Shima. Manual co-design does not require advanced technical equipment, as all the information can be entered by hand onto a customization form that is then sent to the production department. However, manual co-design is labour intensive, since a shop assistant can only serve one client at a time. It also is only applicable to brick-and-mortar stores and not transferable to the Internet.

Digital co-design, on the other hand, encourages customers to do the customization on their own, without the aid of sales personnel. If a store has an ample number of configurators, there will be little risk of queues. Moreover, this technique is ideal for the Internet. The problem of taking body measurements, however, awaits a satisfactory solution and still requires help from shop employees. If customers can be encouraged to this by themselves, as some on-line retailers like Brooks Brothers and Land's End in the US have shown, mass-customised knitted garments could be widely sold on the Internet, thereby reaching vast numbers of customers. Tailor Store is another example of an Internet MC shirt retailer whose customers take their own measurements and enter them on the company's web page. Complete garment technology is also more economical for the manufacturer: there is no material cut-loss, and a minimum of costly post-knitting processes are needed. Disadvantages to date have included limited design options and the need for custom programming of the knitting machine. (In the digital co-design system studied in this thesis, the design options were pre-programmed in the configurator and so a customised garment could be knitted without delay).

Mass customised garments are especially suited for people whose bodies do not fit standard sizes or who wish to create a garment with a unique design (Larsson, 2011). Providing a purchaser the satisfaction of a perfect fit, an original creation, rapid customization, and the opportunity to try one's hand at fashion design opens up many new retail possibilities.

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