INTERSECTIONS
A CONFERENCE EXPLORING COLLABORATION IN TEXTILE DESIGN RESEARCH
13 SEPT 2017
Loughborough University in London

Inflection: Assembling Interdisciplinary Material Knowledge using Knitted Fabric Construction.

A. Dr Jane Scott [1], B. Dr Elizabeth Gaston[2]

1. A. The University of Leeds
2. B. The University of Leeds

PAPER NUMBER [TDRG128]

Abstract: *Inflection is the outcome of interdisciplinary research working across knit design and historic archives held at The Royal Armouries, Leeds. The aim of the research was to develop new knitting techniques using CNC knit technologies through analysis of the functional and performative properties of historic Chinese arms and armour. The methodology applied the concept of the artefact as a means to communicate thinking across disciplines between knit design researchers and historians. Using specific pieces from the collection, research investigated the lacing structures of lamellar armour and the assembled composition of composite bows as methods to achieve complex form in knit at an architectural scale. Key findings evaluate the use of artefacts and prototypes as tools for interdisciplinary collaborative research. In addition the research presents a new material system for knit where the rigid and the flexible are recurved within a knitted assembly creating new large scale geometries.*

Keywords: Knit assembly, architectural interior installation; the artefact as a collaborative research tool, archives, material performance.

Introduction

In February 2017 a sheer, undulating textile form was unveiled in the Hall of Steel, the central void of The Royal Armouries, Leeds. Suspended in the main stairwell, the architectural interior installation *Inflection* comprised structured knit fabric tensioned by a series of clear, lasercut Perspex inserts (figure 1). The installation appeared as part rigid armour, and part draped textile, the result of a collaboration between knit design researchers at The University of Leeds, and the curator of The Oriental Collection.

The initial aim of this research was to design and build a site specific knit installation to reflect the Chinese Armour collection on exhibition at The Royal Armouries, Leeds. CNC Knit technology provides the means to produce highly complex knitted fabrics, however research is required to determine how knitted fabric can be manipulated for use at an architectural scale. Knitted fabric exhibits excellent extensibility, but it has minimal structural rigidity and therefore presents difficulties generating and retaining 3D form at a large scale. In order to address this challenge, the second fundamental aim was to analyse the functional and performative properties historic textile armour to develop a new material system for knit in a spatial context.

The central collaboration within this research was between the curator of the Oriental Collection, Natasha Bennett and knit design researchers Jane Scott and Elizabeth Gaston. Working across the disciplines of textile design and historic archives provided a unique source of inspiration; this was particularly evident when the functionality of specific artefacts was discussed across disciplines. A key objective for the team was to identify suitable historic textile armour, and to analyse the materials and construction processes that lead to performance characteristics of these artefacts. The methodology used for the research explores the use of the artefact as a means of communicating thinking across disciplines between textile design and historians. Two specific historic artefacts were critical to design development; lamellar armour and composite bows. In addition to this, textile samples and prototypes were presented as artefacts to discuss design intentions.

This paper highlights two key findings from the research; firstly, the design and implementation of a new knit assembly system. In this research our interest focused on how to develop new material properties for knitting using an assembly of knit and non-textile components. This material system is informed by the assembled material components used in lamellar armour and composite bows. It is significant that the research outcome, *Inflection,* combines the mechanical properties of extensible knitted fabric and flexible lasercut Perspex. This applies the concepts derived from both historic artefacts in order to produce an assembled material system for knitting which can generate and retain new large scale geometries.

The second key finding relates to the successful implementation of the research methodology from the perspective of collaborative research in textile design. During the research process the artefact was critical in order to communicate textile design ideas. Specifically the artefact was used to explain and analyse the functional and performative properties of varied material systems. This method was successful from the perspective of both the archives, introducing specific historic artefacts, but also from a design point of view, as the concept evolved and ideas could be demonstrated as functioning prototypes. This paper evaluates the use of the artefact across this design process with reference to literature from established design research and strategies from co-design methodologies.

