Proceedings of the 2nd Interdisciplinary World Congress on Mass Customization and Personalization
Department of General and Industrial Management, Technical University of Munich
6-8 October 2003

Knitwear Customisation as Repeated Redesign

Claudia Eckert and Martin Stacey

Author contacts:

Dr. Claudia Eckert, Senior Research Associate
Engineering Design Centre, Engineering Department
University of Cambridge
Trumpington Street, Cambridge, CB2 1PZ, UK
cme26@eng.cam.ac.uk
www-edc.eng.cam.ac.uk/people/cme26.html

Dr. Martin Stacey, Senior Lecturer
School of Computing
De Montfort University
Leicester, LE1 9BH, UK
mstacey@dmu.ac.uk
www.cse.dmu.ac.uk/~mstacey/

Acknowledgements:

Claudia Eckert's research has been supported by SERC ACME grant GR/J 40331 for the knitwear project at the University of Loughborough Department of Computer Studies; by ESRC grant L12730100173 for the MIND project at the Open University Computing Department; and by Open University Research Development Fund grant 717 at the Open University Department of Design and Innovation. Claudia Eckert is deeply indebted to her MSc supervisor, Dr Rowland Lishman of the Department of Computing Science, University of Aberdeen, and her PhD supervisors, Prof. Nigel Cross and Dr. Jeff Johnson of the Department of Design and Innovation, The Open University, and Dr. Helmut Bez of the Department of Computer Studies, Loughborough University. Graham Perkins of the Department of Computer and Information Sciences, De Montfort University, Milton Keynes, provided invaluable support in developing the prototype garment shape design system. We are greatly indebted to all the designers and technicians who gave us their time to talk to them and allowed us to observe them

Abstract: Producing large numbers of garment variants will only be economically viable if it requires very little human effort. But garment customisation cannot always be fully automated. Applying grading rules maintain the same details but sometimes achieves a different overall effect; but the customer expects the same overall effect and is less concerned about details. Choosing between alternative customisations requires a human designer's trained perceptual judgement. Therefore a viable mass customisation support system must support the repeated redesign of a garment by combining automatic design with fast human editing. Evaluating and modifying the suggestions of others is a natural and efficient activity for designers. This paper describes two prototype automatic design systems exploring techniques that could be used for mass customisation of knitted garments – in which the shape and patterns are indivisibly linked. An early pattern placing system that automatically altered both shape and pattern parameters in a variety of alternative ways. A shape design system that generates technically correct and consistent garment shapes from a set of measurements and a verbal description; it works independently of sizes, recalculating the shape for each new set of measurements. Starting from the system's suggestions, designers can very quickly tweak the new design to fulfil their aesthetic intentions.

1. Introduction

The challenge of mass customisation lies in producing garments to individual measurements, while maintaining the design's overall effect. The visual effect of garments is subtle, depending on the balance of elements such as shape, material, print pattern, stitching and so on. Designers' understanding of what *looks* right is tacit: they perceptually *appreciate* the characteristics of the design (Schön, 1983, Schön and Wiggins, 1992). This perceptual understanding is partly general and partly specific to individual designs; it cannot be fully captured in grading rules. Knitwear is more complex then other textile products, because the shape and the pattern are generated at the same time and are subtly inter-linked. Producing knitted garments that retain the same appearance in different sizes and shapes is especially difficult because stitches are large discrete units, so stitch structures and motifs cannot be directly resized.

Garments are designed and sampled in one size shown to retail chain buyers and displayed at trade fairs. All the effort is put into getting the design right for that size. All other sizes are secondary. At present grading is done through the repeated application of grading rules involving potentially time consuming rework by the pattern maker. Grading rules maintain the same details, but sometimes achieve a different overall effect; however the customer expects the same overall effect and is less concerned about details. Sometimes better results could be achieved if the garment were redesigned for each size, with the aim of producing a design that looks equally convincing in all sizes. This might be possible if garments were designed for about ten different sizes. However mass customisation, where large numbers of alternative sizes are produced, or each garment is tailored to the measurements of each customer, places very different demands on the design effort. Full-scale manual redesign is infeasible, though automatic grading from the best of several hand-generated starting points might be effective.

