A Perspective on Seamless Woven Garments

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A Perspective on Seamless Woven Garments

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ABSTRACT

Seamless garment technology is apparently a sustainable and efficient garment-manufacturing approach. This technology is already used in knitting for sportswear, hosiery and other knitted garments. Garment industry relies mainly on weaving technique; therefore, seamless weaving also needs to be studied for its further exploration. This review paper aims to investigate the prevalent techniques for seamless weaving in the textile industry and to explore its future prospects.

KEYWORDS

seamless weaving technique; seamless garment manufacturing; sustainable; textile industry

Introduction

The factor of sustainability is crucial for any Textile and Fashion Industry. It is an umbrella term which covers from efficient power and other required resources to economical raw material to eco-friendly wastage. Besides being cost-effective, it has to be long-lasting and endurable in use to maximize the resource utilization. Seamless weaving technology seems to be a viable option in this regard as it produces garment directly on the loom and conserves time, energy and labor. Nayak and Padhye (2015) enumerate the stages required in conventional garment manufacturing process like fabric and trim sourcing, pattern making, laying and marking, cutting stitching, finishing and zero wastage which become redundant in the cited technique/seamless weaving technique. Despite of its immense potential, viability and durability, the seamless weaving technology has remained a comparatively less-explored area in Textile industry.

For standard two-dimensional weaving process, a woven fabric is achieved by orthogonal interlacing of lengthwise and crosswise yarns. The weaving method developed in early civilizations was found to be done with or without loom consequently giving either two-dimensional or three-dimensional woven fabrics or products. Weaving involves inserting wefts into warps, to form an interlaced structure known as woven fabric. Woven fabric is identified by the order or pattern in which the yarns are interlaced (Wu et al. 2020). The warps are either raised or lowered before adding wefts during weaving depending upon the required fabric structures. This process of lowering and raising the warps creates diamond-shaped opening called shed through which the wefts pass known as shedding. The beating-up involves the pushing of a weft yarn against the previously inserted weft yarn by the reed (a comb-like structure made of evenly spaced set of wires). The repetition of shedding, weft insertion and beating-up results in the formation of a woven fabric (Choogin, Bandara, and Chepelyuk 2013). However, the idea of three-dimensional seamless forms could have been developed.
and inspired from nature such as a bird nest and a spider web. These 3D structures evolved with time and created concept of 3D weaving for textiles and clothing (Gill 1916). The identification of linear to 3D basketry is explained in Figure 1, which can be transformed into seamless fashion when used in large scale (Larsen and Freudenheim 1986).

In comparison with knitting, it is a challenge to create a fully functional seamless garment using weaving method due to the need to interlacing two sets of predetermined yarns. This is one of the reasons that a seamless woven garment cannot easily be found, whereas seamless knitted garments can (Piper and Townsend 2015). Another reason for the underdevelopment of seamless weaving is the tendency of woven products to become loose and the characteristics of unravelling/fraying of threads (Seyam et al. 2014). Up to now, very rare research work can be found on seamless woven fashion, although studies on seamless weaving have been reported for applications in medical (Du 2013, 2014, 2016, 2018; Goldmann, Merckle, and Sievers 2014; Singh, Wong, and Wang 2015), industrial (Hübner et al. 2016; Sugun and Sandeep 2016; Umair et al. 2015; Zheng et al. 2013) and technical textiles (Bhattacharya and Koranne 2012).

**Techniques used in seamless weaving**

Double or tubular woven textiles have the potential to be used for various purposes such as medical prosthesis, intelligent garment or artwork. Seamless weaving is majorly capable of producing semi-finished woven articles without side seams, but few studies proposed ready-to-wear seamless woven garments discussed later in this article. The technology of seamless garments starts with yarn (one-dimension) to a ready-to-wear article (three-dimension). The concept of seamless refers to clothing with no seams (specifically lateral seams) or very few