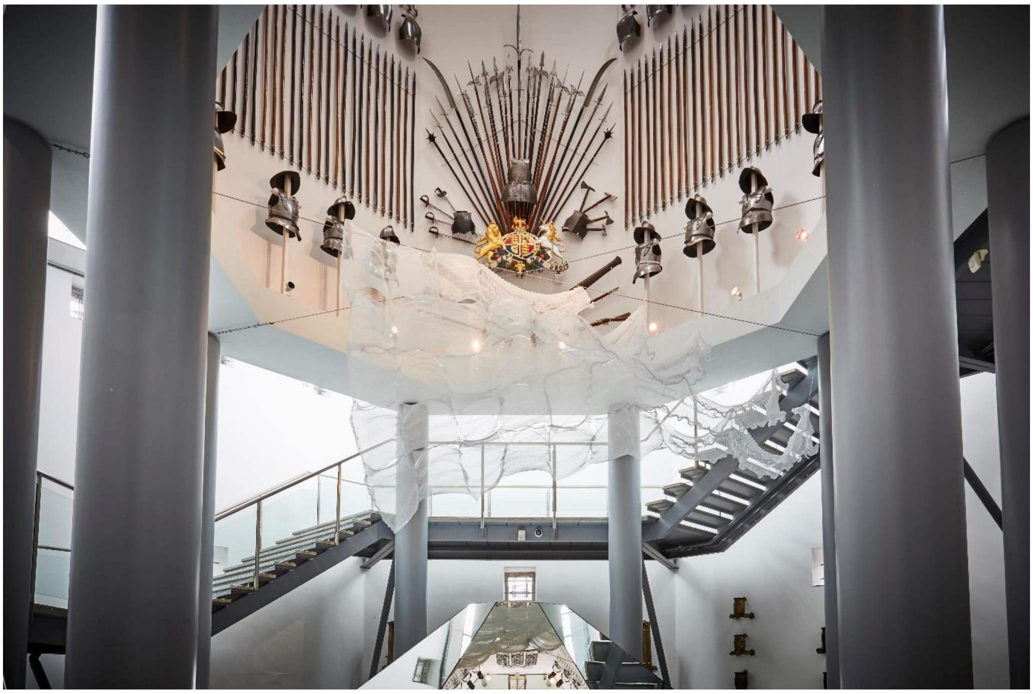

Figure 1. *Inflection*, The Hall of Steel, The Royal Armouries, Leeds.
Source: Scott and Gaston (2017)

Methods: the artefact as a tool for collaborative textile design research.

The artefact is recognised as a key tool used by designers to develop knowledge and understanding during the research process. In this research the artefact is represented by both the historic objects from the museum collection, and the textile samples and prototypes created during the research. However it is significant that the use of the artefact for design research extends beyond analysis of the object itself. Cross (2001) outlines three activities, applied to this research, where the artefact is fundamental to the design research process: the process of designing (1), reflecting on the knowledge embodied within an artefact itself (2), the knowledge that results from making, and reflecting on the process of making the artefact (3) (Cross, 2001).

The collaboration was initiated between textile design researchers Jane Scott and Elizabeth Gaston, and Natasha Bennett, curator of the Oriental Collection at The Royal Armouries. The research began with an introduction to the collection and a tour of the museum stores. This was followed by a discussion around the concept of a site specific installation and a tour of the site. It was immediately apparent that the major challenge of the project would be to produce a material system using knitting that would retain 3D form at a scale suitable for the location within the Hall of Steel.

Analysis of the research process identifies how the design work evolved through a cyclic process, and how closely Cross's three design activities map onto the process undertaken for this research (figure 2).

