

This item was submitted to [Loughborough's Research Repository](#) by the author.
Items in Figshare are protected by copyright, with all rights reserved, unless otherwise indicated.

Collaborative Innovation: Reflections on Research for Smart Textiles in a Theatre and Performance Context

PLEASE CITE THE PUBLISHED VERSION

LICENCE

CC BY-NC 4.0

REPOSITORY RECORD

Robertson, Sara, Sarah Taylor, and Joanna Bletcher. 2019. "Collaborative Innovation: Reflections on Research for Smart Textiles in a Theatre and Performance Context". figshare.
<https://doi.org/10.17028/rd.lboro.9741296.v1>.

Collaborative Innovation: Reflections on Research for Smart Textiles in a Theatre and Performance Context

SARA ROBERTSON, Royal College of Art

SARAH TAYLOR, Edinburgh Napier University

JOANNA BLETCHER, University of Dundee

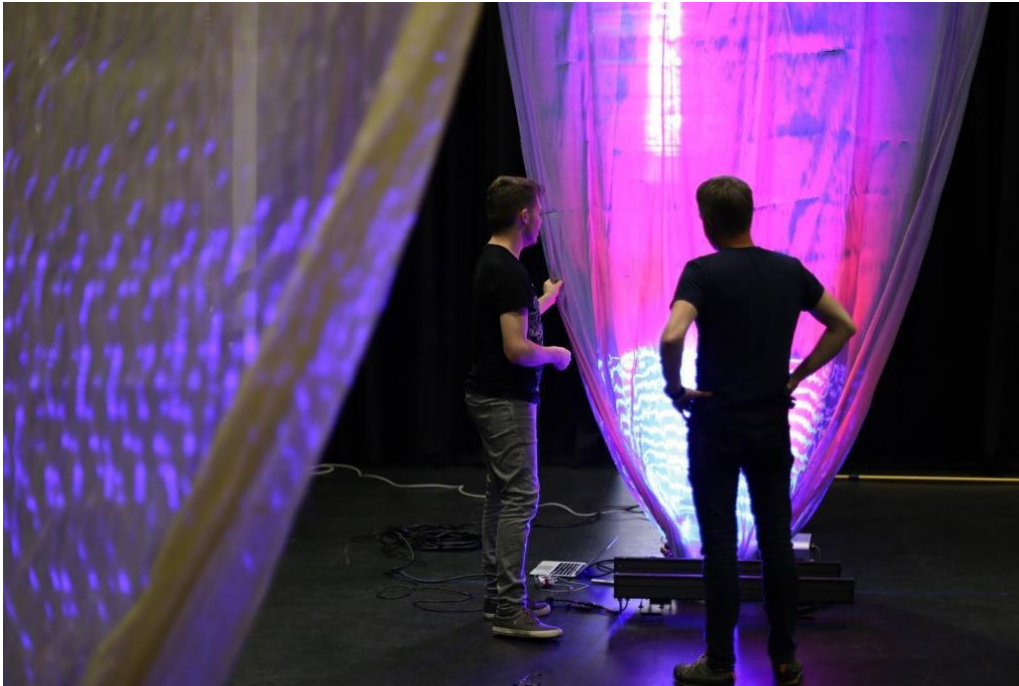


Fig. 1. Design of smart textiles for a theatre and performance context, LIT Lace for Performance project, Stage 3, 2018. Co-design prototyping and onsite theatre testing of Light Emitting Lace.

This paper presents interdisciplinary research initiated through collaboration in the area of smart textiles, prompted by the Scottish Textile Industry's 10-year Strategy (accessed March 2019), which promotes diversification and innovation as one of the most important themes for the global textile industry. The Scottish context goes beyond simply the location of the research and strategic development of the textile industry, to outline and position the growth of the practice originating from a legacy of research at the 'design-technology interface' within a Scottish academic institution (which predated what we now term 'smart textiles'). The paper will highlight collaborative work by Dr Sara Robertson and Sarah Taylor with Scottish heritage lace manufacturers, MYB Textiles that has shaped the progression, design and product development of Light Emitting Lace as smart textiles over five years (2014-2019), through a series of interrelated projects. It maps and reflects on the shifting methods and roles that have emerged throughout the research, and shares how practice-based research can underpin innovation through collaborative co-design. Situated within a theatre and performance context, the paper thus offers insight into innovation for designing smart textiles from one-off, programmable textile artefacts, to industrial scale manufactured products for architectural and performance use.

Additional Key Words and Phrases: collaboration, smart textiles, practice-based, practice-led, co-design, innovation

1 INTRODUCTION AND CONTEXT

Our research practice as smart textile designers is deeply collaborative, and through this practice, we have built new knowledge on the production and application of smart textiles. Fundamental to the research is material curiosity and the exploration and pursuit of new, visual aesthetics in conjunction with interactive and performative function (See Figure 1). Our background as practitioners within the field originates from a legacy at Heriot-Watt University, Scotland which predates smart textiles. From the mid-1990s, at a

Publisher: Loughborough University (© The Author(s)). The authors of this paper acknowledge the right of Loughborough University to publish the paper under the Creative Commons Attribution 4.0 International (CC BY-NC 4.0) licence.