How much design effort can be put into each individual design depends on the price point of the garment. But there is an unavoidable tradeoff between the number of design variants and the effort invested in each one. This paper argues that successfully designing variants of knitwear designs requires human intervention. But mass customisation can only be commercially viable if human participation in designing variants is very cost-effective. This can be achieved by using fast interactive design support systems, that enable the designers to use their talent and skills efficiently while relieving them of tedious routine tasks. We present prototype systems for pattern placement and shape creation that do this by automatically generating design suggestions that the human designer can evaluate and modify. While it might not be practical for designers or technicians to be involved in customising designs for every single order, this approach will allow a company to offer a very significantly increased range of sizes to which the customer measurements can be mapped.

2. Redesign versus automatic adaptation

To remain competitive it pays companies to automate as much as possible. But general-purpose automatic resizing procedures often won't provide the customer with a high quality design. Therefore it is necessary to assess how much of the task automatic design tools can do. Research on shape grammars in architecture has shown that it is possible to automatically generate designs in complex and sophisticated styles such as the villas of Palladio and the prairie houses of Frank Lloyd Wright (Stiny and Mitchell, 1978; Koning and Eizenberg, 1981; see Stiny, 1980; Knight, 1994), and the use of grammars for mass customisation is being explored in other industries (Gero, 2001);

but developing the ruleset for a style or product-type is hugely effort-intensive. So a simpler, more cost-effective approach using more general rules is needed for textiles with its huge numbers of products. If human intervention is required, a decision must be made whether a design should be adapted by a technician or pattern cutter, or has to be redesigned by the original designer.

The difficulty of customisation depends on whether only the shape is customised, or the fabric or the placement of the fabric on the shape has to be adapted to fit. Customisation of garment shapes can be automatic within parameters that need to be defined for each design in a similar way to grading rules. For example, if a garment has a stitched on pocket at waist height, it needs to have a certain minimum width to fit the pocket before the pocket would need to be made smaller. If the garment becomes too wide, the size of the pocket might need to be increased. A human can easily assess by looking at something whether it still looks right; but it is extremely difficult to express this in rules that a customisation system could use. This is not a technical decision but a design decision. The issue becomes more complex when the shape and the pattern interact – shape adaptations can fail to achieve their intended effects, and fabrics may be unusable for particular shapes (see section 4). When simple adaptations produce inadequate results, designers need to rethink aspects of the design and make more radical changes. A viable mass customisation support system must support the repeated redesign of a garment, enabling the designer to loosen the constraint on the adaptations and make rapid manual modifications of details. So it must integrate automatic design with fast human editing.

3. Integrating automatic design into design practice

Knitwear designers' key skills are in understanding the development of fashion, and in perceptually evaluating the characteristics of both designs and finished garments. Research on conceptual design in architecture (notably Schön, 1983; Schön and Wiggins, 1992; Goldschmidt, 1991; Goel, 1995; see Purcell and Gero, 1998) and engineering (Goel, 1995) has highlighted the importance of designers perceiving the characteristics of their own designs as they evolve them. We have observed that knitwear designers' perceptions of the characteristics of their sources of inspiration play a comparably important role in their creative processes (Eckert and Stacey, 2000, 2003). These perceptual evaluations can be complex and subtle, and precisely tuned to the needs of the task in hand; they are also extremely rapid. Knitwear designers, like other designers, are accustomed to evaluating designs that have been produced or developed by others, as a normal part of their working lives; technicians present them with completed implementations of their conceptual designs after a considerable time delay. So critiquing and suggesting modifications is a familiar activity.