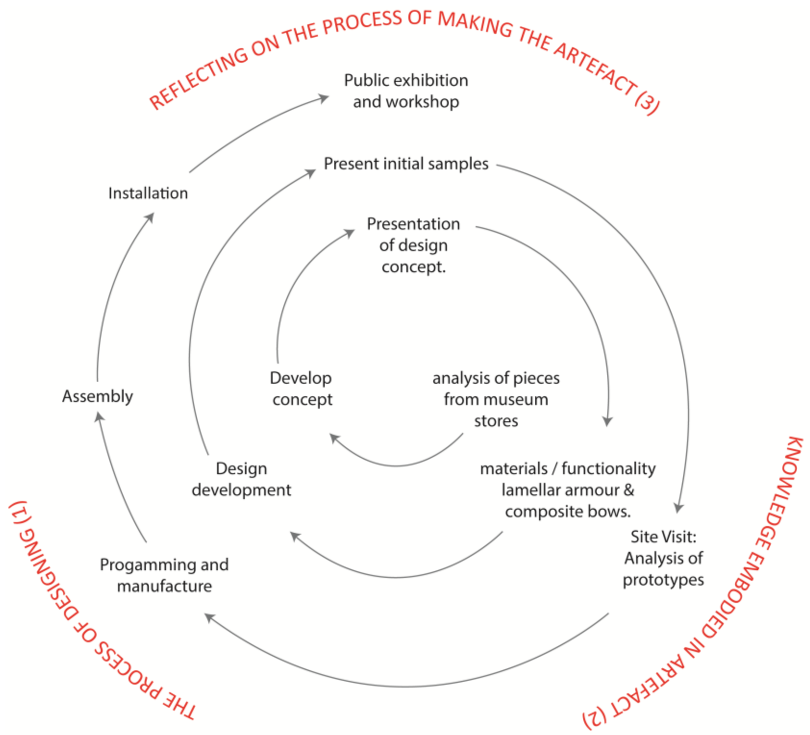

Figure 2: Programme of Research, developed from Cross (2001)
Source: Scott and Gaston 2017

In an initial meeting analysis of a series of historic artefacts provided the initial design inspiration. By developing an understanding of the complex and unique material systems that form the basis of these pieces, a shared language of materials and materiality began to evolve (2). From the perspective of knit design research, it was important to assess how this material knowledge could be applied to knitted fabric design. At this meeting concept boards were presented indicating the scale and impact of a textile installation using examples of previous work (2). Afterwards the creative process of interpreting the information, and the practical tasks of materials sourcing, sampling and programming was undertaken (1). For every subsequent meeting prototypes and fabric samples were presented to Natasha Bennett in order to better communicate design intentions (2, 3).

One challenge when working across disciplines was how to develop a common language that could be used to analyse both historic artefacts and textile samples. It quickly became apparent that performance and materiality were shared terms of reference and the hyper-specification of materials was identified as critical for armour, arms, structured textile design and knit programming. This terminology provided a foundation for the design and development of the knit installation.

The development of a material system inspired by the Oriental Collection

Within the Oriental Collection at The Royal Armouries there are significant pieces of lamellar armour. Chinese lamellar armour often presents as constructed textile armour composed of leather plates laced together with thick leather thongs and assembled into armour plating using a complex pattern of interlacing (figure 3).

Figure 3. Lamellar Armour with interlaced plates.
Source: Royal Armouries

Figure 4a and b. ***Composite bow unstrung (a) and strung (b)***
Source: Royal Armouries

What was immediately apparent was how the interaction of two textile materials using a lacing process generated a three-dimensional form with exceptional strength and toughness suitable for armour. In particular the form of both individual plates, and the overall geometry of the armour was created by the positioning of the lacing within the structure.

Whilst it is evident how lamellar armour could be used to inspire textile design it was critical to adapt this process to knit. In a knitted structure the mechanical strength and flexibility and are generated using a loop construction process to form a continuous material rather than an assembled material. Therefore the contrast between the construction processes can be identified as the difference between mechanical properties achieved from the assembled construction (lamellar armour), and mechanical properties integrated into structure of the materials (knit).

A second series of artefacts which informed the design research were the collection of Chinese composite bows (figure 4a and b). These bows are constructed from a combinations of horn, wood and sinew. Textile in the form of sinew is tensioned by the belly of the bow, which is made from horn and wood which are recurved so that they bend in opposing directions when relaxed or tensioned. The horn is critical to provide flexibility to the belly of the bow as it is 'springy under compression' (Selby, 2000). In contrast the sinew is used to form the back to the bow because it resists stretching, finally the core is constructed from wood. This combination of materials gives the bow its speed and force.

Recurved describes the process of tensioning the bow. In its relaxed state the bow curves in one direction. When strung the bow is recurved in the alternative direction (Richardson and Bennett, 2015). This material system provides a carefully engineered assembly with the material properties of each component engineered to provide the required tension and compression once the bow is recurved, and strung ready for use.

Through analysis of lamellar armour (LA) and composite bows (CB) three construction principles emerged which informed the design of the material system for development:

1. Construction composed of a series of individual shaped pieces (LA).
2. Composite material system engineered to generate a tensioned form (CB).
3. Localised shapes of individual pieces inform the overall shape and form (LA).