<table>
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<tr>
<th>Single Unit</th>
<th>Linear</th>
<th>Planar</th>
<th>3-D</th>
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<tr>
<td>knots</td>
<td>Macramé knot</td>
<td>mat knot, nets</td>
<td>knots</td>
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<tr>
<td>braid</td>
<td>Flat braid, sprang, bobbin lace</td>
<td>3D braiding</td>
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<td>woven tape</td>
<td>plaited mat, weave spiral/radial disc</td>
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*Figure 1. Different types of interlacing – linear to three-dimensional (Larsen and Freudenheim 1986).*
seams. The availability of seamless technology through weaving is limited, and majority of research is carried on the technical issues and purpose other than clothing (Broega, Catarino, and Biolo 2010). Several methods have been researched for seamless woven garments. The conclusion from these studies made is that the fundamental requirement for seamless woven textiles is to develop cavity for the body/wear. Cavity is formed by producing double cloth or tubular weave as shown in Figure 2 (Gokarneshan 2004). Double cloth is combined with various other structural factors to experiment the seamless woven products. Apart from double cloth, the use of yarn shrinkage has also been practiced forming varied shapes in a garment. Similarly, the use of different types of weaves and pick density has also been experimented to shape the garment (Seyam 2011).

A considerable research work has been done to produce seamless garments that require little or no cutting and sewing. However, many methods have production limitations (in terms of speed, labor intensity, level of difficulty), or equipment limitations (specialized looms or required loom parts), or functional/performance limitations. Using weaving looms such as circular weaving machines is also capable of producing tubular textiles (multiphase weaving looms) (Adanur 2020). Seamless woven products developed so far employed various techniques such as use of tubular weaving, engaging and disengaging warps on the loom, adaptations of loom, use of different shaped reed, using different densities of warp feeding to create bulging shapes, use of jacquard weaving and applying shrinkage phenomenon by using stretch yarns or high twist yarns or weaving different patterns of garment on loom and then assembling through stitching. These techniques are categorized on the basis of variations brought in basic weaving mechanisms such as by controlling warp letting off, shedding, pick insertion, beating-up and woven cloth taking-up.

**Manipulating weave mechanism**

**Flat weaving**

Weaving a rectangular shape is one of the simplest activities for weaving straight rectangular garment and keeping front and back of the garment folded. An example of inherently flat weaving is woven vest in which the neck opening is not woven, and the unwoven warps are cut away after the vest is complete. The two sides can be joined together under the armpits. Similarly, the neck opening of a woven kimono is left unwoven and the free ends were cut once weaving is complete (Held 1978).

Jayaraman and Park’s (2002) showed a complete one-piece garment with sleeves that requires little cutting and sewing after weaving. In Figure 3, a complete guide of garment is given with the front and back bodice along with sleeve, which is produced as the whole 2D garment (Jayaraman and Park 2002). However, this method can only produce a flat garment without any shape which is not adequate for garments with fashionable silhouettes. Another type of seamless woven garment with intelligence capability was also reported as shown in Figure 3(b) (Jayaraman and Park 2001). This seamless garment is also a one-piece garment with sleeves produced by using fully-fashioned weaving process. Three different weaving structures were used at different sections of the garment including tubular, double layer and self-stitch weave structures. This garment has no conventional seams or discontinuity. The sensing component incorporated in the weave of garment makes it capable of monitoring body signals and garment penetration. This garment also does not suffice the fashionable silhouettes due to its flat and straight shape.

![Figure 2. Double cloth and tubular woven structure (Gokarneshan 2004).](image-url)
Narrow loom
A tapered woven tubular structure of preset length was developed using a conventional shuttle loom. It was designed for an impermeable spacesuit limb cover as a flexible protective structure. The tubular structure can be achieved by terminating warps. Before the weaving process, a certain number of warps were cut shorter than other lengths. Warp yarns which were cut terminated at specified length to give a tapered shape. It was then woven with weft yarn which formed a complete sphere around the entire length of the sleeve, creating a tapered sleeve. The length of warp ends and the amount of short

![Diagram of garment sections](image1)

**Figure 3.** One-piece garment.

![Diagram of garment with sleeve](image2)

**Figure 4.** Woven tubes using a conventional loom.
warp yarns control the extent of the taper of the tube. Once woven, further stages of the finished sleeve are shown in Figure 4(a) (Lapointe, Wright, and Vincent 1987). However, this method is slow and interrupted as it stops each time when the warps need to be clipped.