Rights: This work is made available according to the conditions of the Creative Commons Attribution 4.0 International (CC BY-NC 4.0) licence. Full details of this licence are available at: <https://creativecommons.org/licenses/by-nc/4.0/>.

DOI: <https://doi.org/10.17028/rd.lboro.9741296>

©2019

time when academic design research was in its relative infancy, Taylor's research into fibre optic technology for woven textiles [1] marked a new wave of researchers exploring the integration, aesthetic potential and functionality of alternative technologies and materials for textiles. These researchers included Frances Geesin (1995) [2], Sharon Baurley (1997) [3] and Janet Emmanuel (2001) [4]. During the mid-2000s, Sarah Taylor (Reader in Design) and Robert Christie (Professor in Colour Chemistry and Technology) established a new breed of textile design researchers working at the *design-technology interface* as it was then termed. These researchers were pioneering new ways of using and incorporating responsive materials for aesthetically-led function, drawing on colour science, colour chemistry, opto-electronics and electrical engineering, and included Robertson, Marie Ledendal (2009-2015), and Stephanie Ward (2012-2018). Robertson's research [5] into the design potential of printed thermochromic textiles incorporating electronic heat-profiling circuitry established pivotal research within the field. This avant-garde approach was part of several emerging platforms in this area, an area which we now recognise as the field of smart textiles.

As researchers, we have drawn on our respective traditional textile design disciplines (Robertson - print, and Taylor - weave) and smart textile expertise within responsive dye (chromic colour - Robertson) and fibre (light - Taylor). This shared, interdisciplinary skill mix has been an important aspect in shaping our design vision, collaborative journey, and approach to innovation over the last five years. This paper draws insight and conclusions from five interrelated projects that have shaped our role as textile design researchers through the different collaborative partnerships involved. The analysis of these projects has also been a collaboration, working with Dr. Joanna Bletcher, using a mapping process developed through her research into the nature of design innovation [6, 7].

From the development of new aesthetics as one-off, programmable textile artefacts to industrial scale manufactured products for architectural and performance use, the paper reflects on our collaborative journey and the ways in which it has shaped our research, our methods and our roles as researchers. This approach has allowed us to innovate and has provided us with new insights into designing for smart textiles specifically for theatre and performance. Within this context, the smart textile product focus has been to develop and explore responsive theatre backdrops rather than wearables (See Figure 1). It has explored the visual capabilities of the material and questioned how best to exploit these qualities within a new environment. Our research has prioritised aesthetic development: a critical element for us as practitioners and designers with a vested interest and curiosity in the visual behaviour of responsive materials as explored through surface and structure (See Figure 2). A core strand in our smart textile practice has been the need to solve the mechanics for stimulating visual function of the textiles. This is distinct from stimuli which promotes non-visual function, for example in some wearable computing applications such as the development of interactive textiles focused on the invisible integration of functional touch sensitivity [8].

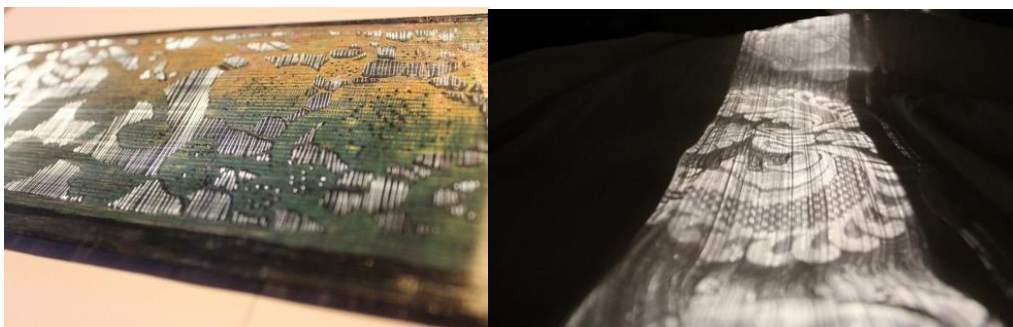


Fig. 2. Experimental prototyping of responsive fibre and dye technologies as practice-based research. Digital Lace close-up (left); light emission through woven structure as practice-led research, Light Emitting Lace (Scottish leno Madras) production sample (right).

This paper offers an overview of the research projects and outlines the evolving methodological approach and shifting roles of the researchers as the aims and objectives for the research developed. It then describes and discusses key insights across what emerge as three distinct stages of research: Stage 1 - New material development of smart textiles; Stage 2 - Technological developments including lighting design; and Stage 3 - Re-establishing creative vision for theatre and performance. The paper ends by

reflecting on the successes and challenges of these stages and how this culmination of learning has informed current and future research in Stage 4.

