The development of methodologies for designers engaging with digital colour inkjet printing in textile design

Becky Gooby

Ms Becky Gooby
3D3 PhD Researcher
Centre for Fine Print Research
UWE, Bristol
BS3 2JT, UK
Email: becky@beckygooby.co.uk

Abstract

Digital textile printing (DTP) offers exciting, creative potential and entrepreneurial business models[1] in textile design. Designers are no longer restricted to a number of colours or pattern repeat. It has become possible to print fabric without large set-up costs. This relatively sustainable technology reduces water-usage and dye-wastage[2]. DTP meets Just in Time, Concept to Consumer[3] demand, reducing stock wastage.

However, there is a marked difference between screen-colour to print-colour and software allows a user to select colours unprintable using CMYK colorants[4]. Colour results are further affected by factors such as structure and composition of the fabric[5], dye type[6], printer communications[7], fabric pretreatments[8] and secondary processes[9]. A textile designer will be required to understand and experiment with a number of variables in order to feel colour confident[10].

These variables were considered, and existing colour management tools and methods evaluated, using a practice-as-research methodology. Experiments showed that neutral and achromatic colours were the most difficult to replicate, and hues with magenta/blue undertones were problematic. The choice of substrate had a sizeable impact on colour visualisation. The results were used to establish a best practice guide for designers wishing to obtain a more acceptable print-colour match.

Key Words: Digital Textile Printing; Colour; Design; Digital Economy; Digitally-Enabled Textile Manufacture; Printing; Coloration; Colour Physics / Measurement; Energy and Water Use in Textile Lifecycles; Practice as Research; Sustainability;

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[1] Ujiie, H. 2006. Design and workflow in digital inkjet printing. In: Ujiie, H. (ed.) Digital Textile Printing. Cambridge: Woodhead Publishing Limited

[2] Tyler, D. J. 2005. Textile Digital Printing Technologies. Textile Progress, 37, 1-65.

[3] Association of Suppliers to the British Clothing Industry 2014 Colour Clues

[4] Henry, P. 2014. The development of a new colour-picker tool, University of Leeds.

[5] George, B., Ujje, H., Govindaraj, M., Freeman, H. & Tonelli, A. 2006. Integration of fabric formation and coloration processes. Digital Printing of Textiles, 123-44.
Ingamells, W. 1993. Colour for textiles. Society of Dyers and Colourists.

[6] Tyler, D. J. 2005. Textile Digital Printing Technologies. Textile Progress, 37, 1-65.

[7] Dawson, T. L. 2006. Digital image design, data encoding and formation of printed images. In: Ujiie, H. (ed.) Digital printing of textiles. Cambridge: Woodhead Publishing
Leak, A. 1998. A practical investigation of Colour and CAD in Printed Textile Design. Nottingham Trent University.

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. In: Ujiie, H. (ed.) Digital printing of textiles. Woodhead Publishing.
Provost, J. 2011. Be Prepared: Pre-treatment is the Key to Success in Digital Textile Printing. Digital Textile.

[9] Tyler, D. J. 2005. Textile Digital Printing Technologies. Textile Progress, 37, 1-65.

[10] Gooby, B. 2016.
Variables that affect colour in digital textile printing PICS2016. University College London, UK.

Introduction

The development of digital printing is a major change within the textile design process as a designer is no longer restricted to number of colours or repeat patterns, and may include photographic images and intricate detail in their design work. It has become possible to print a metre, or hundreds of metres, at the click of a button, without large set up costs, leading to new entrepreneurial business models[11] in the textile industry.

Digital textile inkjet printing[12] is a non surface-impact print process where colorants (primarily dyes, but increasingly pigment inks) are jetted in a dithered matrix of dots to create the appearance of solid colour, onto a specially coated fabric. The print head moves across the fabric, overprinting the same dot to build density so that the print is created in a single pass. The colorant sits on the surface, although, secondary processes, , allow dye molecules to further permeate the fibres. Digital dye sublimation textile printing[13] is the transfer of solid colorant (largely disperse dyes) to a gaseous state. These vaporise, and solidify, on special transfer paper, or treated fabric, as gradated pixels to create an image. A calendaring process uses heat and pressure to apply the image from the transfer paper to fabric. In direct to fabric dye sublimation printing, calendaring is required for fixation. The heat required restricts this process to polyester fabrics or poly mixes only. Additionally, DTP may include solvent, latex, ultra-violet and direct-to-garment printing, for example T-shirt printers.

Digital textile printing (DTP) provides unprecedented opportunity for designers to offer bespoke and customisation of designs. Just in Time and Concept to Consumer production models benefit from short print runs and expedited strike-offs, product sampling and testing made possible by DTP.

Reduced ink wastage and water use makes DTP a more environmentally sustainable printing method in comparison to screen and rotary printing. Digital Print Bureaus (DPBs) are more likely to be located in an urban environment, local to their customers, with reduced transport costs, and occupying less space than a traditional textile mill or factory[14]. Short print runs and

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[11] Kelly, A. 2014. An investigation into colour accuracy & colour management issues in digitally printed textiles for Higher Education.
Ujiie, H. 2006. Design and workflow in digital inkjet printing. In: Ujiie, H. (ed.) Digital Textile Printing. Cambridge: Woodhead Publishing Limited
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Dawson, T. L. 2006. Digital colour management. In: Ujiie, H. (ed.) Digital printing of textiles. Woodhead Publishing.
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Kelly, A. 2014. An investigation into colour accuracy & colour management issues in digitally printed textiles for Higher Education.
[13] Romano, R. 2017. A Closer Look at Digital Dye-Sublimation Printing - WhatTheyThink. [Online]. [online]: Whattheythink.com. Available: http://whattheythink.com/articles/79399-closer-look-digital-dye-sublimation-printing/ [Accessed 5 Sept 2017].
[14] Ujiie, H. 2006. Design and workflow in digital inkjet printing. In: Ujiie, H. (ed.) Digital Textile Printing. Cambridge: Woodhead Publishing Limited

the ability to react quickly to market trends allow businesses to carry less stock, reducing storage costs, and the likelihood of stock wastage as fabric is printed to demand[15]. These changes offer exciting possibilities for designers and SMEs working in the textile industry.

However, there is a marked difference between screen-colour and print-colour. A textile designer will be required to experiment with a number of variables in order to feel confident about the colour outcome of their print which may be time consuming, costly and imprecise. The range of printing machines, and the methods that they use to apply and represent colour, may also impede the designer's understanding. For example: the ink range and colour bank of the printer, variations between one machine and another, the structure and composition of the substrate, fabric pre-treatment, secondary processes and the printer's achievable gamut will all affect final result. A user may choose from a variety of image-editing software and print via inkjet or dye sublimation processes, onto numerous fabrics.