Automatic design systems can generate all the alternative designs that are consistent with (1) the inputs describing the design task, (2) the generative rules and algorithms, and (3) the constraints built into the representation formalism, to map the entire space of designs. If this space is large, further constraints are necessary to keep the number of designs within manageable bounds. Some constraints can be programmed; others can be set by the users of interactive systems. But in aesthetic design fields such as knitwear design, we need to evaluate and select the products of generative systems according to emergent perceptual characteristics that are extremely hard to program, as well as structural features. But this is exactly what human designers are skilled at. We make the case (in Eckert, Kelly and Stacey, 1999) that human and computer designers can work together efficiently and effectively, by the humans evaluating, selecting and modifying some of the many designs created by the generative systems, and that this is a natural activity for human designers. The human can guide the generative system by setting the constraints on the generation process (as in the knitwear design systems discussed here), and/or by selecting alternatives for further iterative evolutionary development (as in William Latham's virtual sculptures [Todd and Latham, 1992] and Ian Kelly's colour scheme design systems [Eckert, Kelly and Stacey, 1999]).

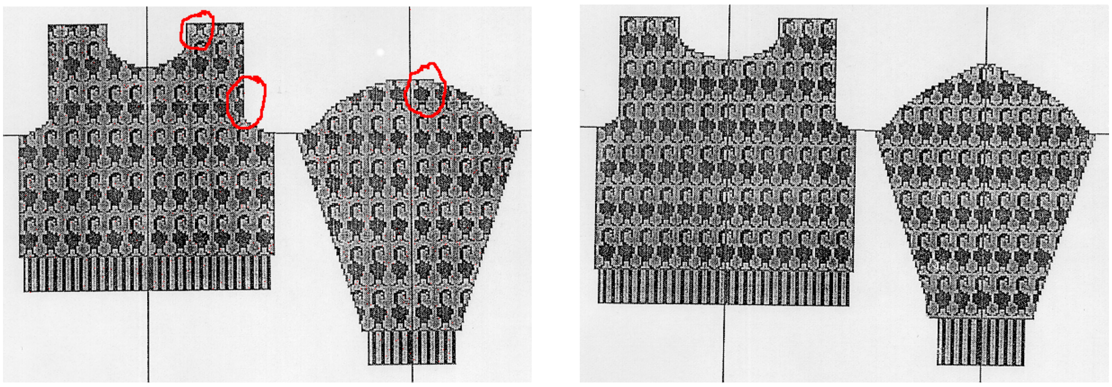

Figure 1. Pattern Placing: No Conflict Resolution Solution: Modified Width of Garment

4. A system for placing motifs on knitted garments

Even in cut-and-sew knitwear the shape cannot always be changed without changing the fabric. For example a sleeve curve may not cut through a cable cross-over otherwise the fabric will unravel. In fully-fashioned knitwear the shape and the pattern are also indirectly linked through the knitting machine operations required to generate the garment parts. All the garment parts are connected and often cannot be changed in isolation.

The problems in customising a knitted garment can be illustrated by a simple example (discussed in detail by Eckert, 1990). Imagine a fair isle overall pattern with a small motif, say a swan of 10 by 25 stitches, which needs to be placed onto a simple set-in sleeve shape. Ideally the swans should not be cut (cables *could* not be cut). The width of the garment is however specified to be 110 stitches. The options are:

- to ignore the problem and accept cut swans(see Figure 1 right).
- to alter the distance between the individual swans (see Figure 2)
- to modify the width of the garment (see Figure 1 left).
- to change the design of the swans.

All of these options are potentially unsatisfactory. In knitwear the shape and pattern are typically designed separately. Pattern placing is a compromise to reach the best possible solution. Even at this late stage the pattern and the shape can be altered.

In 1990 Claudia Eckert developed a simple system for generating gridded motif patterns from finer images (used to create the swan motif shown here); and a prototype system for creating garment shapes and regrading knitted garments using such motifs (Eckert, 1990). This system, which generated the pattern placements shown in figures 1 and 2, calculated the garment shape from input measurements and placed the pattern on the shape according to rigid placement rules which did not allow cutting a motif. If no satisfactory solution could be achieved it increased the distance between pattern elements or changed the length and widths of the design. It presented complete solution suggestions to the user.