2 RESEARCH PROJECTS AND COLLABORATORS

Figure 3 offers a timeline of the research projects discussed, and indicates the different partners involved at each stage of the research. The research projects are: Digital Lace (Phases 1 and 2, 2014-2016): a digitally activated colour-changing and light-emitting textile artefact; Light Emitting Lace (2016-2017) a materials-led academic and industry research project and feasibility study in collaboration with woven lace manufacturers, MYB Textiles; Innovative Lighting Solutions for Smart Textile Production (2017-2018) a design-led academic and cross-sector project with MYB Textiles and lighting specialists, Mike

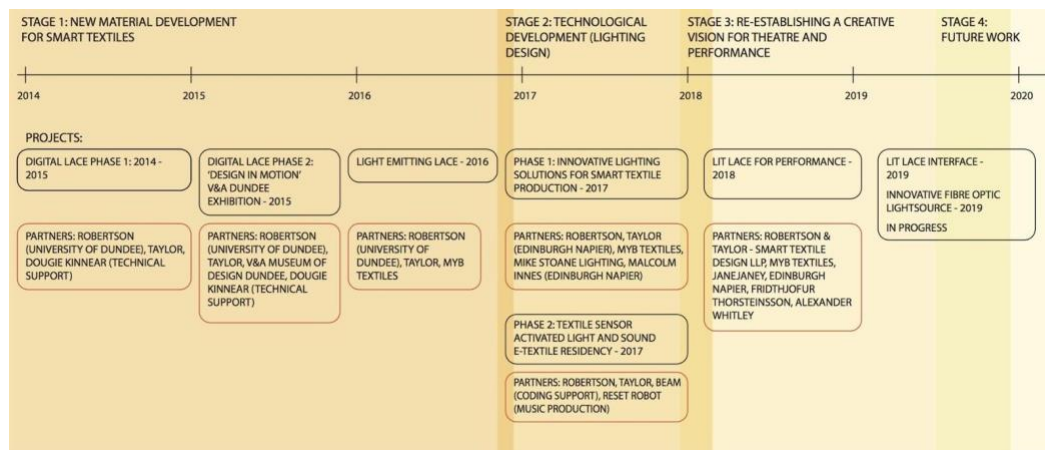


Fig. 3. Research projects and collaborator timeline.

Stoane Lighting; Textile Sensor Activated Light and Sound E-textile Residency, a practice-based, interdisciplinary project with an e-textile coding practitioner (Beam) and sound producer (Reset Robot); LIT Lace for Performance (2018) an interdisciplinary, disruptive design-led project with theatre set and lighting designers (JaneJaney, Fridthjofur Thorsteinsson) and choreographer (Alexander Whitley). Other projects noted in the timeline above (Lit Lace Interface, 2019 and Innovative Fibre Optic Lightsource, 2019) indicate the trajectory of the research going forward, but are still ongoing, and therefore not reported here. Images representing each of the projects can be found in the Appendices (See Figures 12-17).

3 RESEARCH APPROACH

Practice-based research is at the heart of our approach¹. Our craft practice has enabled us to explore and bring to light new knowledge for designing smart textiles within industry and for a specific creative context. Practice-based research was the initial basis of our collaboration in crafting smart textile surfaces. Through experimental prototyping drawn from individual skill sets (See Figure 4, Stage 1), our shared knowledge has enabled us to build and work within larger collaborative teams to further share and develop new knowledge in this field (See Figure 4, Stages 2 and 3). As innovation researcher and consultant Michael Schrage [9] has suggested, prototyping is both a method and methodological approach for 'crafting interactions' between people to stimulate innovation. Bletcher [7] also suggests that

¹ There is no full agreement on what constitutes 'practice-based' versus 'practice-led' research according to Candy and Edmonds [13]; Candy [14], with the terms used interchangeably in some cases, or in different ways across different disciplines. Here, we follow Candy's [14], outline that suggests practice-based research is 'an original investigation undertaken in order to gain new knowledge partly by means of practice and the outcomes of that practice', where the contribution to knowledge is in part based in the creative artefact, with practice-led research 'concerned with the nature of practice' that 'leads to new knowledge that has operational significance for that practice'.

prototyping is a way of exploring a particular ‘design space’, (see Heape [10], and Lim et al., [11] for discussion of the ‘design space’) as a means of manifesting and evaluating design ideas (see also Valentine [12], for further work on prototyping). Prototyping, for us, is both a research approach and mind-set. An in-depth understanding of textile sampling, prototyping and artefact design development has allowed us to transfer and make relevant our practice-based knowledge of materials, processes and design innovation in collaboration with other practitioners, and through practice-led knowledge exchange with industry (Stage 1).

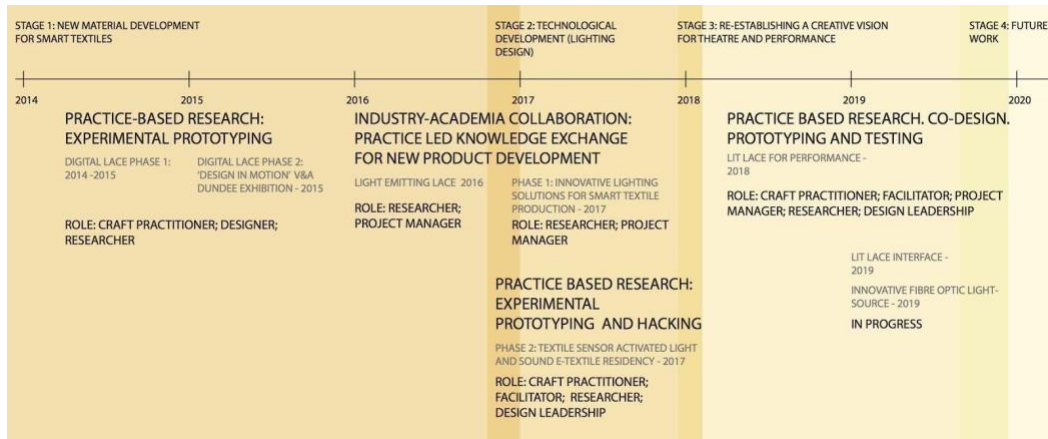


Fig. 4. Methodological timeline and role of researcher.

