Designing Shape-shifting of Knitwear by Stitch Shaping Combinatorics:

A simple mathematical approach to developing knitwear silhouettes efficaciously

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Abstract: This paper describes recent design research into computerized fixed needle count high fashion knitting using computer controlled electronic V-bed flat knitting machine with Seamless garment design and manufacture. This approach is simple, fast and financially economical compared to other methods of shaping knitwear. The research investigated the shape changing effects of 240 different combinations of 14 knit structures in an upper body model garment comprising three different knit structures. In the course of the research, two new forms of data collection instruments and a semi-computerised comparative measurement system were devised by the first named author. The outcomes of this research included: A new semi-computerised standardized approach to measuring knitwear. The research outcomes offer benefits to designers, manufacturers, and consumers by shortening the design process time, improving production efficiency, improving garment shape, and reducing shape changes in use.

Key words: Computerised fashion design, knit garment shaping, sample measuring.

1. Introduction

To date, computerized wholegarment® and seamless knitwear development has been predominately focused on a small suite of common garment patterns (e.g. simple sweaters) for the retail market in which changes to colours and patterns and small details can be made along with the development of a graded range of sizes [1, 2].This is in spite of computerized wholegarment ® and seamless knitting being widely regarded as a major radical improvement in the knitwear design and production worldwide.

The development of the use of this high tech knitwear technology from a designer's perspective or for high fashion design is not yet well developed. This paper and the underlying research provide some contributions to this new field of study. The investigations of this research are part of a larger program of research by the first named author investigating the application of computerized wholegarment seamless knitwear technology into the design and garment production of the high fashion knitwear industry sector. Such exploration of opportunities in semi-automated computerized high-fashion design-led knitwear design and production, particularly wholegarment (seamless) knitwear production of the sort developed and patented by Shima Seiki and Stoll are important because it offers potential to revolutionize both the retail and high fashion knitwear industry worldwide.

This paper reports design-focused research by the authors exploring three issues in the development of design-led use of wholegarment® /seamless computerized knitwear design and production technologies:

- An investigation into how knit structure can be used in fixed needle count computerised wholegarment knitting to produce significant shape changes in a predictable manner
- An exploration of whether a combinatorics approach from Mathematics could provide the basis for identifying and displaying patterns of shape structures of use by high fashion houses in terms of mapping style opportunities. This was demonstrated in terms of the permutations and combinations available through combinations of triplets of knit structures on a model upper-body garment in computerized whole garment knitting
- An investigation into the development of a new knitwear shape measurement technique that improved significantly on flat sample swatches in the identification of garment silhouette when the garment had been knitted.

Each of these issues is important to the future of high fashion and retail fashion industry with the increasing uptake in the industry of computerized wholegarment® and other seamless knitwear design and production with its economic advantages. Fixed needle count knitting offers significant production and cost advantages over other knitted garment shaping techniques such as 'cut and sew'. Underpinning this issue however has been the design problem of creating garment shape in a predictable and interesting manner. The research reported in this paper has identified and demonstrated how garment shaping can be managed with fixed needle count computerized knitting.

Another issue not yet well addressed in knitwear design is the mapping of computerized knitted garment solutions and solution spaces in general and onto house ‘styles’, and along with that, the identification of as yet untapped design opportunities in the same design solution space. The research reported in this paper developed and demonstrated the use of a combinatorics approach that provides a means to identify and delineate the design solution space of an individual fashion house style and to identify new knitwear design opportunities for designers to create garments in conform to the parameters of that fashion house’s style.

Both of the above approaches depend, however, on resolving a core measurement and sampling problem in knitwear design and production. Conventionally, knitwear uses a small square flat sample swatch to gauge the likely output size of knitting undertaken with a particular combination of yarn, needle type and number, yarn and machine tensions and knit structure. This approach provides a rough idea of average garment size. It provides no information however about garment shape of the complex of different shape gradient s that result from combinations of different knit structures. In part this is because they do not accurately represent the shape changes and in part because they suffer from significant problems of curling. The curling makes the sample impossible to measure without stretching some areas of the fabric and thus creating significant measurement errors and poor visual representation of real garment knit shapes, i.e. the ‘tubes’ common in clothing. To resolve all of these problems, the first author has developed and trialed a new semi-computerized silhouette-based tubular gauge swatch to replace the conventional flat sample swatch. This new semi-computerized silhouette gauge tube swatch approach has now been practically tested this and related research projects across hundreds of designs.