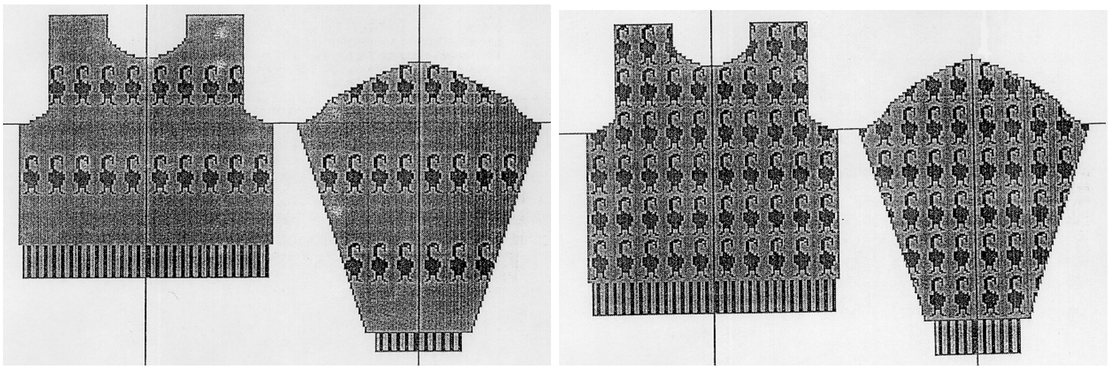

Figure 2. Pattern Placing: Changed Distance between Pattern Elements

5. A system for designing shapes of knitted garments

The key to achieving the efficiency in designing needed for mass customisation in any industry is understanding and improving the design process (Lindemann, 2001; Eckert, Zanker and Clarkson, 2001). The knitwear design process in industry is frequently severely hampered by the ineffectiveness of the communication between the designers and the knitting machine technicians who do a lot of detailed design in the course of developing knitting machine programs, including making adjustments for fabric properties and shaping instructions, and modifications to minimise knitting times. While communication problems are exacerbated by a variety of secondary factors (and are often not recognised as *being* communication problems), they arise primarily from the difficulty of interpreting what are often vague, ambiguous, incomplete, inconsistent and inaccurate specifications (Eckert, 1997, 2001; Stacey, Eckert and McFadzean, 1999). But creating accurate knitwear design specifications on paper is intrinsically hard and time consuming and maybe not cost-effective (Eckert, 1997, 2001). Moreover, the designers usually get very little feedback apart from the appearance of the finished sample garments, so cannot unpack the influence of the technicians' adjustments from the influence of inadequacies in their own specifications, so they cannot learn from their mistakes how to adjust their specifications to meet the technicians' needs. These problems could be greatly reduced by a computer program that enabled the designers to quickly create complete and consistent specifications that correspond to their intentions, and ideally, to get rapid technical feedback on the feasibility of their ideas.

A similar fast feedback approach has been introduced in fashion information systems, such as the Gerber GERBERsuite system, where designers can specify a design for a tailored garment by modifying older designs, and can receive initial costing feedback by manipulating a two dimensional outline of the garments and adding and deleting standard features. Altering the shape of a knitted garment is far more complex than for a woven garment, because the feasibility and cost of the garment depend on details of the stitch structures and the placement of design elements on the shape, and different materials can behave very differently. Automatic generation of costing feedback (in the form of knitting times) is a feature of knitwear CAD systems, but it requires complete designs, because seemingly small changes to a design can require radically different technical solutions.

We have developed a prototype system to create conceptual designs of garment shapes automatically from designers' customary specifications (category descriptions, and sets of *measurements*, that is, parameter values) (Eckert, 1997, 2001; Eckert, Cross and Johnson, 2000). The system handles the designers' desire to employ incomplete sets of measurements by using sets of default values; these could easily be set to company standard values or taken from a previous design. (The system could sensibly be extended using Case Based Reasoning techniques [Kolodner, 1993; Voss, 1996; Voss, Bartsch-Spörl and Oxman; 1996] to choose appropriate previous designs to supply the default measurements for incomplete designs.) It deals with inconsistency indirectly by showing the designers the consequences of their mistakes.