Through this approach, new knowledge has emerged and in-turn, we have needed to straddle both Practice-based and Practice-led research as overarching ways of navigating ever-shifting research aims. Temeltas [15] highlights ways in which craft practice can contribute to innovation: through the transfer of craft knowledge; the craft practitioner and designer working together in collaboration; or the craft practitioner providing the inspiration through craft knowledge. This resonates with our approach, however we have been shifting our role between craft practitioner, designer, researcher, facilitator, project manager and design leadership. Figure 4 above charts our methodological timeline and the shifting roles we have had to adopt as the research has progressed. Shifting between different roles within industry and academia for practice-based textile design research is analysed by Hall and Earley [16] through a lens of entrepreneur and researcher. They highlight three different approaches for shifting between wearing these two different ‘hats’: *divide*, *switch* and *blend*. Their work suggests that ‘blend’ offers fluid methods of blending between entrepreneur and researcher when required. This blending of roles has been essential in our work, to move between the different stages of the research.

Collaboration with other creative practitioners from different creative sectors allowed us to use a range of disparate practices to design and develop smart textiles for theatre and performance environments. Briggs-Goode et al. [17] describe developing a new methodology utilising co-design and craft making for electronic textiles by bringing together a multidisciplinary team within a person-centred framework. Fairburn, Steed and Coulter [18] use co-design within the design of wearables to shift the development of technology as merely an added extra (for marketing) to a more ‘informed and harmonised position as a central part of the design’. Co-design has a long history stretching from Scandinavian Participatory Design, highlighted by Ehn, Nilsson and Topgaard [19]; Björgvinsson, Ehn and Hillgren [20], to the human-centred design processes of international firms such as IDEO, where designers look to the ‘user’ for stimulating innovation within business (cf. Brown [21], Kelley [22]). For us, co-design has emerged more organically through practice and has offered us a new way of working. As a key part of our research approach, co-design has emerged as a core method for innovation, to reveal new approaches to the design of technology, shared practice and knowledge transfer within different disciplinary and industry contexts, and theatre and performance environments.

4 RESEARCH STAGES

Through analysis of our research using a mapping process developed by Bletcher [7], we have been able to identify distinct differences within three stages of the research (See Figure 4 above), and the benefits and
Textile Intersections – 12-14 September, 2019 – London, UK

challenges of designing smart textiles products through collaboration. These stages are not necessarily described here in chronological order but have allowed us to reveal the differences in approach, and the particular values and insights that have emerged from the research.

4.1 Stage 1: New Material Development for Smart Textiles

This stage involved collaboration through: 1) interdisciplinary practice-based research (involving individual discipline expertise and smart textile specialisms); and 2) experimental practice-led research (based on combined smart textile practice in conjunction with textile industry specialists). The fundamental emphasis was focussed on exploiting smart material properties through conventional and unconventional textile techniques, processes and application, and in conjunction with other material types. This research aimed to challenge new material capabilities, communicate aesthetic function as new material surfaces and generate interest in the potential use of these materials within new applications and within the field.

There were two parts of this stage: 1) the development of a handcrafted textile artefact (Digital Lace Phases 1 and 2, Figure 5) and, 2) the development of industrially manufactured textiles (Light Emitting Lace, Figures 6 and 7). The process of developing a smart textile artefact created a shared collaborative practice for exploring new processes together, and an aesthetic language for smart textile surfaces. Our interdisciplinary, practice-based approach, through a series of creative projects, enabled us to challenge our own smart textile practice. It allowed communication of our respective tacit knowledge and creation of a shared vision for our joint practice and future work together.



Figure 5. Digital Lace experimental prototype development as interdisciplinary practice-based research, Crystals Expert Workshop, Plymouth College of Art (PCA). Images courtesy of PCA.

The impact from the work showcased in the V&A Dundee exhibition *Design in Motion* (See Appendix A.2) led to an opportunity to exploit the potential of smart textiles with heritage lace manufacturers, MYB Textiles (See Appendix A.3). We worked with the mill over 6 months to develop a vision for a research project that fitted with their existing manufacturing set up and could lead to new product innovation. With a clear focus on aesthetics and new material development, the research aimed at investigating the weaving capacity of Light Emitting Lace. Using an experimental practice-led process, we developed a wide range of new material prototypes and worked together with MYB Textiles to explore the feasibility of weaving polymer optical fibre using their existing 100-year-old Nottingham Lace and Scottish leno lace looms (See Figures 6 and 7).

The need emerged for a suitable light source to maximize the weaving capacity of the loom and to allow us to develop a fully integrated Light Emitting Lace product for interiors. Light sources used for the majority of commercial optical fibre products offered limited light output capability and suitability for lighting the woven Light Emitting Lace. The idea to develop a static, white light illuminator bar that would light the selvedge edge of the lace led us naturally to Technological Development (Stage 2) within the trajectory of the research.



Figure 6. Light Emitting Lace experimental prototyping of optical fibre, practice-led Academic-Industry research, Nottingham Lace production looms, MYB Textiles.