The Knitted Assembly

In order to produce a large scale knit installation based on three construction principles outlined above the development of a composite material system was required. The use of knit fabric within a spatial context is demonstrated in research by a number of designers investigating the material properties and the potential of knit at a building scale. Recent research highlights both the scope of knit as an installation material, but also the fundamental difficulty of using a material with minimal rigidity within a spatial context.

In order to form knit fabric into an appropriate material for this context it is utilised in combination with some kind of structural framework to support the textile material. This allows the knitted fabric to become part of a greater assembly composed of a rigid framework and flexible knit surface. The support could be used to enhance the drape and movement of a knit fabric; illustrated in the room sized installation *Slow Furl* (Ramsgaard Thomsen and Bech, 2012). Alternatively the framework can tension a fabric at the edge. Examples of this include the textile hybrids designed by architect Sean Alhquist (2013). These installations use deformable composite frames to generate controlled tension between the fabric and the frame producing complex 3D form. In contrast to the reciprocal relationship generated by a flexible framework, *myThread Pavilion* (Sabin, 2013) is composed of a steel cable net and aluminum rings forming the exterior of a knitted pavilion. Here lengths of tubular knit are tensioned within the framework to produce the pavilion's form.

An alternative solution was developed by Jane Scott in the design of *The Species* (Scott, 2013). In this iteration of the knitted assembly the non-textile material is a series of lasercut wood veneer panels inserted into shaped panels of tubular knit fabric. Under tension this allows each knit/veneer segment to produce an independent form, and consequently an overall 3D form is generated (figure 5). The significant difference in this approach is that the non-textile components act individually, tensioning one area of the assembly rather than creating tension by framing the work at the edges. The knit assembly system used in *Species* informed the construction process for the design of *Inflection* (figure 8, 9, 10).

Figure 5. Species, S3 Close shows individual lasercut inserts.
Source: Scott (2014)

Materials

Whilst the composition of both lamellar armour and the composite bows exploit the exceptional properties of natural materials, restrictions placed on the project demanded that the installation was composed of synthetic materials. To prevent contamination it is necessary to freeze natural materials before they are exhibited, and due to project deadlines this was not feasible. Instead synthetic materials were selected with the required properties for construction. The knitted fabric was composed from nylon monofilament and lurex, and the inserts were composed of 2mm clear Perspex.

Design Development

A series of experimental prototypes were produced at an early stage to demonstrate the assembly concept, and these were presented alongside sketches indicating the final appearance of the installation (figure 6). Discussing each stage of the design process with Natasha Bennett provided an excellent tool to reflect on the process of making the artefact, and to reflect on the artefact itself. Feedback at this stage refined our thinking around the concept of curving and recurving (from composite bows) as a method to generate form in a knit/Perspex assembly.

The installation was designed as five horizontal panels composed of two different structures; sections of tubular fabric, and sections of a highly structured links/links fabric. After knitting individual lasercut Perspex inserts were positioned by hand into the tubular fabric, bending into position and forming a curved surface to each section. The highly structured links/links fabric echoed the shape of the lamellar armour and repeating patterns of artefacts on display in the Hall of Steel. On assembly the five individual panels were attached together, overlapping at the top and bottom. This altered the individual geometries of the curving surfaces, *recurving* each insert against the adjacent ones and generating a pronounced curve across the overall installation piece. The fabric was programmed using the Shima Seiki Apex1 system and CNC knitted on the Shima Seiki NSSG5gg.

The Perspex inserts were cut from individual sheets using a zero waste cutting sequence, so that all of the material within an individual Perspex sheet could be used within the assembly. This produce four differently shaped inserts from each sheet (figure 7). Each panel produced a different, yet complimentary, form when inserted into the tubular fabric. Here the design of the cutting sequence was inspired by the lacing structure used in the lamellar armour.