Colour is critical[16] in the textile industry both in terms of meeting trends, client requirements and obtaining consistent colour. The choices a designer makes about the colours in their designs may come from trend forecasts[17] or be dictated by the brand or textile agent the designer is working for. Achieving the correct colours and meeting seasonal trends can ensure a product's success.

The Research Project

This research inquiry considers how designers can ensure colour assurance when digitally printing through an exploration of existing colour tools and methods. The aim, to produce an accessible colour toolkit for designers, artists, makers, and SMEs, that may not have access to highly technical equipment and software, providing specific knowledge as to how designers can achieve and maintain colour assurance and accuracy. This toolkit will take the form of videos, instructions and downloads available online through a dedicated website.

The research set out to initially identify the variables which affect colour outcome. These were then explored, using a Practice as Research methodology, to discover the impact on printed colour. Existing software, methods and processes were surveyed to determine their usefulness and accessibility. The work was documented, and reflected upon, providing a durable record of the practice and progress of the research inquiry and will inform best practice guidance and online toolkit.

The thinking-doing approach was informed by Professor Robin Nelson's understanding of Practice as Research and follows the know-how, know-that, know-what model of praxis he has established. This model is useful for the research because textile design, and working with cloth, is naturally a nonverbal experience. Research undertaken in this field requires visual and tactile semiotics to make 'the tacit, explicit'[18].

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[15] Ujiie, H. 2006. Design and workflow in digital inkjet printing. In: Ujiie, H. (ed.) Digital Textile Printing. Cambridge: Woodhead Publishing Limited
[16] Kelly, A. 2014. An investigation into colour accuracy & colour management issues in digitally printed textiles for Higher Education.
[17] Cassidy, T. D., Tracy 2005. Colour Forecasting, Oxford, Blackwell.

[18] Nelson, R. & Arlander, A. 2013. Practice as research in the arts: principles, protocols, pedagogies,

Know-How
The personal expertise and experience of the researcher are as a freelance, computer-aided-design, printed textile designer. First engaging with DTP in 2008 the researcher has seen the industry develop in the UK. The researcher has experience of colour matching and consistency issues in her practice, which were confusing and frustrating, primarily because the process is outsourced.

Know-That
Research has been examined in the field of DTP and beyond, encompassing, but not limited to; colour theory, colour and colour use, digital printing in other mediums, DTP from a scientific and manufacturers perspective, design history (interwar period), colour management, colour measurement and colorimetric analysis, textile chemistry (dyes and inks, pre and post processing), and design education. Additionally, the research has considered how colour mixing and colour theory is explored in the visual arts.

Know-What
The collation and analysis of practical experiments, interviews and workshops, archival study, and a compiled a body of knowledge, has set out to achieve the aim of the research.

Aim
- to create a tool kit, accessible to artists, textile practitioners and similar, without access to commercial resources and chemical colour knowledge/ science, which provides guidance to assuring a colour match when printing from digital printers on to fabric

The work has been underpinned and informed through a number of research activities utilising additional methodologies; Interwar Colour Archive (historical research), Case Studies (descriptive research) and Workshops (participatory action research).

A range of designers and SMEs were interviewed on colour in their practice. The interviews set out to discover if they encountered issues with colour fidelity in DTP, and, if so, what colour management methods they employed.

A comparative case study was made to observe how colour use developed in a past era of technological innovation. The British Interwar period was a time of technological modernisation and change, with the advent of cheap, chemical colorants, synthetic fabrics and the emergence of silk screen printing. Many of the colours associated with this era, smoky, dark colours, neutrals, pastels and strong earth colours, identified from archival and primary sources, proved hardest to replicate in DTP[19], and will be used as a test colour palette to provide an unusual comparison.

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resistances, Basingstoke, Palgrave Macmillan.

[19] Gooby, B. 2017 Colour Reference Book (Figure 2)
Clark, D. N. W. 2017. Colour Conversation. In: Gooby, B. (ed.). (interview)
Loser, E. & Tobler, H. P. 2010. ICC Color management for digital inkjet textile printing.

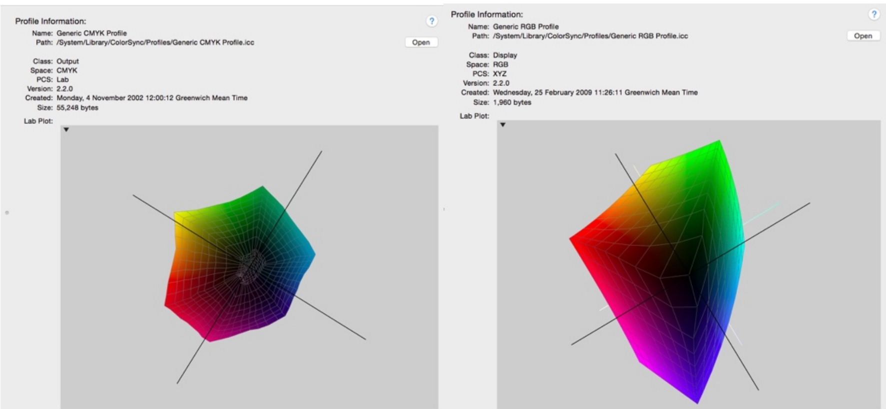
The research project encompasses two themes; Colour Expectation and Colour Archive and primarily looks to answer the question, what measures must a designer take to feel confident with their colour use in DTP?

This paper presents highlights from the progress of the research to date; the creation of a colour reference book, analysis and resulting findings, the emerging themes from interviews with practitioners, and the primary causes of colour issues identified from a contextual review. The full research findings will be published in the form of a thesis comprised a written component, exhibition of practice work, and online tool kit.

The Creation of a Colour Reference Book

In order to evidence that there is a difference between screen colour and print colour in DTP, and further variations between substrates, a colour chart was created using the 1137 colours in the Pantone© solid uncoated colour library in Adobe Photoshop Creative Cloud (APCC). The chart was printed on 4 different substrates (wool, linen, cotton and silk) using an inkjet Mimaki TX2-1600, with reactive dyes. The digital make up of each colour was documented and compiled into a table alongside a visual reference. The table was printed on paper and incorporated individual fabric swatches for each colour (Figure 2). The resulting colour reference book provides a visual comparison of colour differences between the four substrates, an indication of the shift from screen to print colour, alongside the numeric data for each of the 1137 colours in the library.