Figure 7. Light Emitting Lace experimental prototyping of optical fibre, practice-led Academic-Industry research, Scottish leno Madras production looms, MYB Textiles.

4.2 Stage 2: Technological Development (Lighting Design)

In order to develop the right technology to ultimately allow Light Emitting Lace to be effectively illuminated and used creatively, led to our focus on the design and development of bespoke lighting technology, specifically for lace manufacture. The core aim of this stage was product resolution, to allow further aesthetic development and to enable the team to fully exploit the potential of Light Emitting Lace as a combined textile and light product. To achieve this, the collaborative partnership grew with the support of further funding, and brought on board Mike Stoane Lighting, Edinburgh, and artist and lighting designer Malcolm Innes (Edinburgh Napier University). Thus the collaboration moved from purely a textile focus to a cross-sector interdisciplinary collaboration.

In this stage the research approach became primarily practice-led, with a number of different methods employed to gain an understanding of how to develop technology specific for a woven smart textile product. There were two phases, firstly a funded phase, 'Innovative Lighting Solutions for Smart Textiles' and secondly, a residency, 'Textile Sensor Activated Light and Sound E-Textile Residency', to explore the potential of the Light Emitting Lace as an interactive textile interface. This second phase was done by integrating new technology platforms, sensor technology and materials in collaboration with sound and coding experts. The first phase required certain roles, such as researcher and project manager, and methods, such as iterative fabric design development, testing, prototyping, specific fabric function knowledge transfer, and overseeing light source development

(See Figure 8). Prototyping and design development of the light source was completed by the lighting experts. Unknown to us at the start of this stage, the technological development was to result in much longer-term research goals towards the development of a light source and control technology. The second phase (which was short in timespan) was about maximizing the interactive potential of Light Emitting Lace: examining ways to create light and sound interaction through digital means (exploiting Arduino and Touch Board technology); and creating sound compositions in response to the textile/environment

(integrating bespoke sounds in collaboration with a music production specialist) (See Figure 9). Through this phase we were able to bring our practice-based approach back to the fore, were able to generate new knowledge and know-how for the next stages of the research, and establish new collaborative partnerships.



Figure 8. Prototyping and design of fabric illuminators and combined textile and modular system, Mike Stoane Lighting; Iterative textile production design development with MYB Textiles, researcher and project management as practice-led knowledge exchange.



Figure 9. Experimental practice-based prototyping and hacking: Textile Sensor Activated Light and Sound E-Textile Residency with sound producer (Reset Robot) and e-textile coding practitioner (Beam), E-textiles summer camp residency, Paillard Centre d'Art, France, 2017.

4.3 Stage 3: Re-Establishing Creative Vision for Theatre and Performance

Knowledge and lessons learnt from the previous two stages suggested the need to re-examine lighting technology development options, and to exploit a more creative and relevant context for the Light Emitting Lace, building on its performative potential. An opportunity to work with set and costume designers, Jane Wheeler and Janey Gardiner (JaneJaney), helped establish a new, creative design vision. In continued partnership with MYB Textiles, this stage sought to explore the newly developed cloth within a theatre and performance environment. With additional lighting design and theatre-based technical support from Edinburgh Napier University, and end-user input from theatre lighting expert Fridthjofur Thorsteinsson and choreographer Alexander Whitley, we were able to lead the newly formed collaborative team for the project, 'LIT Lace for Performance'. It aimed at exploiting the potential of Light Emitting Lace (LIT Lace) as a programmable backdrop cloth, and provide sustainable options and alternative solutions for stage and set design.

Within this stage there was a shift to bring back practice-based research as a central method for sharing knowledge with our collaborators. Sharing our respective practice was a critical element of the research and was used to facilitate co-design of the LIT Lace within a theatre setup. Working with our end-users as equal stakeholders, we used an iterative design process for developing a holistic, user-friendly system for the creative use and control of the Light Emitting Lace. This environment provided new direction for both the LIT Lace and the lighting technology requirements. We used structured workshops to situate and allow testing of physical LIT Lace prototypes, and to facilitate a creative design process and dialogue through collaborative on-site testing (See Figure 10). Co-design offered us a new way of working, enabling us to generate a more meaningful design dialogue, and to be objective about design progression.

Working at scale and in the right environment established the potential impact of LIT Lace for performance.



Figure 10. Co-design, practice-based research: Structured workshops and physical prototyping of Light Emitting Lace with theatre and performance end-users in theatre setup.

5 DISCUSSION

Our approach of collaboration, collaborative practice and co-design, allowed an articulation of the complexity of craft and design practice, which is arguably often bound by its tacit nature. This process has taken time, funding and the careful building of relationships. We have discovered that co-design can support innovation at the juncture between different disciplinary practices, ultimately revealing potential new design approaches for smart textiles. The following diagram charts the development of our methods, roles, values, mind-set, and conditions from the different research stages that ultimately reveal a design process for smart textiles within a theatre performance context.