In a research it was found that textile grafts could line arteries and prevent from blood clotting (Blakemore and Voorhees 1954) followed by the development of tubes from sail cloth which shows the correct observation and leads to what is known as arterial reconstructive surgery (Callow 1986). Nowadays, several manufacturers are producing polyester textile prosthesis in a wide variety of configurations, shapes, sizes and compositions.

A woven tube is a tubular fabric formed by joining two-dimensional fabrics at the edges with a consistent diameter. To make a seamless tube, shuttle loom was engaged with weft yarn loops peripherally from the bottom to the upper layer warps (Clarke 2000). Apart from simple tubular shape, prosthesis shown in Figure 4(b) can also be manufactured in split/bifurcated shape. As the name indicates, split shape means that one tube splits into two branches. For such woven structure, a narrow shuttle loom with multiple shuttles can be employed. For the main/joint part of the tube, weaving can be done with one shuttle, where the branches require two shuttles to weave two tubes simultaneously. Figure 4(c) represents the tear-shaped bulge of ascending aorta in which straight tube is sewn with three individual parts of woven textile at one side of tube. This prosthesis is produced manually and hence is inefficient in terms of time, chance of human error, labor intensity and potential for defects (Anderson 2005).

Another seamless woven product for damaged arteries is Gel weave Valsava™ which was developed by Vascutek Ltd – one of the leading companies of designing and manufacturing vascular products for treating cardiovascular disease (Vascutek Ltd 2019). Gel weave Valsava™ comprises three segments – body, skirt and collar, as shown in Figure 4(d). The skirt lies between the collar and body of the graft, and skirt and collar are sewn with the body of tube. Though the product is superior and improved than straight tube, it is labor intensive, costly and susceptible to human error since it is hand-sewn (Singh, Wong, and Wang 2015).

By controlling beating-up mechanism
Adaptations and adjustments in the weaving machines and their parts may be required in order to produce varied shape of woven textiles. Most of these adaptations are exploratory and have not yet been widely used by the weaving industry. Bringing variations in the density and direction of weaving yarns both warp and weft through re-invented devices can help to transform the two- and three-dimensional shapes of woven textiles. Different prototype textiles have been reported such as spiral (Aucagne and Martinet 1993), three-dimensional (Horovitz 2000) and shaped tubes via Faber’s reeds (Anderson 2005). The number of shapes achieved through this method was limited.

There is a possibility of using an adjustable reed to produce shaped fabric. Adjustable reed is supposed to have its dents pushed apart or close together, and the warp density would be controlled with this movement without re-drawing the warps. Fan-shaped reeds, also called ondulé reeds (The Wool Gatherers 2017), were initially used for adjustment of warp yarns width-wise to be fit on the warp beam. Apart from width adjustment, the fan-shaped reeds were also used to produce fabrics with decorative designs. As the name indicates, fan-shaped reed has inclined (angled) dents. The size of the fan reed varies according to the end use of fabric. Figure 5(a) represents single fan-shaped reed continued across the width of loom, and Figure 5(b) represents small multiple fan-shaped reed. The working mechanism of reed involves a lever/treadle to move the fan-shaped reed up or down after each weft insertion. This movement displaces the warp yarns for each dent and changes the number of warp yarns per unit length in order to press yarns sideward (warp displacement as shown in Figure 5(c)), giving an undulating structure along warp direction (Seidl and Kellenberger 1993).

Apart from wavy structure, fan-shaped reeds are capable of producing tubular shaped silhouette. A single fan-shaped reed is fitted on a shuttle loom, through which the warp width can be easily adjusted by elevating or dropping the lever. Such shuttle loom can produce seamless tubular shapes, presented in Figure 5(d). However, the reeds installment is limited only to looms with reed motion in
horizontal direction while beating up. In high-speed looms where reed turns during the beating-up process, it will lead to up-and-down movements of warp yarns within the dents of reed. So, if the fan-shaped reed moves in up-and-down mode in an angled dent, it will cause abrasion and breakage of warp yarns, and unintended fabric width. In order to have more shape choices through weaving, the reed needs to be designed more inclined (greater degree of angles). This requires larger reed which makes the reed heavier and consequently difficult for the adjustment, resulting in slow weaving operation. In addition, the resultant fabric has diverse warp densities due to warp displacement. There is less shrinkage in areas with more warps and more shrinkage in areas with less warp ends (Anderson 2005).