Digital screen colour, a mix of red, green and blue light known as additive colour, has a broader colour range (Figure 1) to printed colour, primarily a mix of cyan, magenta, yellow and black pigment primaries known as subtractive colour. Whilst there are overlaps between the two colour spaces there are many colours possible in one but not the other, thus out of gamut (Figure 1).



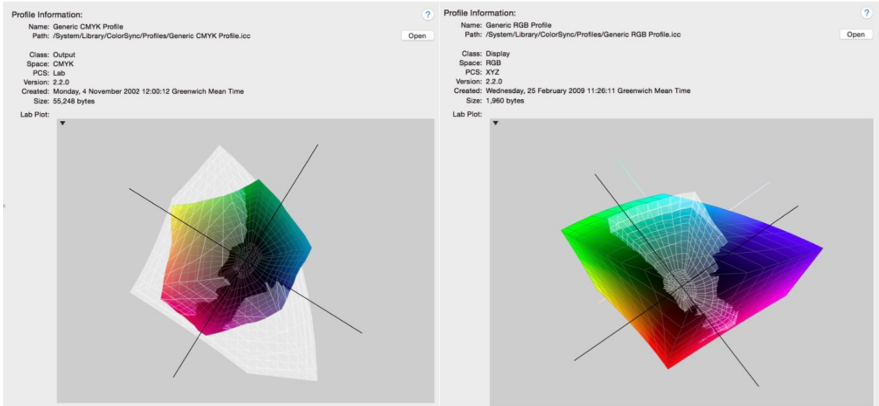
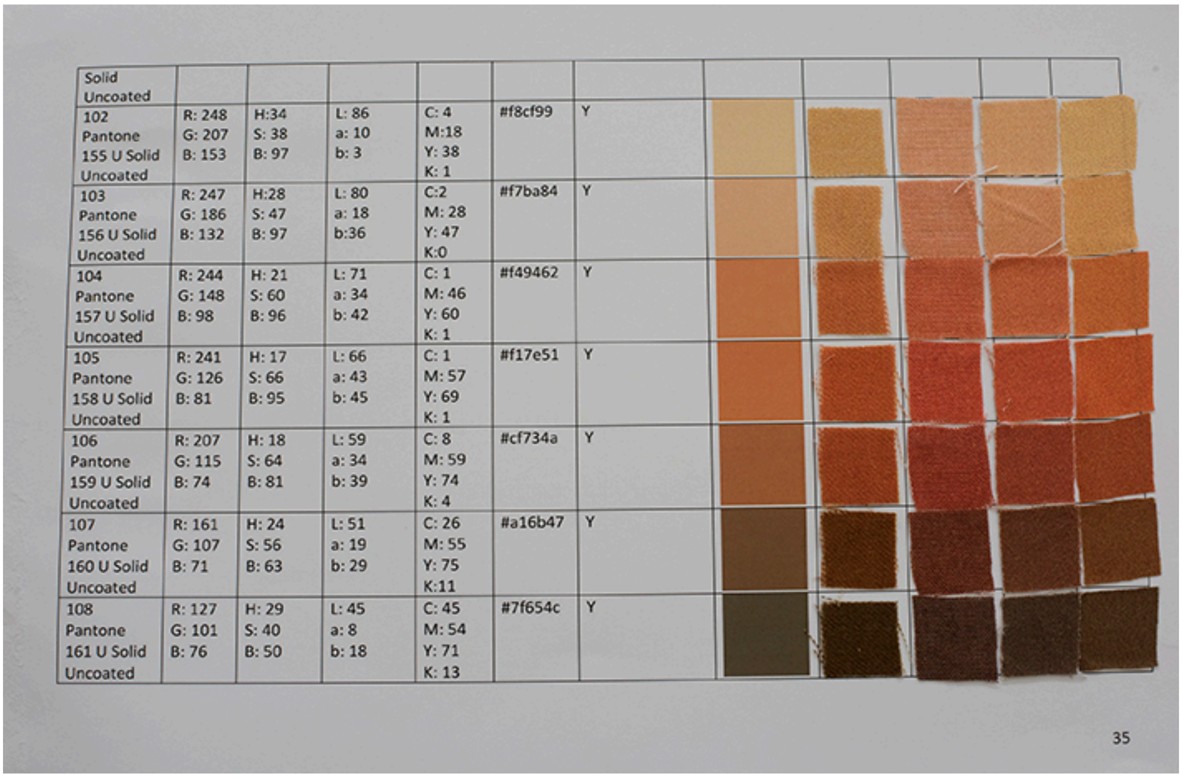


Figure 1 Gooby, B, 2017 Apple Mac ColorSync Screen Grabs (Researcher's own collection). Apple Mac's ColorSync's representation of CMYK and RGB colour spaces. Top Left Generic CMYK Colour Space, Top Right Generic RGB Colour Space, Bottom Left Generic CMYK Colour Space compared with Generic RGB Colour Space, Bottom Right Generic RGB Colour Space compared with Generic CMYK Colour Space.



Solid Uncoated											
102 Pantone 155 U Solid Uncoated	R: 248 G: 207 B: 153	H:34 S: 38 B: 97	L: 86 a: 10 b: 3	C: 4 M:18 Y: 38 K: 1	#f8cf99	Y					
103 Pantone 156 U Solid Uncoated	R: 247 G: 186 B: 132	H:28 S: 47 B: 97	L: 80 a: 18 b:36	C:2 M: 28 Y: 47 K:0	#f7ba84	Y					
104 Pantone 157 U Solid Uncoated	R: 244 G: 148 B: 98	H: 21 S: 60 B: 96	L: 71 a: 34 b: 42	C: 1 M: 46 Y: 60 K: 1	#f49462	Y					
105 Pantone 158 U Solid Uncoated	R: 241 G: 126 B: 81	H: 17 S: 66 B: 95	L: 66 a: 43 b: 45	C: 1 M: 57 Y: 69 K: 1	#f17e51	Y					
106 Pantone 159 U Solid Uncoated	R: 207 G: 115 B: 74	H: 18 S: 64 B: 81	L: 59 a: 34 b: 39	C: 8 M: 59 Y: 74 K: 4	#cf734a	Y					
107 Pantone 160 U Solid Uncoated	R: 161 G: 107 B: 71	H: 24 S: 56 B: 63	L: 51 a: 19 b: 29	C: 26 M: 55 Y: 75 K:11	#a16b47	Y					
108 Pantone 161 U Solid Uncoated	R: 127 G: 101 B: 76	H: 29 S: 40 B: 50	L: 45 a: 8 b: 18	C: 45 M: 54 Y: 71 K: 13	#7f654c	Y					

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Figure 2 Gooby, B, 2017 Colour Reference Book (Researcher's own collection) An example of the colour reference book. Each row consists of the digital numeric values (RGB, HSB, Lab, CMYK and Hex) and indicates whether a colour is considered in the gamut of a generic CMYK printer (Y or N). The swatches (left to right) are paper print, wool, linen, cotton and silk.