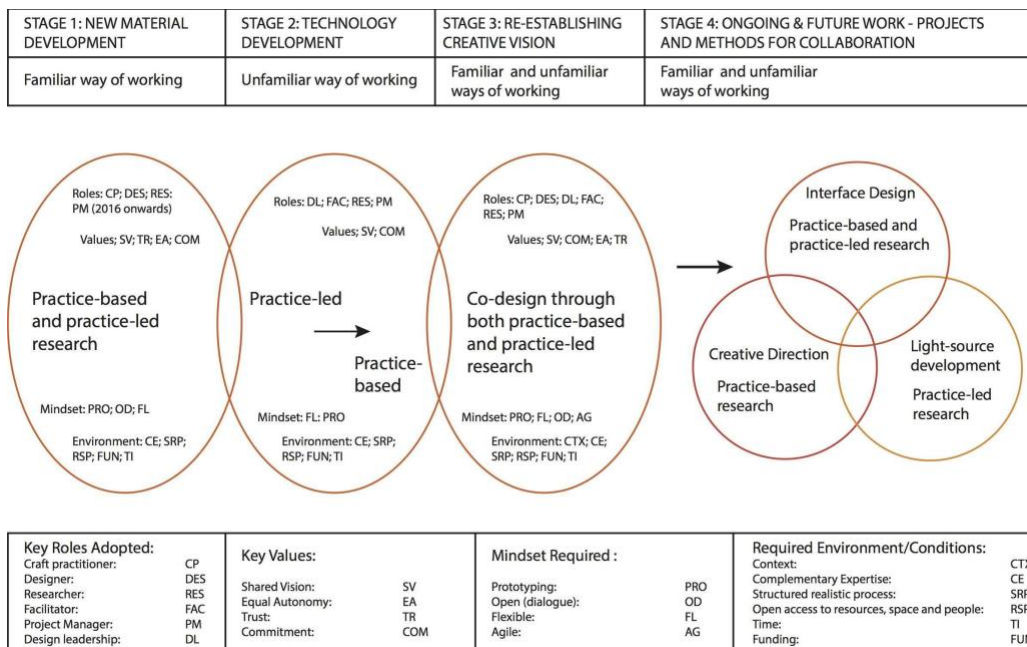


Figure 11. Methods and shifting roles, values, mind-sets and conditions of collaboration for the development of smart textiles for a theatre performance context.

Collaboration has profoundly shaped the direction of the research, requiring and enabling us to move between different roles, and has provided different challenges along the way. These have played an equal part in developing our research, prompting us to ask critical questions and forcing us to accept elements

of the research that have developed in ways we had not anticipated. Our transition from a joint collaboration, to a team of industry-based lace experts during Stage 1, allowed us to transfer essential knowledge of craft-based smart textile surfaces from practice-led research, towards large scale manufacture (See Appendix A.1). Our time working onsite at the mill over 6 months enabled the team to build trust and develop shared knowledge through new working methods, and through a balance of skills and expertise within industrial lace manufacture and smart textile design. The familiarity of practice-based and practice-led research allowed us to shift 'fluidly' between craft-practitioner, designer and researcher.

Stage 2 brought new challenges and an unfamiliar way of working, and allowed us to see the limitations of the interior-focussed textile and lighting product. Although a necessary development, in hindsight the development of a static, white light illuminator bar was a one-dimensional interpretation of the lighting design. Retaining autonomy and creative direction over the design

process was also challenging due to our different expertise, funding and time. During the second phase we saw an opportunity to re-invigorate the creative vision for the technological development alongside the aesthetic potential of the cloth, and took a multi-dimensional view of the technology. This shift back to a practice-based approach supported the development of the next research stage, and was fundamental in leading to a new collaboration, bringing on board end users from the theatre and performance industries.

Throughout Stage 3, the importance of creating the conditions for creative and design autonomy for collaborators emerged as being integral to the success of this practice-based, co-design research. We developed a shared vision for design, enabling us to generate an environment for our collaborator end-users to work intuitively with the cloth and lighting systems. This prompted new designs for specific end uses for both creative performance and technical development, and confirmed the right design context for Light Emitting Lace as a dynamic backdrop cloth. It also reaffirmed the interactive and performative potential of the cloth and was a pivotal point for the future performance direction of the work.

6 CONCLUSION

Reflecting on five years' worth of research has allowed us to gain insight into the multiple methods, roles, values, mind-sets and conditions needed to design smart textiles for a specific theatre and performance context. This paper articulates a situated example of interdisciplinary research that thrives through collaboration. Co-design, built upon and through the deep knowledge of different practices of these collaborators, has emerged as central for innovation in the smart textiles context.

Going forward, as a culmination of our learning based on the previous stages, Stage 4 will allow us to test different research methods and approaches through a series of interrelated projects. In collaboration with The National Research Institute for Mathematics and Computer Science in the Netherlands, Centrum Wiskunde & Informatica (CWI), we aim to develop an interface system to control the LIT Lace within a theatre environment setup. With ENU, we aim to develop a bespoke light source compatible with the interface system. Our aim is to realise the combined research as a complete design system, and to promote this research through a live performance in collaboration with our end users. In order to achieve autonomy for ourselves as collaborative smart textiles designers, and to provide creative autonomy in the use of the LIT Lace for our collaborators whilst managing the different expertise and research challenges of these parallel projects, we will continue to draw on and build our co-design approach through practice-based and practice-led research. Through smart textile product diversification, we hope to further accelerate innovation within the field, and open up new opportunities for creative theatre and performance works beyond Scotland.