Figure 5(e) presents the working mechanism of Ashford table loom with fan-shaped reed, which is suspended freely with two cords in order to have flexibility in design. The up-and-down movement of reed is aided by the two buttonhole cords and arrow pegs. The cords attached to the reed are wound through the holes already present in the overhead beater (The Woolgatherers 2017).

Some applications of seamless woven textiles are not for clothing. Weaving method can integrate single- and multi-layered textiles which can also be converted to shaped textiles by some designers and researchers (Bhattacharya and Koranne 2012). A device is developed for 3D preforms straight from loom including 3D shell shape (refer to dome shape in Figure 5(f)). In studying woven 3D shapes, Busgen (1999) worked on a weaving machine that is controlled through computer with fixed shaping devices attached to it. The shaping devices are responsible for controlling the length of warp and weft yarns, and yarns are over fed at those areas where bulge or dome is required. After setting up the weave details in software, a separate design method is present for the shell-shaped structure and set jacquard program permits interlacing to be
allocated to precise areas of the shell-shaped structure. There are other factors that are adaptable such as fabric layers, connection between layers and the length of weave floats. Weft insertion information is also fed in the software as per the required shape of shell, whereas warp yarns must pass from a specified creel for regular tension as warps are in different lengths. Manual work makes this process costly, and inaccuracies may present in terms of quality control (Buesgen 1995).

By controlling shedding mechanism
Seamless woven garment has more options for different weave integrations with jacquard weaving (Ng et al. 2007). A study was carried out to investigate the basic design and manufacturing of seamless shapeable garments by using jacquard shedding mechanism. Variation in weft yarn configuration and type of weave gave different dimensional changes and novel textures in the finished woven textile. Comparative experiments were conducted on two groups with different weft yarn combinations. Two different weft yarns (A and B) were employed: yarn A comprised of nylon/spandex, and B was non-elastic viscose yarn. As shown in Figure 6(a), Group 1 was woven with only weft yarn A, whereas group 2 was interlaced with both weft yarns A and B on alternate basis. The study found: (1) Group 2 gave rougher and warmer surface than Group 1. (2) Tighter weave gave crinkled texture, while loose weave resulted in uneven texture. (3) Weft faced weave structure had naps on the surface while warp faced had a glossy appearance. (4) Three-dimensional forms were influenced by weft shrinkage, i.e., with more shrinkage in weft, the vertical lines of three-dimensional shape bent more, and vice versa (Wang et al. 2009).

Shapeable woven garments were produced by Ng, et al. (2010) using compound weave on Jacquard loom. Earlier discussed shapeable seamless garments were investigated using simple weave in which warp and weft were on the same layer of the woven cloth (Wang et al. 2009). However, in this study compound weaves with jacquard weave design were employed. In stitching weave as shown in Figure 6(b), one set of weft yarns (face wefts) is woven with warp yarns and at the same time more weft yarns need to be arranged in the base layer to be interlaced with warps. The resultant woven product has weft-faced on face and warp-faced on back. In experiments it was found that with weft-backed and self-stitched double weaves, the appearance of the final woven products has more options of transformation in texture, silhouette shape and color. The garments produced with compound weaves are heavier and therefore suitable for winter wear (Ng et al. 2010).

Leffert used jacquard method to produce three-dimensional garment using synthetic yarns. The purpose of using synthetic yarns in her research was that upon heat cutting the fibers were bonded and not to be raveled. The completed woven garment only required minor finishing by cutting extra yarns and turning over. Apart from three-dimensional woven garment, Leffert also worked on her sustainable collection named as TWO (To Weave Objects) which was a sustainable approach achieved through one process of producing woven objects rather than cutting and sewing from 2D flat fabrics (Lefferts 2016). Figure 6(c) presents a top produced through jacquard weaving with its final product’s illustration.

Bae and Donaldson (2005) suggested a seamless jacquard woven shirt by applying double weave structure, in the bodice areas along with sleeves, whereas single-layer cloth with 2/2 weave was used for seams. The jacquard seamless shirt is presented in Figure 6(d). As reported by authors, weave structure must be selected carefully as it must provide the same amount of tightness at different areas made of double- and single-layer cloth; otherwise, it may cause ruffle at the edge. When weaving was complete, the shirt shape was cut, single-layer cloth of 0.5 inches was left as allowance for outside seam. The woven shirt was flipped inside out to make it ready to wear.