The fabric swatches were subsequently measured using a Kodak-Minolta FD-7 spectrodensitometer. Two colour sets were identified to focus upon, reducing the data range from over five thousand swatches. Set One consisted of the first 24 colours in the Pantone© Library which covered a set of highly saturated, spectral colours (red to purple). Set Two was based on colours from the Colour Tile, a colour rendition chart[20], used by Dr Philip Henry at the University of Leeds, for his ColourMimix[21] software. The Colour Tile image was translated into the Pantone© Library using the colour picker tool in APCC. visual adjustments made where colours were selected that weren't a perceived visual match (Figure 3). For example, the colour picker selected Pantone© Orange 021C for the first colour in the tile, however visually, Pantone© Red 32C was a better match and so substituted.

Figure 3 Gooby, B, 2017 Colour Set Two (Researcher's own collection)

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[20] McCamy, C.S., Marcus, H. and Davidson, J.G., 1976. A color-rendition chart. J. App. Photog. Eng, 2(3), pp.95-99.
Colour rendition charts were created as visual evaluation tools for the photographic, television and printing industries. They are made up of a set of essential colours based on RGB and CMYK primaries, and colours that are challenging to reproduce. Colour rendition chart article

[21] http://colourmimix.co.uk/
Colour Mimix is a colour tool that uses a visual gamut mapping exercise which is carried out by the user enabling them to gain knowledge about the screen to print colour differences for their particular set up. Using a set palette of colours, a tile is printed to gauge the print environment. The user adjusts the colours on screen based on the printed colours. This palette forms the base of all subsequent colour mixing which is done subtractively rather than additively.

Digital Colour Swatches and Digital Lap Dip Tests

The LAB coordinates returned for the sets by the spectrodensitometer, were used to create digital colour swatches. A spectrodensitometer will return sophisticated colour measurements using filters to measure the wavelengths reflected from the colour sample[22]. In this experiment the spectrodensitometer was set up to measure the reflectance value under D65 illuminant conditions, the standard for measuring textiles[23], and return LAB and wavelength (nm) values from 380-730nms.

The visible light spectrum begins at violet (400nm) and moves from indigo (445nm), blue (475nm), green (510nm), yellow (570nm), orange (590nm) to red (700nm)[24]. The CIE International Commission on Illumination established the LAB colour space in 1976[25]. The three values represent the hue lightness (L) and it position on a red-green (a) and blue-yellow axis (b) of this three dimensional model. LAB is a larger colour space than RGB (additive / screen) or CMYK (subtractive / print) and is device independent. The LAB coordinates were inputted to the colour picker tool to display a digitised version of the printed swatch.

The digital colour swatches were plotted onto colour maps to demonstrate hue, saturation and brightness (HSB) shifts from the screen colour, symbolising a digital lab dip test. The HSB colour model was chosen as an accessible, and visual means, of showing colour changes, in comparison to the mathematical LAB model. The colour picker tool was used to translate the LAB to HSB values. Saturation provides the intensity of the colour and brightness, the lightness of the colour. A colour with 100% saturation and brightness will be very vivid but a colour with 0% will be black. A median value for each set's shift was presented as indicator colours and used to trial whether such adjustments provide an indication of print colour.

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[22] Society of Dyers and Colourists. 2008. *Colour matching assessment of textiles and textile products*, Society of Dyers and Colourists.
[23] Society of Dyers and Colourists. 2008. *Colour matching assessment of textiles and textile products*, Society of Dyers and Colourists.
[24] Feisner, E. A. & Reed, R. 2014. *Color studies,* New York; London; Fairchild Books.
[25] Baumann, U. *ColorSystem* [Online]. [online]: ColorSystem. Available: http://www.colorsystem.com/ [Accessed 5 Sep 2017].

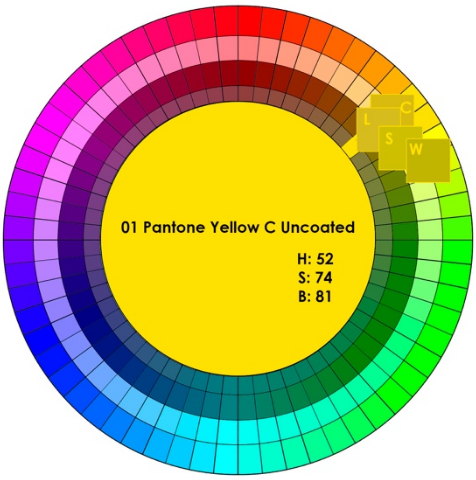

Figure 4 Figure 3 Gooby, B, 2017 Example of a Colour Map (Researcher's own collection)

An example of a digital colour map. The hue circle is divided into 6 degree segments beginning at red 0/360 degree, yellow 60, green 120, cyan 180, blue 240 through to tones of magenta from 300 degrees. The outer ring has 100% saturation (S) and brightness (B). The rings decrease first in saturation (50%S 100%B) and then brightness (100% S, 50%B) and finally both saturation and brightness (50%S, 50%B). In this particular example the centre is filled by the screen colour with its original HSB values, and the digital versions of the fabric swatches placed around the outside to indicate HSB shifts

A series of colour maps was produced for both sets, with two maps per colour. One showing the indicator colour in comparison with the screen colour, the second showing the digital swatches in comparison with the screen colour (Figure 5, Figure 6).

Figure 5 Gooby, B, 2017 Set One: Pantone© Colour Library 1-24, 48 Colour Maps (Researcher's own collection)

Figure 6 Gooby, B, 2017 Set Two: Visual Pantone© Colour Tile: 48 Colour Maps (Researcher's own collection)

The resulting work was presented at DataAche, a conference and supporting exhibition hosted Digital Research into Humanities and the Arts, Plymouth University, 10-13 September 2017.

A selection of the colour maps were displayed at the Gallery Kopio, University of Lapland, Finland from July to September 2017. The exhibition was a group show of research by PhD Researchers and staff in the 3D3 Centre for Doctoral Training.

Wavelength Data

The wavelength values for each swatch provided by the spectrodensitometer were recorded as line graphs (Figure 7) and the changes in spectral ranges noted. Comparisons were made against the paper print. A pattern emerged where the fabric prints had lower readings of the violet-indigo-blue spectral range (400-475 nm), and higher readings of the upper-red spectral range (700-775nm), to the paper print. These findings will be tested to determine whether increasing the blue content, and decreasing the red content of a screen colour, provides an improved colour match with intended print colour.