The research described in this paper was undertaken as part of a Masters study by the first named author supervised by the second named author. The research was undertaken at the Dept of Design at Curtin University of Technology in Western Australia and was supported by the Department of Agriculture and Food of Western Australia through the provision of access to a Shima Seiki wholegarment ® knitwear machine. The direction of this research has since been extended into doctoral study investigating design processes in high fashion knitwear design using computerized seamless knitting technologies, which will be reported under a separate title.

This paper is composed of six parts. Following this introductory section, the second section, describes the first author’s development of a new measurement approach for assessing knitwear shape in garment form to provide a more realistic visually and metrologically accurate representation of knit samples involving multiple knit structures. The process is semi-computerised and results in fast measurable electronic records for comparing knit samples and for prototyping wholegarment knitwear techniques. The third section describes the fixed needle approach to shaping knitwear using combinations of knit structures and identifies its advantages. The fourth section describes the use of the combinatoric technique developed by the authors, based on the work of the previous two sections. The fifth section, describes how the combinatoric approach using samples using the new tube sample model of measurement and the combinatoric approach can be used to map out knitted garment design solution ‘shape space’ for a variety of knitwear shapes and structures that provides the basis for a fashion house to identify the design space boundaries of its ‘house style’, as defined by senior designers, and provide a way of guiding new or junior designers in experimenting with a variety of options within the ‘house style ‘ of knitwear design space. The approach provides a means of indicating to designers as yet untried opportunities for fashions whilst echoing and remaining within the ‘house style’. Section six, the concluding section summarizes the paper and points to new directions in design research in this area.

2. Silhouette tubular gauge swatches: A new sample measurement technique for knitwear designers

Measurement of knitwear is difficult. The most common approach is the use of a 10cm knitted square sample – a gauge swatch. In conventional knitwear design, the first step of garment development is to create this gauge swatch, regardless of whether the garment is hand knitted or machine knitted. The gauge swatch indicates the likely size of knitting using that yarn, needle type and positioning yarn and machine tensions and knit structure. Making the gauge swatch enables the knitwear designer to estimate the correct parameters such that the garment that s/he has planned will turn out approximately the intended size. When knitted, the gauge swatch is usually bigger than a 10cmx10cm square. When it is completed, 10cm across the square is measured and marked with pins, and then the same is done vertically to provide a ten cm reference square. The number of stitches and rows between the pins is counted to provide the sizing information.

Although the gauge swatch is useful to sizing knitwear in a general manner, the standard flat gauge swatch is not helpful in visualizing the silhouette of a completed garment because it is flat and two-dimensional. It presents problems in other than plain stitch. In addition, it cannot accurately represent the shaping effects f knit structures because its curling requires that the knot shapes are distorted heavily in flattening the sample of measurement. During the research project described in this paper, it was necessary to develop a new way of measuring size and shape as influenced by the stitch structure e via the creation of 'silhouette tubular gauge swatch.

A gauge swatch can be developed with any stitch structure. Different knitted structures are, however, more or less useful in understanding relationship between types of stitch structures and garment silhouettes, shapes and size. The stitch structure sample developed during this research is a 'gauge tube' composed of two parts: a 'plain structure' part (top) and a 'sample stitch structure' part (bottom) (see Figure 1). Overall, the gauge tube is a half of the standard of a size 8 female torso. Thus, it directly illustrates the shape effect for a female torso at a size that is convenient to handle, large enough to show the shape effects clearly, and is economical in terms of yarn and sampling time used.