Piper also suggested shaped garment using jacquard weave shedding mechanism, by which 3D weaving production with minimal wastage was achieved. This method also eliminated wastage of fabric during cutting by making exact shaped patterns (Piper and Townsend 2015). Figure 6(e) shows woven pattern being made on loom and the final woven jacket with its illustration (Dekhla 2018).
By controlling warp yarns

Nuñez and Schmitt (1998) produced a seamless tubular-shaped woven textile be used as prostheses by changing the number of warps along the length of the product. Before this graft, where change of diameter is required, the diameter of a tubular textile is changed by slashing and sewing, as shown in Figure 7(a). To remove this slashing and sewing line, warps are disconnected where tapered shape is needed.

For this shaped tube product, shuttle loom with Jacquard shedding motion is required; it is controlled by computer-aided design system. The structure is achieved by disengaging pre-defined warps and weft yarns that are not interlaced according to the shape requirement of tubular woven graft, presented in Figure 7(b). The warps are engaged once the tapering is achieved. Once woven, graft is taken for heat setting process. Disengaging warp approach can produce variety of tapered shapes also including split or bifurcated and trifurcated grafts, presented in Figure 7(c). When weaving a bifurcated or trifurcated graft, warp yarns are required to be split evenly at crotch area so that the tubular graft can be woven into two or more separate grafts. The division of yarns is made in such a manner that an odd number would form continuous plain weave tubular. So, it is to be kept in...
consideration that while the warps are split at the crotch area for bifurcated graft, both tubes must be woven simultaneously with odd numbers; otherwise, it would result in false weave pattern at the fabric edge of any tubes. This is because the disengagement of warps (See Figure 7(d)) lets an end to be disconnected in interlacing, thus allowing only odd number warps to be woven on both tubes. This method can only be used to produce gradual taper in the woven tube as disengaging of warps will create more taper shape, but it can also cause holes if more than three yarns are disengaged. Apart from its structure, a creel is always required to maintain tension during weaving as disengaging of warps can cause inconsistent tension and slackness of disconnected warps causing yarns to break. Manual cutting is time-consuming and causes yarn wastage (Nuñez and Schmitt 1998).
A weaving machine named as “Bemm” was invented for making seamless garments, which is capable of engaging and disengaging warp yarns according to the design requirements. Some parts of the loom including cloth beam, warp beam, reed, harnesses and breast beam are remodeled synthetically for the use of producing seamless woven structures and garments. However, woven garments made by the loom are flat and plain, and the machine still requires further development for its effective applications especially for seamless garments (Yengkhom 2006).

Primentas and Primentas (1997) have also experimented a seamless tunic by devising a mini version of vertical loom, as shown in Figure 7(e). In the loom warps are passed over the string attached to the U-shaped frame in such a manner that half of warp length goes to both sides, i.e., right and left. The warp yarns are fastened to pins affixed with a block at the bottom of frame. These blocks are arranged to pass weft yarn through warps (shed). Weft yarns are inserted through a shuttle which is passed through the warp yarns to make the neck and shoulder area of the tunic. Once the neck opening and shoulder are made (see Figure 7(f)), the second shuttle is used so that the two shuttles with each from front and back side of the tunic. The front and back fabric pieces keep detached until the armholes of the tunic are created. When the armholes are formed, the second shuttle is taken off and a tubular woven structure is continued until the desired length is formed. This method needs detailed manual work. It makes the method very difficult to produce with modern weaving techniques.

There is a method of combining connected and unconnected double woven construction employed in the construction of seamless airbags. Dobby or jacquard looms can be employed to weave these seamless airbags. Dobby loom has design limitations, i.e., circles with squared edges could only be produced, due to limited control of warp yarns, whereas jacquard loom has fewer design limitation as every warp yarn is controlled individually. Plain, twill and satin with variety of their variations have been used for this woven product using polyester or polyamide yarns. The airbags are constructed by employing a combination of attached or unattached double weave, shown in Figure 7(g). When weaving is complete, coating of the woven polymer material is applied on both sides and a hole is made in every disconnected area of woven structure (Kitamura 1998).