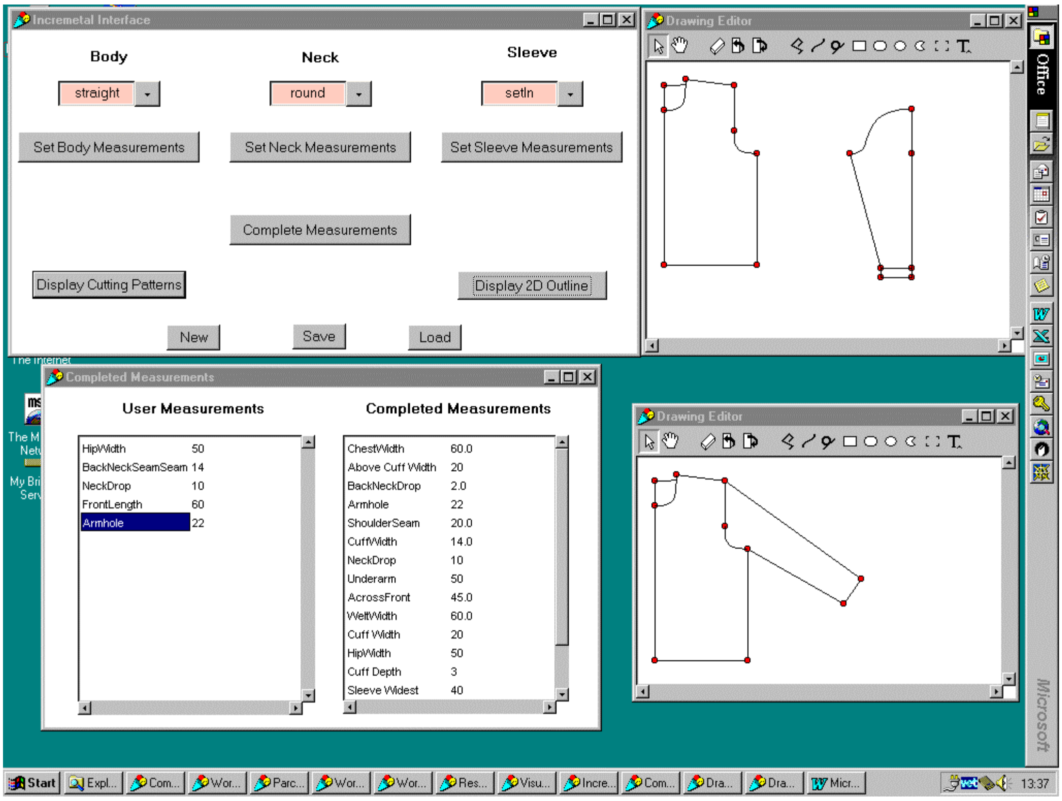

Figure 3. Prototype Garment Shape Design System

Figure 3 shows the user interface for the prototype system, which was implemented by the first author in VisualWorks®, which is an implementation of Smalltalk-80. The user can specify the garment shape by choosing the category for the body, neck and sleeve. The user is asked to put in specific values for the measurements for a garment of the chosen category. All measurement inputs are optional; missing values are completed using the default values for the category. It takes less then a minute to specify a garment shape with the tool. Informal evaluations with designers are highly encouraging; the techniques employed in the system are now being developed as part of a commercial CAD system.

To fit into the designers' customary working practices and thinking style, garment shapes are displayed in three forms: two-dimensional outlines, so that the proportions are easily visible; as cutting patterns for the individual garment pieces, which is often a better representation for editing details; and as a set of measurements. The system's suggestions could be evaluated visually and edited by the designers while maintaining internal consistency, though we haven't implemented direct graphical manipulation in our prototype. The design that the knitwear designers pass on to the technicians is presented in multiple representations that are technically correct, complete, consistent, and correspond to the designers' intentions. These shapes represent the final shape of the garment independent of fabric properties. They could be used as a starting point to create the final cutting pattern or the shape of the garment piece for a specific fabric. An automatically generated design solution has a reliably consistent quality of specification, and the generators and the receivers can learn to interpret and trust it.

This system employs novel mathematical models of garment shapes to generate the shapes from sets of constraints defined by the garment categories and the measurements (Eckert and Bez, 2000). Traditionally garment shapes are constructed in the knitwear industry using a manual craft approach. The pattern cutters use measurements provided by the designers to derive the dimensions of the garment; they have remarkable tacit skills in drawing curves for armholes and sleeves that have exactly the same lengths and the right shape within company parameters. The system's construction of garment shapes achieves the same results by employing mathematical methods to guarantee that two curves that need to be joined have lengths that are the same or in a specified ratio.