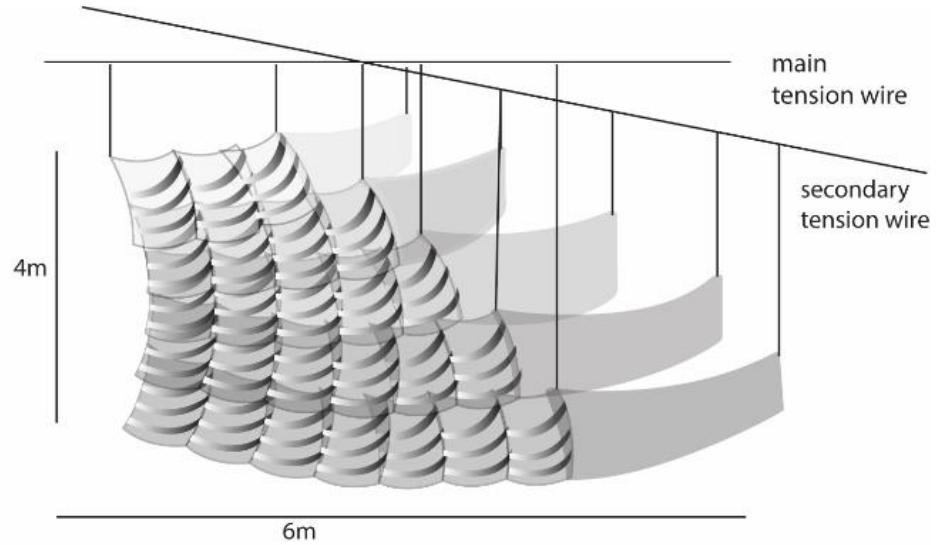

Figure 6. Inflection: original sketches.
Source: Scott (2017)

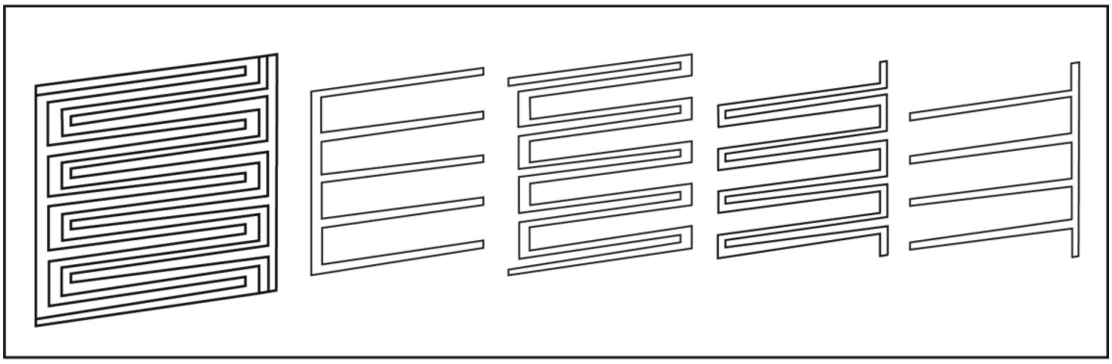

Figure 7. Cutting sequence of an individual Perspex sheet (left), and the four resulting inserts.
Source: Scott (2017)

Analysis

Analysis of assembly system

The design of *Inflection* was informed by all of the construction principles identified through analysis of the historic artefacts (LA and CB). The combination of knit and lasercut Perspex created a series of individual shaped pieces (LA). Each insert produced a different 3D form depending on its shape, and on its position within the installation. Although each tubular section produced a unique tensioned form (LA), the five sections overlapped each other at the top and bottom, *recurving* the overall piece in a new direction. Recurving is a key term in reference to composite bows because it describes the process of changing the direction of curve under tension. Inflection produced a recurved form using a composite material system, engineered to generate a tensioned form on installation because of the knit/Perspex construction (CB).

Figure 8. Inflection echoes repeating forms within Hall of Steel.
Source: Scott and Gaston (2017)

Figure 9. Inflection, detail of individual lasercut inserts in fabric.
Source: Scott and Gaston (2017)

Analysis of the artefact as a tool for design research.

At each stage of the research project the artefact was critical to developing collaborative thinking. This artefact was either located within the museum collection (composite bow and lamellar armour) or developed during the design process (textile samples), however the use of a physical entity to focus discussions was a key tool within the collaborative research process.