**By controlling weft yarn materials**

Anderson and Seyam (2004) developed a 3D shaped seamless woven fabric by the use of shrinkable polyester yarns at different sections of the woven product for medical applications. Shrinkage factor along with weave structure is an integral parameter to be considered to produce shaped seamless garment. The higher the number of interlacing, the lesser the shrinkage (Topalbekiroğlu and Kaynak 2008). Seyam et al. (2014) employed the shrinkage of weft yarn and variation of weave structure to form tubular woven garments. In their experiment, warp kept unchanged, whereas weft yarns and weft density were experimented with different weave structures using dobby shedding. Spandex was used tactically at specific areas where shrinkage was required to meet the shape requirements of the garment. However, stitching was used at certain areas for finished look, shown in Figure 8(a).

The combined use of elastic and non-elastic yarns in weaving can shape the whole garment and form gathers in a woven fabric. This weaving method was introduced by Sawhney (1972, as cited in Anderson, 2005). This integral weaving method involves tubular weaving along with the use of yarns with varied shrinkage to produce seamless garment. Silhouette shape and fullness are given in various sections of the fabric by employing elastic and non-elastic yarns. As shown in Figure 8(b), a 5-end sateen weave was used for zone A and B of the garment. For zone A, the upper portion of skirt where shrinkage is required, weft with elastomeric core was used. For zone B, where required a wider area, regular cotton yarn was used. The weft yarn used in zone A causes an appreciable peripheral shrinkage in the fabric in relaxed position, whereas there is no considerable shrinkage in zone B. Gathers are formed in zone B upon heat setting of the fabric. Similarly, other shaped garments using same principle made by weaving are shown in Figure 8(c-d). This weaving produced various shapes, but it is very difficult to weave elastomeric weft yarns. For this reason, the tension of yarns must be controlled precisely throughout the weaving process (Sawhney, 1972, as cited in Anderson, 2005).
Figure 8. Variations in use of weft material.

(a) Seamless woven garments (Seyam et al. 2015).

(b) Elastic and non-elastic yarns (Sawhney, 1972, as cited in Anderson, 2005).

(c) Different stretch yarns (Sawhney, 1972, as cited in Anderson, 2005).

(d) Pre & post finishing (Sawhney 1972, as cited in Anderson, 2005).

(e) Seamless garment in multiple ways of wear (An 2019).

(f) Hollow woven structures using heat-activatable materials (Lowe 1985).
An (2019) also examined yarn shrinkage with high twist wool yarn for seamless garments. This study reveals various textural effects and shapes by using yarns’ characteristics such as yarn shrinkage mentioned previously with work done by Ann Richards. Unlike research work discussed earlier, in order to understand the yarn shrinkage for seamless garment, different combinations of weft and warp yarns were experimented in An’s work. It was reported that fabric sett and weave structure affect the shape of finished fabric, but shrinkage is the main characteristics of creating seamless woven fabric shapes. Based on the calculation results, yarn was inserted in the required area to achieve the desired shape. In his experiments it was observed that the finishing process caused 10–15% of shrinkage. In Figure 8(e), a versatile seamless tubular woven garment is given which can be styled in multiple ways.

Certain hollow woven structures are woven with thermoplastic fibers which help in bonding with each other. Figure 8(f) exhibits the hollow woven shaped structures comprising heat-activatable materials whose inherent shape achieved through weaving (Lowe 1985).

Several research works executed the successful development of seamless garments emphasizing shapeable stretch. There are seamless woven garments with shapeable stretch for better fitting and structure with variations of simple and compound weaves (Ng et al. 2010; Wang et al. 2009). Concept of three-dimensional seamless woven garments (Wang, Ng, and Hu 2013) and research of shaped seamless woven garments (Seyam et al. 2015) suggest jacquard method as prospect for seamless woven garments. Though the studies introduced new process for fashion industry, these studies are targeting on textile engineering side of seamless woven garments such as manipulation of weaving machinery and mechanism and functionality aspect of the fabrics.