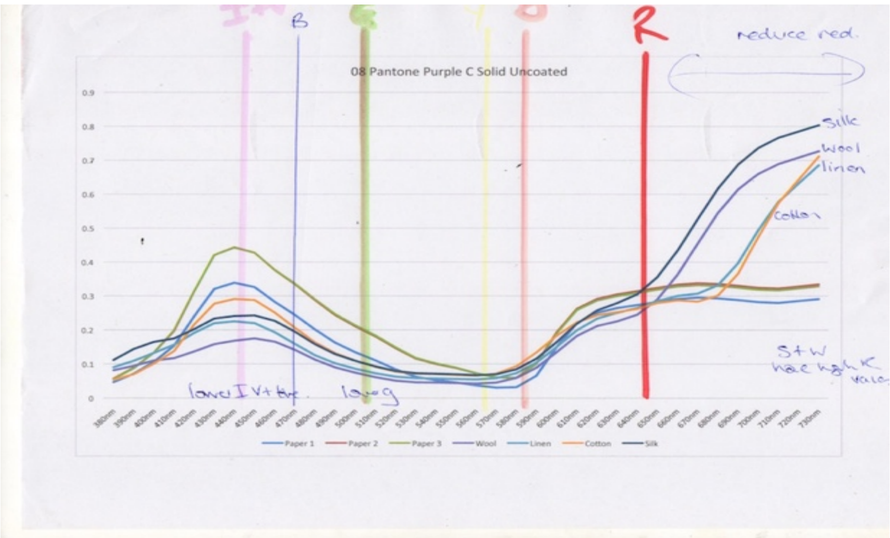

Figure 7 Gooby, B, 2017 Example Wavelength Line Graph (Researcher's own collection) An example of a wavelength line graph produced using the spectrodensitometer readings. This graph is from Set One, 08 Pantone© Purple C Solid Uncoated. Comparisons were made between the path of the values returned by the paper print(s) and the fabric substrates.

Patterns in Colour Data

The numeric values (RGB, HSB, L*a*b*, CMYK and Hex) from the table were also examined to determine whether there were any patterns, or assertions that could be made, to whether a colour is printable. A set of parameters were identified and questions drawn up based on the assumption that high values of certain data would cause translation issues across colour spaces. The data was analysed using xml code written by Dr Paul O'Dowd, and a set of histograms produced with the results. The histograms demonstrated that a colour with a high red (Table 1**Error! Reference source not found.**) or brightness value (Table 2) would be considered out of gamut for a generic CMYK printer by APCC's gamut warning tool. This out of gamut set is of interest because it can be presumed that it is difficult to predict how these colours will print. There are various methods[26] which map an out of gamut colour into another colour space which depend primarily the colour management used in the print environment set up.

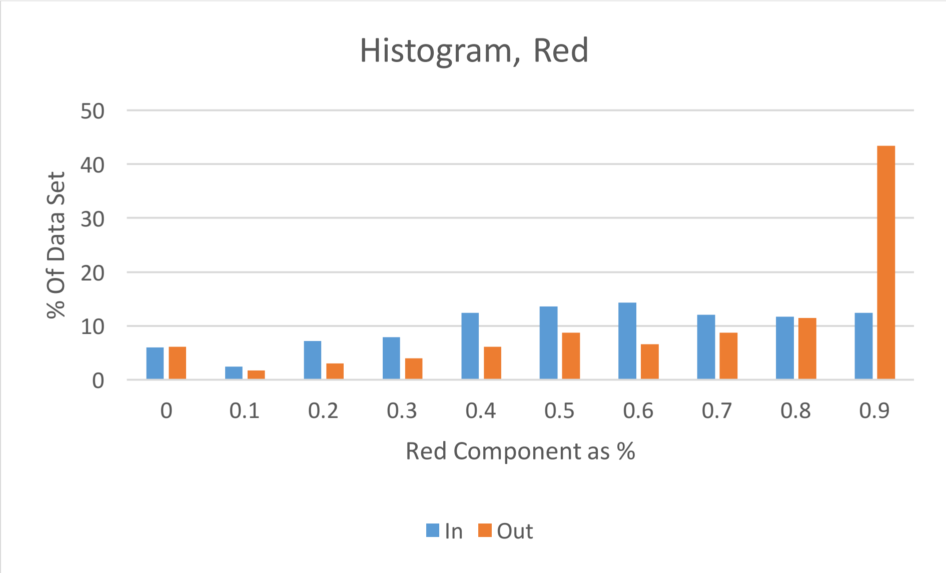

Table 1 Histogram comparing the set of data for colours in gamut (blue) and colours out of gamut (orange) and the proportion of red in their RGB value. High red values indicated that a colour would be out of gamut with 45% of out of gamut colours having a red value of 229 or above.

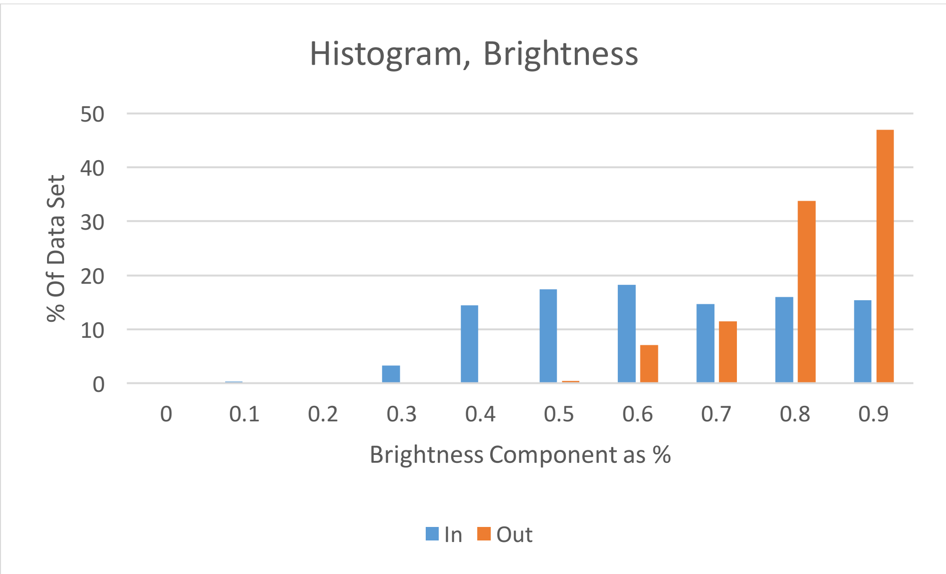

Table 2 Histogram comparing the set of data for colours in gamut (blue) and colours out of gamut (orange) and the changes in brightness value. Brightness is measured as a percentage. an 80% brightness value and above were proportionately likely to be out of gamut.