Figure 1: Gauge tubes

The two part tubular shape of the gauge tube is useful for two reasons. A human body is three-dimensional, not two-dimensional. Also, the human body can be simplified as tubular geometric shapes (i.e. the torso, arms and legs)[3]. The tubular shape of gauge tube also removes the not insignificant problem of curling in flat gauge swatches. From experience, it is much easier to compare the plain structure with a sample stitch structure when both are in a tubular form. A single layer of plain structure fabric curls to the technical face in the horizontal direction and to the technical back in the vertical direction. This curling of the sample swatch makes it difficult to get an accurate measurement, especially when being compared to another sample fabric with a different stitch structure.

To develop knitwear silhouettes, having a simple sample reference stitch structure is necessary to make a comparison of what kind of change occurs to another stitch structure. Expansion and contraction of silhouettes are relative phenomena, not absolutes. In that respect, 'plain' stitch is suitable for a reference stitch structure. 'Plain' is the most basic stitch structure because it is solely composed of knit stitches, one of the fundamental stitches in weft knits (see Appendix A and D).
The knitted tubular silhouette gauge swatches were post-processed via computer to provide accurate design information and for cataloguing in a way that would enable them to be potentially used in a design role via software.

The overall silhouette gauge tube sampling and measurement process consists of the following steps:

- Identify knit structures to be trialed.
- Knit silhouette gauge tube samples
- Place samples in scanner and scan to graphics software.
- use software to semi-automatically generate smoothed shapes of accurate size to represent the swatches
- Overlay these computerized representations of the garment shapes onto a measurement grid using the graphic software.
- Catalogue the sample graphics with knit data in a database

Examples of typical computerized graphic representations of standardized gauge tube samples are shown below in Figure 2.

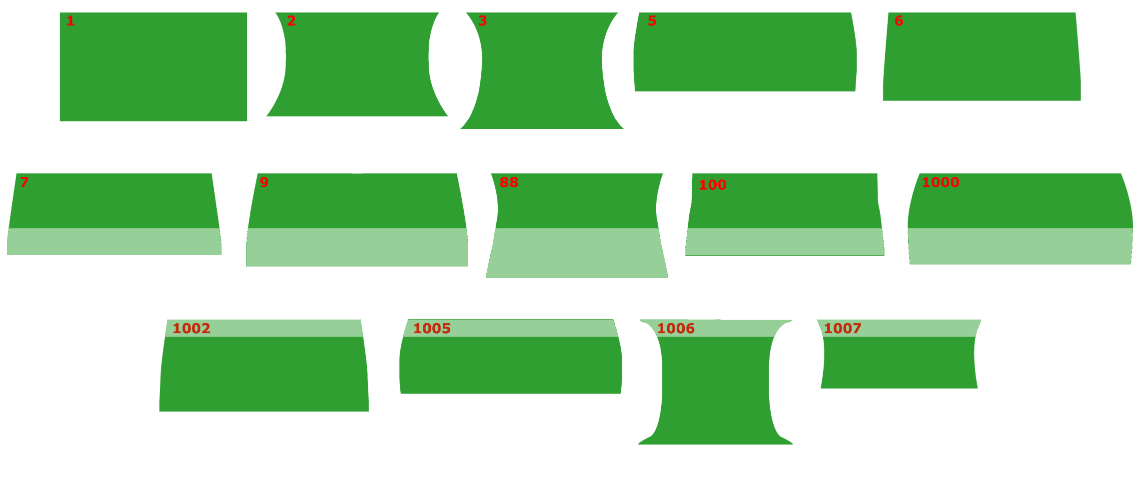

Figure 2: Graphical representations the bottom section of the gauge tube

The experience from this research is that knitwear designers can be expected to get a direct idea about the garment shape at the beginning stage of the knitwear design development process by creating the new gauge tube swatches described above.