7 ACKNOWLEDGMENTS

These projects were supported by Plymouth College of Art (Digital Lace Phase 1); V&A Museum of Design, Dundee (Digital Lace Phase 2); Textile Future Forum Challenge Award and MYB Textiles (Light Emitting Lace); Textile Future Forum (TFF) Challenge Award, MYB Textiles and Mike Stoane Lighting (Innovative Lighting Solutions for Smart Textile Production); Edinburgh Napier University and TFF (Textile Sensor Activated Light and Sound E-textile Residency); EU WEAR Sustain (LIT Lace for Performance); EU WORTH

Partnership (Lit Lace Interface). Photography by Margot Watson (Figures 1, 10 and 17) and Colin Andrews (included in Figures 6, 7 and 8).

8 APPENDICES

The following images illustrate the above projects described Stages 1 to 3, page 4, (See figures 12, 13,14,15,16 and 17).

A.1 Stage 1: Digital Lace Phase 1 (Practice-Based Interdisciplinary Research)



Figure 12. A digitally activated colour-change and light-emitting textile artefact, International Symposium of Wearable Computers Design Exhibition and EMP Museum & Microsoft Research, Seattle, USA 2014.

A.2 Stage 1: Digital Lace Phase 2 (Practice-Based Interdisciplinary Research)



Figure 13. Digital Lace Phase 2 exhibit, V&A Museum of Design, Dundee's touring exhibition, Design in Motion; Exhibition travelling Gallery, Lewis, Scotland, 2015. Photographs courtesy of V&A Museum. See <https://www.vam.ac.uk/dundee/info/national-projects> for more details.

A.3 Stage 1: Light-Emitting Lace (Practice-Led Interdisciplinary Academic-Industry Research)

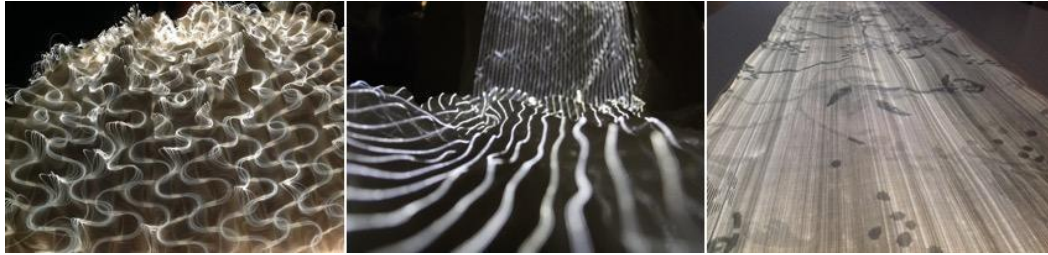


Figure 14. Light emission effects, Scottish leno Madras experimental prototyping samples using polymer optical fibre (woven width/drop 3.6m), MYB Textiles, 2017.

A.4 Stage 2: Innovative Lighting Solutions for Smart Textile Production (Design-led Academic-Industry Research)



Figure 15. Selvage lighting bar illuminators (left); Combined textile and lighting modular system for Light Emitting Lace, 2018 (right).

A.5 Stage 2: Textile Sensor Activated Light and Sound E-textile Residency (Practice-Based Research)



Figure 16. Prototype (left) and live performance (right) of Light-Emitting Lace as textile sensor and activated light and sound piece, Paillard d' Art, France, 2017.

A.6 Stage 3. LIT Lace for Performance (Practice-based, co-design research)

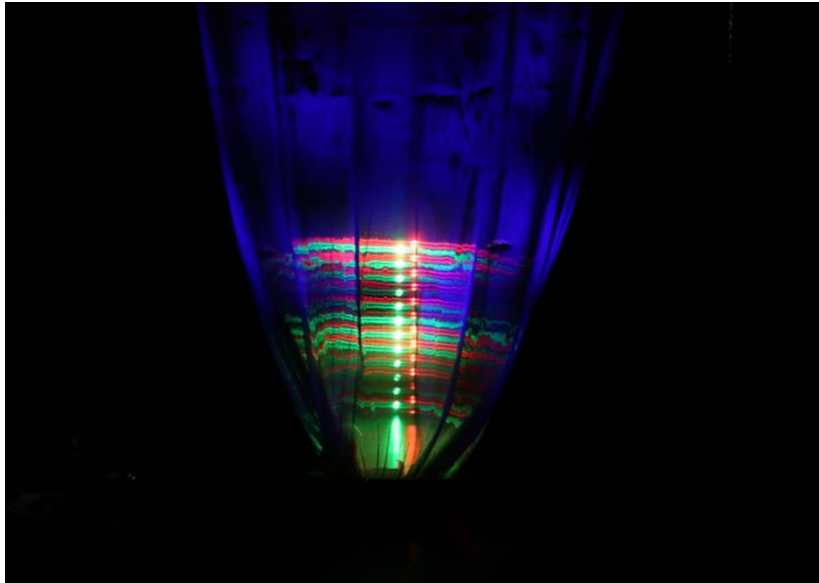


Figure 17. LIT Lace within a theatre setup as a dynamic backdrop cloth (3.6m fabric drop, 5m width). Intensified lenticular and holographic colour lighting effects.