[26] Dawson, T. L. 2006. Digital colour management. In: Ujiie, H. (ed.) Digital printing of textiles. Woodhead Publishing.
Leak, A. 1998. A practical investigation of Colour and CAD in Printed Textile Design.

Proving the hypothesis that high red RGB values and significantly bright colours are out of a generic CMYK gamut, thus unprintable, indicates that designers may wish to avoid using overly bright or saturated red colours if they wish to achieve colour fidelity. However visual observations of the printed colour demonstrated that there may be greater disparity in achromatic and neutral colour ranges which are not flagged as out of gamut.

A Visual Assessment of the Colour Reference Book

A visual assessment was made of the colour reference book to observe the appearance of colours that were identified by APCC as being out of gamut. None of the grey tints displayed a gamut warning, yet the print appearance differed widely[27].

Figure 8 Gooby, B, 2017 Example of Achromatic colour prints from Colour Reference Book (Researcher's own collection). The swatches (top to bottom) are paper print, wool, linen, cotton and silk.

The gamut warning tool in APCC indicated that 227 of the 1137 colours were out of gamut for a generic CMYK printer. Of these 227 the majority (53 purple and 38 pink) were identified to be from the magenta range. 46 green shades were flagged as being out of gamut, followed by 27 red, 21 blue, 20 yellow, and 20 orange. Only two were considered to be neutral colours and classified as brown by the researcher. The mapped colour was observed to be duller in comparison to the original, and frequently darker, when viewed on screen. However, when the printed swatches were examined, the differences between the print colour

[27] Clark, D. N. W. 2017. Colour Conversation. In: Gooby, B. (ed.) (interview)

and screen colour were not as stark for most of the out of gamut set. These colours bore more of a likeness to the original screen colour rather than the mapped screen colour. This resolution may have been performed by the Raster Image Processor algorithm that communicates data between the computer and the Mimaki TX2-1600 printer, overriding APCC's colour management. Additionally, the printer uses a broader ink set than a generic CMYK printer, incorporating red, blue, light cyan and light magenta, reactive dyes increasing the tonal range but not broadening the gamut boundaries. The wool prints were consistently different to the screen colour, as the substrate was not optic-white, but the greatest inconsistencies were in the neutral ranges (grey, brown, black), and where colours were observed to have a high blue and magenta appearance.

The Impact of the substrate on colour outcome

It was observed that the substrate had a great affect on the resulting colour, with cotton the closest match to the screen colour. The colour appearance of the wool was the most affected. The construction, yarn and weave of a fabric all affect the achievable colour gamut[28]. Wool is a keratin protein, animal fibre which naturally repels moisture but does absorb dyes[29]. However, it is acidic and will dissolve if bleached meaning whitening pre-treatments are complex. Leaving wool in its natural state reduces the cost but leaves a yellow undertone which affects the printed colour. The wool substrate used in this experiment is a twill with a diagonal weave and has the greatest texture of the four substrates. Similarly, silk is an animal fibre, made up of 80% fibroin and 20% sericin proteins, and has comparable elastic properties[30]. Silk absorbs dye well and the smooth texture and reflective qualities of the satin silk tested provided strong colour results when printed. However, whilst the colour was strong, frequently the tone was darker than the screen colour.

Conversely, linen, a cellulose fiber constructed from flax plants, does not absorb dye particularly well[31]. The juniper linen tested has the loosest weave of all four substrates and natural slubs in the fabric can cause printing issues. Linen has a natural resin, lignan, but does not repel moisture like wool. The colour match on linen appeared good, but the saturation was greatly reduced and the resulting shade less vivid than the screen colour. The linen prints lost a lot of dye when undergoing the secondary processes to fix the colour. Cotton is also cellulose, derived from cotton plants, but absorbs and retains dye well[32]. The cotton satin tested has a tight weave and smooth surface and provided good colour results, the closest to screen colour of the four substrates. Like the silk, both the linen and cotton were bleached white in the preparation for print.

[28] Kim, Y. 2006. Effect of pretreatment on print quality and its measurement
. In: Ujiie, H. (ed.) Digital printing of textiles. Woodhead Publishing.
[29] Wilson, J. 2001. Handbook of textile design, Elsevier.
[30] Udale, J. 2014. Textiles and fashion: exploring printed textiles, knitwear, embroidery, menswear and womenswear, London, Fairchild Books.
[31] Udale, J. 2014. Textiles and fashion: exploring printed textiles, knitwear, embroidery, menswear and womenswear, London, Fairchild Books.
[32] Udale, J. 2014. Textiles and fashion: exploring printed textiles, knitwear, embroidery, menswear and womenswear, London, Fairchild Books.

Digitally printed fabrics require additional pre-treatments[33] to other fabrics prepared for print, known as P2P. Much of the binders and chemical properties included in traditional dyes have to be coated onto the fabrics intended for digital printing, as they cannot be incorporated into the jetted dye without affecting the print mechanisms. Different coatings are required for different fibers and further variations needed, depending on colorant (reactive, acid, disperse or pigment ink). The substrates tested here were all purchased pre-coated but further experiments have been conducted to understand how the coating affects colour outcome.

Emerging Themes from Interviews with Practitioners Engaging with Digital Print

A range of designers and SMEs were interviewed on colour in their practice. The interviews set out to discover if they encountered issues with colour fidelity in DTP, and, if so, what colour management methods they employed.

A number of themes emerged, which are outlined below, and were presented as a poster at the Textiles and Life, Textile Institute Student Conference in Manchester, 22 November 2017[34].

Reducing or Controlling Colour Fidelity Variables

The majority of designers interviewed reduced colour fidelity variables by working with one substrate, or a limited number of substrates, which enabled them to build up a colour knowledge-bank in order to make adjustments to the digital files which accommodated colour changes caused by the structure and composition of the cloth.

Designer / Printer Communications

Several designers had built up a good working relationship with a particular DPB having trialled several bureaus and encountered issues such as colour mismatches. Reduced costs or free colour sampling, good colour management communication, such as providing an ICC profile to embed, and consistent results were all cited as important when out-sourcing DTP.