**Seamless structures**

In A-POC (A Piece of Cloth) seamless wear collection, Miyake and Fujiwara exhibited some seamless woven garments along with the knitted whole garments. In the collection named as “A-POC Inside”, the concept of “whole panel weaving” is presented. An issue with the woven seamless garments in their collection was that the woven structures still needed sewing for assembling as a garment (Miyake and Fujiwara 2002). A-POC zero waste patterns ready for assembling to make garment are presented in Figure 9(a). The Miyake Studio also used Jacquard for complicated designs and radically experimented variations in its design such as shape of garments, density of weave, and the yarn thickness (Scanlon 2004). The methods of A-POC are sustainable and zero waste, but the proposed production process is technologically unfeasible for majority of manufacturers (Rissnan 2005). Figure 9(a) shows the cutting lines to follow in order to make the garment ready to wear (Sissons 2010).

Another example is from Manonik studio aiming to develop fully fashioned woven garments by weaving three-dimensional patterns. It includes creation of different parts of garment separately through hand weaving. Though this technique lessened the wastage as compared to conventional pattern cutting and cut and sew method, still hand sewing was required to convert into a full garment (Manonik 2014). Figure 9(b) represents the woven pattern of bodice and sleeve which require sewing to be converted into garment. Similarly, Friends of Light, a weaving cooperative of New York, has worked on hand woven jacket. Unlike conventional looms, pin looms were used for shaping 2D patterns into finished 3D garment. Figure 9(c) presents the different woven patterns of garment using the pin loom. However, the idea behind this concept was to restore craft with novelty, sustainability, reconnecting materials, processes and rejoicing faultiness (Klee 2016).

In fashion context, an Indian designer Siddhartha Upadhyaya developed fully fashioned clothes under the label of techno brand August (August 2006). The garments under DPOL (Direct Pattern on Loom) were produced by weaving shaped panels on jacquard loom. Figure 9(d) shows different woven panels and final product from these panels. The panels were cut and sewn using conventional cut and sew method; however, pattern making and cutting, and grading were eliminated in their production process (Ukey, Kadole, and Borikar 2013).
Conclusions

This review paper builds up the literature of seamless woven garments by critically reviewing the existing methods for seamless woven textiles. Very limited seamless garments were found in the literature produced using shuttle loom, and those garments have limited styles and lack of curves and sleeves attachment. The design innovations of these reported seamless woven garments have generally been based on intuition. Extensive literature review suggests the garment industry is still deficient of systematic research regarding seamless woven garments through conventional weaving mechanisms in industry. Seamless woven garment is an efficient sustainable approach in garment manufacturing as it not only prevents fabric wastage during manufacturing (patternmaking, cutting and sewing), but also consumes lesser workspace and eradicate various steps during garment manufacturing consequently saving time, cost and energy. Therefore, design innovations in seamless woven garment to be implemented in industry require more critical research which should not just be based on intuitions.

There are a number of questions developed to overcome the deficiencies in existing seamless woven garments: (1) how to develop a woven fashion item which fits perfectly according to body
shape, is comfortable and does not require stitching at all? (2) How to prevent raveling of woven fabrics without seams? (3) How yarn characteristics influence silhouette and comfort of seamless woven garment?

This review aims to develop design concept for ready to wear seamless woven garments of predetermined shape needed for body curves with focus on design practicality and aesthetics, i.e., silhouette and comfort of the wearer along with the versatility of the garment. Future research can further explore design development using different shedding systems such as dobby and jacquard and using of yarns with certain twist and elasticity by employing various weave design parameters and explore its practicality in achieving the shape of garment. This will help in critically evaluating different relationships among design factors and their functionality in seamless woven garments in light of performance and comfort.

**Highlights**

This review paper aims to investigate on the prevalent techniques for seamless weaving in the textile industry, to explore its future prospects and build up the literature of seamless woven garments by critically reviewing the existing methods for seamless woven textiles. This paper categorizes the literature on the basis of weaving mechanisms such as controlling of beating-up mechanism, shedding mechanism, warp control, weft material and seamless pattern.

There are a number of questions developed to overcome the deficiencies in existing seamless woven garments: (1) how to develop a woven fashion item which fits perfectly according to body shape, is comfortable and does not require stitching at all? (2) How to prevent raveling of woven fabrics without seams? (3) How yarn characteristics influence silhouette and comfort of seamless woven garment?

**Disclosure statement**

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