In this research the use of textile sampling and prototyping extends beyond the object itself and instead becomes a process of making, and explaining the ideas implicit within a prototype, identified in codesign methodologies as "making, telling and enacting" (Sanders and Stappers, 2014:7). Using prototypes to articulate thinking and materialise the design concept provided a valuable tool and acted as a means of communication across the disciplines of textile design and historic archives. In this experience the textile artefact was a central concern of both areas of work, and from a design perspective it was particularly interesting to consider the perspective of the curator who confronted each knit prototype as she would an historic artefact, analysing the materials and construction process incorporated within the fabrics. From the design perspective we were particularly interested in how the historic artefacts produced and retained their 3D forms, looking for opportunities to develop this in knitting.

In terms of materials, the historic artefacts were composed of 100% natural materials, precisely specified to provide the functionality demanded by the arms and armours. Due to museum regulations it was necessary to interpret the design of *Inflection* in synthetic materials. However the mechanical properties of flexibility, tension and compression remained critical to the selection of both constituent materials (monofilament, lurex and 2mm Perspex) and the construction processes, (knit assembly composed of knitted fabric and lasercut inserts).

Figure 10. Individual tensioned sections produce the overall form.
Source: Scott and Gaston (2017)

Table 2 assesses the importance of the artefact in this collaboration between designers and historians. Here each artefact has been mapped against the activities; making, telling and enacting. Whilst the historic artefacts provide excellent tools for collaborative analysis and interpretation (telling and enacting) the textile samples and production of *Inflection* further enhance the role of the artefact through the process of making (making, telling and enacting). The making stage is critical to the creative process, it is at this stage that the concept for *Inflection* was developed from analysis of the historic objects. This supports the design research process outlined by Cross (2001) who identifies the unique knowledge that results from making and reflecting on making an artefact. Enacting is also a critical process for this collaborative research.

For this research the *enacting* stage evaluates the behavioral properties of each composite system. In the lamellar armour the composite system comprises individual leather plates which are formed initially by patterns of interlacing and subsequently by their use as armour on the body. In contrast the composite bow integrates materials into the structure of the bow and the behaving function is the speed and power generated by recurving the bow for use. Inflection presents a combination of these techniques; knitted sections are individually assembled into unique 3D forms, however an alternative profile is generated when the installation is constructed by overlapping the sections. *Enacting* therefore becomes a particularly useful term for analysis of these transformable and behaving material systems.

Table 2. Table mapping 'making, telling and enacting' against artefacts for collaborative research process.			
Artefact	**making**	**telling**	**enacting**
Lamellar armour		Shapes of individual pieces determine the overall shape and form.	Construction composed of a series of individual shaped pieces laced together.
Composite bows		Composite material system engineered to generate a tensioned form.	Recurved when strung.
Textiles samples	1: Materials sourcing. 2: Fabric testing.	Analysis of material behaviour and assembly process.	Tubular sections assembled with Perspex inserts to generate 3d curved profile.
Inflection	1: CNC knitting. 2: Zero waste laser cut Perspex.	Analysis of *Inflection* in relation to historic artefacts.	1: Individual tubular sections assembled. 2: Each assembled length overlapped top and bottom to recurve overall form.

Conclusions

The first key finding from this research is demonstrated in the development of a new material system for knit at an architectural scale. One particularly ambitious aspect to this research was the determination to produce a 6m x 4m installation from knitted monofilament. Clearly the material properties of both the constituent yarn and the knit process itself are not conventionally associated with either building scale production, or the ability to retain a three dimensional form at such a large scale.

Whilst precedents for large scale knitted architectural installations have been set by Alhquist, Ramsgaard Thomsen and Sabin, analysis of lamellar armour and composite bows provided two material systems that generated inspiration for the design of the assembly. The use of an assembly system, inspired by a combination of the mechanical properties of the historic artefacts, (integrating the Perspex inserts into the sections of tubular knit, tensioning each section individually) provided a means to generate a larger 3D expanse that produced new geometries on installation in The Hall of Steel. The approach developed in this research is different to previous assemblies because each Perspex insert is individually positioned within the fabric, generating unique 3d profiles. On assembly these geometries are recurved as the installation is itself tensioned. This technique has been developed through analysis of the lacing structures in lamellar armour and the concept of recurving, the technique used to tension composite bows ready for use.