Designer's Eye

All of the designers made tacit adjustments in their digital files to allow for colour changes between screen and print colour. These adjustments were made based upon past experiences,

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[33] Hawkyard, C. 2006. Substrate preparation for ink-jet printing
In: Ujiie, H. (ed.) Digital printing of textiles. Woodhead Publishing.
Kim, Y. 2006. Effect of pretreatment on print quality and its measurement
. In: Ujiie, H. (ed.) Digital printing of textiles. Woodhead Publishing.
Provost, J. 2011. Be Prepared: Pre-treatment is the Key to Success in Digital Textile Printing. Digital Textile.

[34] https://digitaltextileprintingblog.wordpress.com/2017/11/19/dissemination-textiles-life-textile-institute-student-conference-manchester-22nd-november-2017-2/

built up tacit knowledge and haptic intuition, as well as digital colour knowledge. Designers talked about adjusting levels, saturation, brightness, mid tones and shadows to control colour.

Colour Management Education and Accessibility

Established colour management practices such as ICC profiles and colour measurement procedures (for example, using a spectrophotometer), utilised by the graphic and photographic industry for digital paper printing, do not appear to be the primary source of colour control for designers working in this medium. Several of the designers were not aware of these processes or did not understand them. The majority did not have access to colour measurement technology such as a spectrophotometer or bespoke DTP software. The designers who did incorporate these controls had greater industry experience, combined additional tacit adjustments on top of these practices, and incorporated customised ICC profiles for their print environment.

Colour Testing

Colour sampling and colour palette testing was shown to be a simple yet useful and accessible method which designers incorporated into their design process. This visual process built up tacit knowledge of digital colour and colour changes.

Entrepreneurial Business Models

All of the designers interviewed felt that DTP had enabled and empowered their business model. Designers cited small print runs, reduced overheads, quick turn-around times and the ability to respond quickly to design trends as reasons for engaging with digital textile print technologies. Many liked the ability to produce innovative and customisable fabric designs for a small, or particular, market which allowed them to test out design styles without the risk of having to hold large amounts of stock which they may have to scrap or reduce if unsuccessful.

Contextual Review

Research has been examined in the field of DTP and beyond, encompassing, but not limited to; colour theory, colour and colour use, digital printing in other mediums, DTP from a scientific and manufacturers perspective, design history (interwar period), colour management, colour measurement and colorimetric analysis, textile chemistry (dyes and inks, pre and post processing), and design education. Additionally, the research has considered how colour mixing and colour theory is explored in the visual arts.

A contextual review established several primary causes which contribute to screen to print colour differences in DTP

Gamut Mismatches

There is a mismatch between the gamut range of the digital screen colour, a mix of red, green and blue light, to that of the printed colour, primarily a mix of cyan, magenta, yellow and black (CMYK) pigment primaries[35]. Whilst there are overlaps between the two colour spaces, there are many colours possible in one, but not the other, thus out of gamut. Design software allows a user to select colours from the screen gamut which are unprintable using CMYK colorants leading to frustration and confusion when printed designs don't match expectations based on what is seen on screen.

Numerous Variables

There are numerous variables[36] that affect colour fidelity in the digital textile print process. Many of these are out of the designers control and difficult to predict. Some are distinct to DTP, such as the structure and composition of the fabric substrates[37], the fabric pre-coating[38] and the secondary processes[39]. Others are problems shared with the reprographics and photographic industry. A textile designer will be required to experiment with a number of variables in order to feel colour confident.

An early identification of the variables that affect colour outcome was outlined and presented at the Progress in Colour Studies Conference in London, September 2016.[40] The findings set out twenty-three variables that impact on printed colour but Provost[41] ascertains that there are at least forty which need to be considered. Many will be out of the designer's control but gaining an understanding of their impact will assist designers to identify and resolve colour issues.

Adapted Technology and processes

Added problems stem from the adaption of existing print machinery[42] and colour management systems from reprographic and photographic digital printing technologies.

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[35] Green, P. 2010. Color Management: Understanding and Using ICC Profiles, Chichester, West Sussex, Wiley Blackwell.
Fraser, B. M., Chris; Bunting, Fred 2004. Real World Color Management California, Peachpit Press
[36] Gooby, B. 2016.
Variables that affect colour in digital textile printing PICS2016. University College London, UK.
Provost, J. 2011. Be Prepared: Pre-treatment is the Key to Success in Digital Textile Printing. Digital Textile.
[37] George, B., Ujje, H., Govindaraj, M., Freeman, H. & Tonelli, A. 2006. Integration of fabric formation and coloration processes. Digital Printing of Textiles, 123-44.
Ingamells, W. 1993. Colour for textiles. Society of Dyers and Colourists.
[38] Hawkyard, C. 2006. Substrate preparation for ink-jet printing
. In: Ujiie, H. (ed.) Digital printing of textiles. Woodhead Publishing.
Provost, J. 2011. Be Prepared: Pre-treatment is the Key to Success in Digital Textile Printing. Digital Textile.
[39] Tyler, D. J. 2005. Textile Digital Printing Technologies. Textile Progress, 37, 1-65.
[40] https://digitaltextileprintingblog.wordpress.com/2016/10/03/dissemination-pics2016-conference-2/
[41] Provost, J. 2011. Be Prepared: Pre-treatment is the Key to Success in Digital Textile Printing. Digital Textile.
[42] Carden, S. 2015. Digital textile printing, London, Bloomsbury.

Digital colour management structures do not yet accommodate for the chemistry of pre and post treatment processes[43], although there have been developments[44]. The characteristics of cloth substrates, and the pre-requisites of their end use, further compromise methods optimised for paper printing. For example, the drop shape of the colorant emitted by an inkjet print head alters when it impacts with the fabric substrate, spreading differently to if dropped onto a smooth paper surface[45]. As digitally printed colour is built up through a dithered matrix of dots of colorant, changes to the dot shape will affect the achievable colour gamut.

Additionally, colorant chemistry has been modified from traditional textile practices[46] where binders and thickeners required to enhance chemical activity, are applied in a pre treatment stage rather than included in the dye paste. This ensures better viscosity and drop flow, decreasing the likelihood of print head malfunctions[47] but increases the likelihood of colour variance by further increasing the number of colour variables to control.

Design Education

Digital colour education is inconsistent across undergraduate design curriculums and an understanding of DTP is lacking in the wider design community[48]. The lack of comprehension hinders the designer's understanding of the digital print processes.