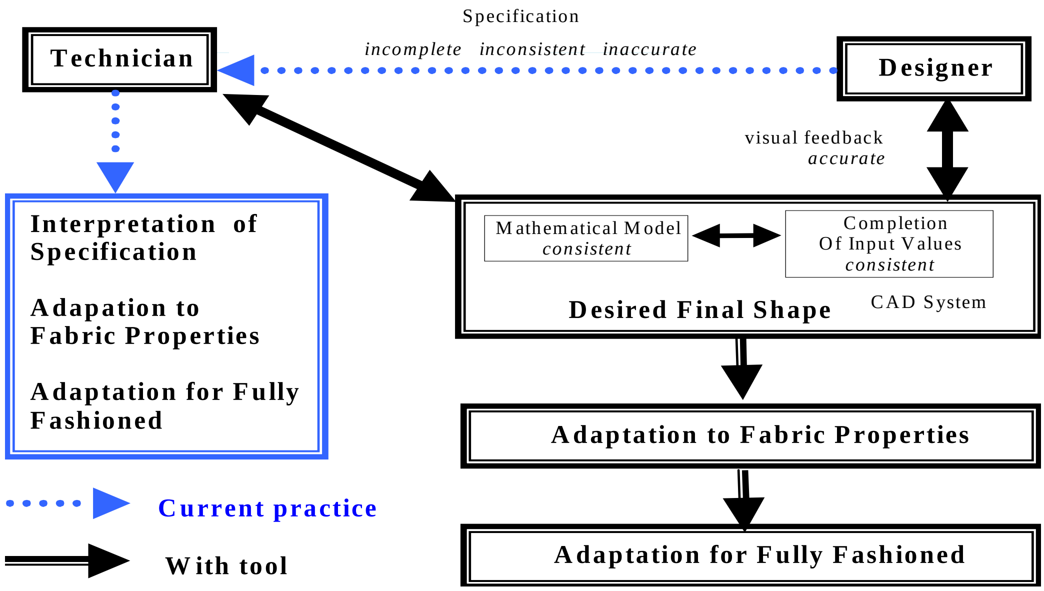

Figure 4. Communication Through an Automatic Shape Design System

The grey dashed arrows in Figure 4 show current design practice: a designer hands an incomplete, inaccurate and inconsistent specification to the technician and the technician interprets the specification and makes all necessary adjustments for customers, fabric properties and shaping instructions in the course of detailed design. The black arrows show the process using the prototype system. The tool enables the designer to generate a consistent description of the shape of the final garment, which they can modify until it corresponds what they want. Discussion of changes to the garment shape can be grounded in an accurate representation.

6. Conclusions

The key to mass customisation in textiles is supporting the design process to make it faster, to enable either rapid human redesign, or the generation of a number of design variants to which automatic grading procedures can be applied. Systems that enable designers to choose from and edit automatically generated design suggestions can contribute to this. In this paper we present a prototype support system that creates shape designs from category descriptions and sets of measurements, which enables designers to produce accurate and technically consistent design specifications in less time than physically producing a technical sketch on paper. The knitwear design process would also be made more efficient by alleviating the severe problems in the communication between knitwear designers and technicians, that arise primarily from the need to interpret ambiguous and inaccurate specifications. The primary purpose of our prototype system is to enable designers to communicate their true intentions to technicians quickly and efficiently. We anticipate that the tool will reduce the numbers of samples needed to reach the same standard of design quality. However, it is reasonable to expect that this technical innovation like previous innovations will lead to more complex products, rather than a reduction in workload. It should also make customising shapes easier and more efficient.

References

Eckert, C.M. (1990): Prototype of an Intelligent CAD System for Knitwear Design, MSc Thesis, Department of Computing Science, University of Aberdeen, Aberdeen, Scotland.

Eckert, C.M. (1997): Intelligent Support for Knitwear Design, PhD Thesis, Department of Design and Innovation, The Open University, Milton Keynes, England.