3. Shape Changing in Fixed Needle Count Computerized Seamless Knitting

In knitwear, garment shape can be significantly changed by *stitch shaping* that is ‘changing the nature of stitch structures without altering the total number of needles that are in action’[4], That is, changing the stitch structures changes garment shapes. This form of knitwear shaping is important because it is simple, economical and fast compared to other shaping methods of knitwear such as 'cut and sew'. Stitch-based shaping keeps needle numbers constant and uses the fact that areas of a garment that have different knit structures have different widths and lengths for the same number of knitted ‘knots’. This is commonly seen in the use of ‘rib’ knitting around cuffs of sweaters to produce a gathered finish to the sleeve. By changing the type of knit structure at appropriate points in a garment, garment shapes can be created.

An example of the way a garment can be shaped is illustrated in Figure 3 below, which shows a knitted tubular test sample using a triplet of three different stitch structures as converted for measurement by the above gauge tube measuring method. One can image this shape might be for a long top garment for a ‘pear-shaped’ female with strong shoulders, narrow waist and full hips.

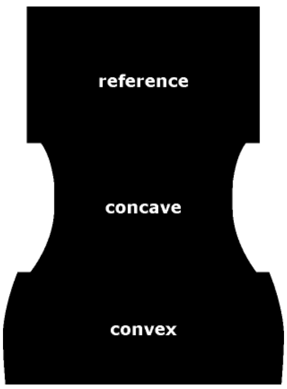

Figure 3: Triplet string of the reference, concave and convex shape

In the above case, from the top the three sections were knitted in plain, single rib and plating.

4. Applying Combinatorics to identify and map Design Solution Spaces in knitwear design

Combinatorics is the Mathematically-based study and mapping of the possible combinations of different options that can be arranged together [5],

The following example demonstrates how a simple combinatoric approach contributes to knitwear designers in their creative processes through exploring the mapping of the feature ‘options’ of a sweater:

Two key questions are:

- How many potential designs are possible?
- What shape is the solutions space that designers can draw on using particular combinations of options?

Answering the first of these questions is illustrated by the example below. An approach to answer to the second question is outlined in section five following the example.

4.1. Example: Sweater Combinatorics

To design a sweater, a knitwear designer needs to identify a number of design possibilities. In terms of silhouette, the designer must define at least five design features each with a variety of options: neck design, shoulder line, body shape, sleeve design, and edge. Additional features such as pockets and embellishments are also options, but not considered in this example[6].

Applying combinatorics, each appropriate collections or patterns of options describe different sweater designs. A single sweater design requires one neck design, one shoulder line, one body shape, one sleeve design, and one edge. In the design language of the combinatorics of sweater design, a single sweater design with only a single option for each feature is a combination of (1x1x1x1x1) =1, a single design. If the designer takes into account two style options for each design feature, the options create a total number of thirty-two possible sweater designs (2x2x2x2x2) =32 possible sweater designs. If the designer does same with three style options for each design feature, then these options result in the total number of possible sweater designs increasing to two-hundred-forty-three possible combinations (3x3x3x3x3) =243 possible sweater designs.

A similar approach applies when the numbers of each option differ. For example if there are three possible options of each feature for a sweater except the neck design of which there are only two, then the number of possible sweater designs in this design solution space comprises (2x3x3x3x3)=162 possible designs.

The research project described in this paper used triplets of three knit structures with each knit structure drawn from a selection of 14 knit structure options leading to a total combinatoric solution space of (14x14x14) = 2744 different possible designs. A sample of these shape triplets is shown in Figure 4 below.