REFERENCES

- [1] Sarah E. Taylor. 1995. *An investigation into fibre optic technology and novel yarn types for textile materials*. Master of Philosophy's thesis. Heriot-Watt University, Scotland, United Kingdom.
- [2] Frances Geesin. 1995. The chemical and structural manipulation of fabrics and fibres through stiffening techniques with specific emphasis on electrodeposition: the resulting materials have applications in fine art, fashion and the applied arts. Ph.D. Dissertation. Royal College of Art, London, United Kingdom.
- [3] Sharon Baurley. 1997. *An exploration into technological methods to achieve three-dimensional form in textiles*. Ph.D. Dissertation. Royal College of Art, London, United Kingdom.
- [4] Janet Emmanuel. 2001. *Textile manipulation: using ultrasonic technology to develop three dimensional products*. Ph.D. Dissertation. John Moores University, Liverpool, United Kingdom.
- [5] Sara Robertson. 2011. *An investigation of the potential of thermochromic textiles used with electronic heat-profiling circuitry*. Ph.D. Dissertation. Heriot-Watt University, Scotland, United Kingdom. Available at: <https://www.ros.hw.ac.uk/handle/10399/2451>
- [6] Joanna Bletcher. 2017. The Constellation: a framework for conceptualising design as a process of innovation. *The Design Journal*. 20 (Sup1), S4552-S4564. DOI 10.1080/14606925.2017.1352952.
- [7] Joanna Bletcher. 2016. Prototyping the Exhibition: a practice-led investigation into the framing and communication of design as a process of innovation. Ph.D. Dissertation. University of Dundee, Scotland. Available at: https://discovery.dundee.ac.uk/files/9196765/JoannaBletcher_ThesisFinal_2016_1_.pdf (Accessed 07 June 2019).
- [8] Ivan Poupyrev, Nan-Wei Gong, Shiho Fukuhara, M. Emre Karagozler, Carsten Schwesig, and Karen E. Robinson. 2016. Project jacquard: Interactive digital textiles at scale. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, CHI '16, New York, NY, USA, ACM, 4216–4227.
- [9] Michael Schrage. 2013. Crafting Interactions: The Purpose and Practice of Serious Play. In Louise Valentine. (Ed.). *Prototype: Design and Craft in the 21st Century*. Bloomsbury, London; New York; New Delhi; Sydney. 19-28.
- [10] Chris Heape. 2007. *The design space: The design process as the construction, exploration and expansion of a conceptual space*. Ph.D. Dissertation. Mads Clausen Institute for Product Innovation, University of Southern Denmark.
- [11] Youn-Kyung Lim, Erik Stolterman and Josh Tenenber. 2008. The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. *ACM Transactions on Computer-Human Interaction (TOCHI)* 15:2 Article 7. DOI 10.1145/1375761.1375762.
- [12] Louise Valentine. 2013. Introduction. In Valentine (Ed.) *Prototype: Design and Craft in the 21st Century*. Bloomsbury, London. 1-17.
- [13] Linda Candy and Ernest Edmonds. 2018. Practice-Based Research in the Creative Arts: Foundations and Futures from the Front Line. *Leonardo*. 51:1, 63-69. DOI 10.1162/LEON_a_01471.
- [14] Linda Candy. 2006. *Practice-based research: A Guide*. CCS Report: 2006-V1.0 November, 1. Creativity and Cognition Studios, University of Technology, Sydney. Available at: <https://www.creativityandcognition.com/resources/PBR%20Guide-1.1-2006.pdf> (Accessed 07 June 2019).
- [15] Handan Temeltaş. 2017. Collaboration and exchange between “Craftsman” and “Designer”: Symbiosis towards Product Innovation. *The Design Journal*, 20:sup1, S3713-S3723, DOI: 10.1080/14606925.2017.1352876.
- [16] Cathryn Hall and Rebecca Earley. 2019. Divide, Switch, Blend: exploring two hats for industry entrepreneurship and academic practice-based textile design research, *The Design Journal*, 22:sup1, 19-35, DOI: 10.1080/14606925.2019.1595848.

- [17] Amanda Briggs-Goode, Martha Glazzard, Sarah Walker, Sarah Kettley, Tincuta Heinzl and Rachel Lucas. 2016. Wellbeing and Smart Textiles: Reflecting on Collaborative Practices and the Design Process, *Journal of Textile Design Research and Practice*, 4:1, 63-83, DOI: 10.1080/20511787.2016.1256599.
- [18] Sue Fairburn, Josie Steed, and Janet Coulter. 2016. Spheres of Practice for the Co-design of Wearables, *Journal of Textile Design Research and Practice*, 4:1, 85-109, DOI:10.1080/20511787.2016.1255445.
- [19] Pelle Ehn, Elisabet M. Nilsson and Richard Topgaard. 2014. *Making futures: marginal notes on innovation, design, and democracy*. MIT Press, Cambridge.
- [20] Erling Björgvinsson, Pelle Ehn and Peranders Hillgren. 2012. Design Things and Design Thinking: Contemporary Participatory Design Challenges. *Design Issues* 28:3, 101-116 DOI 10.1162/DESI_a_00165.
- [21] Tim Brown. 2009. *Change by Design: How Design Thinking Transforms Organizations and Inspires Innovation*. HarperCollins, New York.
- [22] Tom Kelley. 2001. *The Art of Innovation: Success Through Innovation the IDEO Way*. HarperCollins, London.