The outcome, *Inflection* spanned 6m across The Hall of Steel, suspended on tension wires and producing a novel curved profile reminiscent of the lamellar armour which inspired its construction. The installation was very well received and remained on exhibition for three months, however the significance of the research extended beyond the artefact itself. Rather the importance of the research is in the development of a common language of materials and performance which evolved through collaboration between textile designers and the curator of the Oriental collection. The use of the artefact to inform this language was critical; particularly through the evaluation of the material properties of textile samples and prototypes, in relation to the historic artefacts selected from the Oriental Collection.

The second key finding relates to the successful implementation of the research methodology from the perspective of collaborative research in textile design. Whilst the critical analysis of prototypes and samples are fundamental to textile design research, we were particularly pleased that this methodology could translate so readily across disciplines. The artefact became a central part of the collaborative process, and an opportunity to share knowledge from both the perspective of the museum collections, and our specific interest in knitted fabric design. It was important that all contributors were able to bring new artefacts for discussion, and that the research process was not limited to a specific material or technique. It is acknowledged that this could have presented a problem when the aim was to construct the outcome using CNC knit technologies. In this research the concept of enacting is developed as a means to explore material behavior, and this offers insight into how the methodology can be applied to new classes of active and behaving textiles.

In conclusion this paper demonstrates the importance of collaborations between textile design and museum collections, working across disciplines with curators and historians has enabled the development of advanced material understanding based on historic construction principles. In addition this paper highlights the potential for knowledge transfer from a historic context to contemporary technologies through analysis of the artefact using the shared language of materials and materiality.

Acknowledgements
The authors would like to extend thanks to The Royal Armouries, Leeds. In particular we would like to thank Natasha Bennett, the Curator of the Oriental Collections for working so closely with us in order to develop the concept for *Inflection*. In addition we would like to thank Helen Langwick and Giles Storey their expertise and encouragement during the planning and installation of the work.

This research has been funded by Arts Council England as part of The Yorkshire Year of The Textile programme. The authors would like to thank Professor Ann Sumner and the Cultural Institute at The University of Leeds for all the project support.

References

Ahlquist, S. and Menges, A. 2013. Frameworks for Computational Design of Textile Micro- architectures and Material Behavior in Forming Complex Force-active Structures. In: *Proceedings of ACADIA2013, Adaptive Architecture, 21-27 October 2013, Waterloo.* Canada: Riverside Architectural Press, pp.281-293.

Cross, N. (2001) Designerly ways of knowing: design discipline versus design science. Design Issues, 17(3) pp. 49–55.

Ramsgaard Thomsen, M. and Bech, K. 2012. Suggesting the Unstable: A Textile Architecture, *Textile.* 10(3), pp.276-289.

Richardson,T, and Bennett, N (2015) Indian Arms and Armour, Royal Armouries

Sabin, J. 2013. myThread Pavilion, Generative Fabrication in Knitting Processes**.** In: *Proceedings of ACADIA2013, Adaptive Architecture, 21-27 October 2013, Waterloo.* Canada: Riverside Architectural Press, pp.347-355.

Sanders, E B N, and Stappers, P J. (2014) Probes, toolkits and prototypes: three approache to making in codesigning, *Codesign: International Journal of CoCreation in Design and the Arts*, 10:1, 5-14.

Scott, J (2013) Hierarchy in Knitted Forms: Environmentally Responsive Textiles for Architecture, In: *Proceedings of ACADIA2013, Adaptive Architecture, 21-27 October 2013, Waterloo.* Canada: Riverside Architectural Press, pp.347-355.

Selby, S (2000) Chinese Archery, Hong Kong Press.

Jane Scott
j.c.scott@leeds.ac.uk

Dr Jane Scott is a knitted textile design specialist whose research focuses on programmable material systems, environmentally responsive textiles, and biomimicry. Her wider interests interrogate the transformational role of textiles as site specific architectures. Her work has been exhibited internationally and she was recently awarded the Autodesk ACADIA2016 Emerging Research Award (projects category) for her work *Programmable Knitting*.

Elizabeth Gaston
e.a.gaston@leeds.ac.uk

Dr Elizabeth Gaston is a textile designer, maker and researcher. An international textile design career has led to her current role as the programme manager of BA Textile Design at the University of Leeds, where she specialises in research and teaching of knitted and stitched textiles.