Eckert, C.M. (2001): The Communication Bottleneck in Knitwear Design: Analysis and Computing Solutions, Computer Supported Cooperative Work, Vol. 10, pp. 29-74.

Eckert, C.M. and Bez, H.E. (2000): A Garment Design System Using Constrained Bézier Curves, International Journal of Clothing Science and Technology, Vol. 12, pp. 134-143.

Eckert, C.M., Cross, N.G. and Johnson, J.H. (2000): Intelligent support for communication in design teams: garment shape specifications in the knitwear industry, Design Studies, Vol. 21, 99-112.

Eckert, C.M., Kelly, I. and Stacey, M.K. (1999): Interactive generative systems for conceptual design: an empirical perspective, Artificial Intelligence for Engineering Design, Analysis and Manufacturing, Vol. 13, pp. 303-320.

Eckert, C.M. and Stacey, M.K. (2000): Sources of inspiration: a language of design, Design Studies, Vol. 20, pp. 523-538.

Eckert, C.M. and Stacey, M.K. (2003): Sources of inspiration in industrial practice: the case of knitwear design, Journal of Design Research, Vol. 3.

Eckert, C.M., Zanker, W. and Clarkson, P.J. (2001): Aspects of a Better Understanding of Change, Proceedings of the 13th International Conference on Engineering Design: Design Applications in Industry and Education, pp. 147-154, Glasgow, UK: Professional Engineering Publishing.

Gero, J.S. (2001): Mass Customization of Creative Designs, Proceedings of the 13th International Conference on Engineering Design: Design Research – Theories, Methodologies and Product Modelling, pp. 339-346, Glasgow, UK: Professional Engineering Publishing.

Goel, V. (1995): Sketches of Thought, Cambridge, MA: MIT Press.

Goldschmidt, G. (1991): The dialectics of sketching, Creativity Research Journal, Vol. 4, pp. 123-143.

Kolodner, J. (1993): Case-Based Reasoning, San Mateo, CA: Morgan Kaufmann.

Koning, H. and Eizenberg, J. (1981): The language of the prairie: Frank Lloyd Wright's prairie houses, Environment and Planning B: Planning and Design, Vol. 8, pp. 295-323.

Knight, T.W. (1994): Transformations in Design: A Formal Approach to Stylistic Change and Innovation in the Visual Arts, Cambridge, UK: Cambridge University Press, 1994.

Lindemann, U. (2001): Product Innovation on Demand – Fiction or Truth?, Designs, Proceedings of the 13th International Conference on Engineering Design: Design Research – Theories, Methodologies and Product Modelling, pp. 47-54, Glasgow, UK: Professional Engineering Publishing.

Purcell, A.T. and Gero, J.S. (1998): Drawing and the design process, Design Studies, Vol. 19, pp. 389-430.

Schön, D.A. (1983): The Reflective Practitioner, New York: Basic Books.

Schön, D.A and Wiggins, G.A. (1992): Kinds of seeing and their function in designing, Design Studies, Vol. 13, pp. 135-156.

Stacey, M.K., Eckert, C.M. and McFadzean, J. (1999): Sketch Interpretation in Design Communication, Proceedings of the 12th International Conference on Engineering Design, volume 2, pp. 923-928, Munich: Technical University of Munich.

Stiny, G. (1980): Introduction to shapes and shape grammars, Environment and Planning B: Planning and Design, Vol. 7, pp. 343-351.

Stiny, G. and Mitchell, W.J. (1978): The Palladian Grammar, Environment and Planning B: Planning and Design, Vol. 5, pp. 5-18.

Todd, S. and Latham, W. (1992): Evolutionary Art and Computers, London: Academic Press.

Voss, A. (1996): Towards a methodology for case adaptation, Proceedings of the 12th European Conference on Artificial Intelligence, Budapest, Hungary: John Wiley.

Voss, A., Bartsch-Spörl, B. and Oxman, R. (1996): A study of case adaptation systems, in: J.S. Gero and F. Sudweeks (eds): Artificial Intelligence in Design '96, Dordrecht, Netherlands: Kluwer Academic Publishers, pp. 173-189.