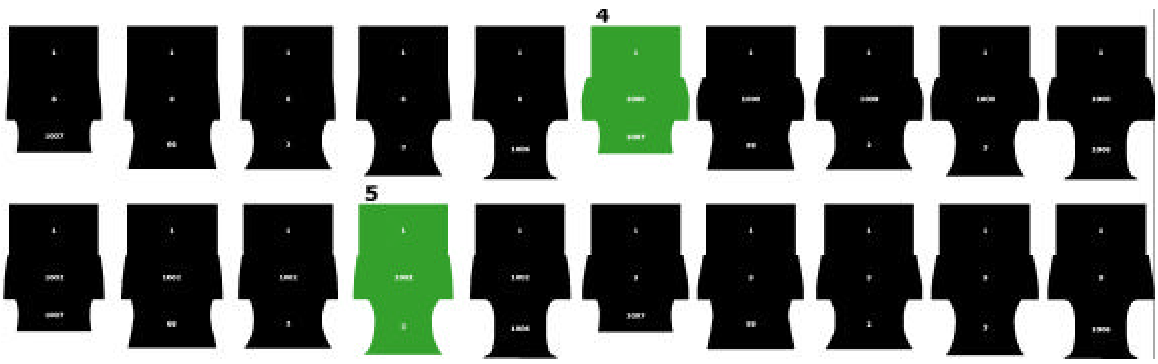

Figure 4: Triplet knitted samples of reference, convex and concave shapes (from samples 50% of women size 6.

5. Using Combinatorics for defining Fashion House Style and guiding designers

The outcomes of this research described in the preceding sections include greater understanding of designing changes to garment shape and styling changing through changes to stitch structure supported by the new silhouette gauge tune measurement approach and by identifying the scope of potential design opportunities via combinatorics. This new combination of approaches is particularly relevant to knitwear design processes involving wholegarment® and seamless knitwear production systems such as that of Shima Seiki and Stoll.
High Fashion knitwear houses and knitwear designers can further benefit by the combinatorics approach developed in this research in terms of maintaining and enhancing companies' existing styles.

At its simplest, the Combinatorics approach described above provides designers with the basis to categorize all the permutations of the numerous knitwear silhouettes that can be created by different types of combinations of stitch structures and garment feature options along with the other categories/types of information needed in knitwear design. For example, combinatorics can also be used in the categorization of variables of contemporary fashion trends or a company's existing styles. Applying combinatorics to knit structure requires only that the stitch structure combination is in an orderly arrangement.

Mapping the combinations of options used by a single knitwear fashion design house (in however many dimensions) provides a multidimensional map of the house style. The authors are aware that this is no longer a matter of simple combinations as it requires a rule-based approach in addition to the simple combinatorics to provide meta-information about how certain options are only used (or not used) with other options. Nevertheless, the approach is mathematically and computationally straightforward and has been used in other areas of design (engineering design) since the early 1970s and was an early feature of AutoCAD.

Interrogation of this mapping of a knitwear fashion design house's combinatoric map of house style options offers multiple benefits. It provides a basis to identify as yet untried garment types; it offers the basis for controlled expansion of the house style by adding new features within the existing combinations and rule set; and it provides the means for new , junior or production designers to ensure that their designs are within the house style.

6. Conclusion and summary

To summarise, the research described in this paper explored how combinatorics can assist in developing knitwear silhouettes that can be directly translated onto body shapes through garment shape changing done by changes to stitch structure rather than changes to needle count. This involved also creating a new swatch instrument, the silhouette gauge tube swatch and its associated computer based conversion to make it amenable to being developed into a database of findings. This improves on the standard 10 cm square flat swatch method in terms of better representation of different stitch structures, representation of real garment shapes, representation of transitions between and across differing stitch structures, removes the problem of curling and results in a more accurate electronic record. This use of a gauge *tube* and the conversion of gauge tube data into graphical form comprise a new potential standard for swatch-based analysis and assessment of knitwear for designers. This gauge-tube approach and the related analytical techniques also visually and efficiently relate combinatorics to the knitwear silhouette development process. Together they provide a new standard design method/process that offers many benefits to designers, manufacturers, and consumers by shortening the design process time, improving production efficiency, improving garment shape, and reducing shape changes in use. In addition, the combination of using combinatorics to map design solutions spaces for different knitwear features provides a basis to accurately map (in knitwear design terms) the design solution spaces of individual knitwear design house styles. This offers a range of benefits to knitwear design houses and their designers as detailed above. Taken together, the features of this new approach also offer the opportunity for knitwear designers to put more resources into other aspects of achieving better design outcomes and use their time in a more effective way.

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