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[43] Dawson, T. L. 2006. Digital colour management. In: Ujiie, H. (ed.) Digital printing of textiles. Woodhead Publishing.
Javoršek, D. & Javoršek, A. 2011. Colour management in digital textile printing. Coloration Technology, 127, 235-239.
Kelly, A. 2014. An investigation into colour accuracy & colour management issues in digitally printed textiles for Higher Education.
[44] RIPMaster V11 is mentioned by several users in 'Ding, Y. 2016. Color Gamut Comparison Methodology and Evaluation for Textile Inkjet Printing.' as a RIP that is able to consider textile variables
[45] Dawson, T. L. 2006. Digital colour management. In: Ujiie, H. (ed.) Digital printing of textiles. Woodhead Publishing.
[46] Hoskins, S. 2004. Inks, London, A&C Black.
[47] Freire, E.M., 2006. Ink jet printing technology (CIJ/DOD). In Digital Printing of Textiles (pp. 29-52).
[48] Burton, R. 2005. Creativity, method and process in digital fabric printing: a 21. Digital Creativity, 16, 217.
Bunce, G. 1993. An Investigation of CAD/CAM possibilities in the printing of textiles: with reference to the application of complex repeat patterns. Doctor of Philosophy, The Nottingham Trent University.
Carden, S. 2015. Digital textile printing, London, Bloomsbury.
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Townsend, K. 2004. Transforming Shape: Hybrid practice as group activity. The Design Journal, 7, 18-31.

Additionally, there is a gap between what a designer is led to believe is possible, and what is achievable. This design mirage is created through a number of means.

Firstly, software allows users to select unprintable colours, viewed on a luminous screen which is able to display a broad range of saturated, bright colours through additive mixing. Printed colour in comparison does not convey the same intensity and brightness of colour because it is subtractive, colour perceived by the absorption of light rather than reflected. Replication of traditional mark marking and the expedition of hand techniques in computer software supports a belief that computer-aided-design offers miraculous possibilities. This perception can mask the restrictions and limitations of the conversion from screen to print, which coupled with an outsourced, and therefore removed, print process, may lead to disappointment and frustration with the printed outcome[49].

Secondly the communications between DPBs and designer is problematic partly motivated by the need for secrecy in a commercial set ups but also due to financial barriers and vocabulary misunderstandings. There is little explanation by DPBs around resolving colour differences and the key variables in the process that will affect colour outcome. Designers are unable to ask the right questions of their DPB because they are unsure what questions to ask.

Traditionally gaining industry experience has improved designers' comprehension of production processes[50], however the opportunities to gain industry experience have decreased with changes to the way design work is commissioned[51]. The entrepreneurial potentials of DTP have led to more designers setting up their own businesses, but without the support of such experience. In addition, DTP has permitted designers from other disciplines (interior, illustration, graphic design and photography), to design for printed textiles, without textile know-how leaving them unprepared to solve colour issues[52].

Conclusion

The three components of the research to date presented in this paper set out to support the research project's aim to create a tool kit, accessible to artists, textile practitioners and similar, without access to commercial resources and chemical colour knowledge/ science, which provides guidance to assuring a colour match when printing from digital printers on to fabric. The creation of a colour reference book evidenced that there is a colour match issue between screen and printed colour. The different substrates were considered and the impact of the fabric characteristics considered. A colour measuring exercise provided the basis for the development of several methods which will be tested to examine whether they aid colour

[49] Burton, R. 2005. Creativity, method and process in digital fabric printing: a 21. Digital Creativity, 16, 217.

[50] Burton, R. 2005. Creativity, method and process in digital fabric printing: a 21. Digital Creativity, 16, 217.
Treadaway, C. 2006. Digital Imaging: its current and future influences upon the creative practice of textile and surface pattern designers.

[51] Services such as Pattern Bank https://patternbank.com/, and the now defunct Surface Pattern Print, allowed companies to purchase stock designs, bypassing textile agents and freelance designers

[52] Carden, S. 2015. Digital textile printing, London, Bloomsbury.

matching and expectation. A visual colour map was created to visualise indicator colours and colour shifts.

Interviews conducted with practitioners engaging with DTP further evidenced the colour issue and looked at the existing ways that designers were using to control colour outcome. A contextual review, researching a broad range of topics, set out to establish the primary causes for colour matching and consistency issues in DTP.

The Creation of a Colour Reference Book

The research findings established that the substrate has a great impact upon colour outcome. The yellow undertone and weave of the wool twill tested greatly impacted the printed colour. Silk absorbs the dye well and provides a strong, vivid print colour but this was observed to frequently be of a darker shade to the screen colour. The weave and characteristics of the juniper linen tested resulted in a paler printed colour result to the screen colour, although the hue match appeared to be good. The cotton satin tested provided the closest, visual colour match to the screen colour. Visual analysis of all four substrates demonstrated poor colour fidelity for neutral and achromatic colours (browns, blacks, pastels and greys) and there were further issues with colours with a magenta or blue undertone.

Initial analysis revealed that 227 of the 1137 colours were considered out of the printable gamut of a generic CMYK printer. Of these 227 the majority were from the magenta tonal range (53 purple and 38 pink), whilst 46 were classified as green, 27 red, 21 blue, 20 yellow, 20 orange and 2 brown. This classification was undertaken by the researcher using observational analysis. Further analysis established that a hue with a high red RGB value would be likely to be out of gamut. Additionally, bright colours were likely to be out of gamut.

A set of indicator colours was produced using mean averages of HSB value shifts for two sets of colours which in general decreased in both saturation and brightness by 10-20% and shifted clockwise around the hue circle from 2-25 degrees. The shifts will be used to predict the change from screen to print colour. Wavelength analysis demonstrated that in general the substrate prints decreased in indigo-violet-blue reflectance data in comparison to the paper prints and increased in red reflectance data. Wavelength analysis implied that the reflectance data in the yellow and orange range was similar except where the perceived hue was a shade of yellow or orange.

Emerging Themes from Interviews with Practitioners Engaging with Digital Print

Interviews with practitioners identified some emerging themes around engagement with DTP. These were that reducing or controlling colour fidelity variables aided colour outcome and it was important to have good designer / printer communications. The Designer’s Eye plays an important part in colour control, as does colour testing but that there is a lack of colour management education and accessibility for designers. DTP is creating Entrepreneurial Business Models in the textile industry.

Contextual Review

A contextual review established several primary causes which contribute to screen to print colour differences in DTP. These were; Gamut mismatches, Numerous variables, Adapted technology and processes and Design Education. The review established that there is minimal support, and no existing best practice guidance, for designers engaging with DTP, to aid colour matching and consistency from screen to print.

These findings will be taken forward to shape and inform an online tool kit which will have a focus upon education (for example, impact of variables, colour management, printer technology, how to work with a DPB). The toolkit[53] will have a number of downloads including colour rendition charts and test prints that include challenging colour ranges for designers to use and adapt when trialling a new fabric or DPB. The toolkit will also offer methods for designers to use to make adjustments to their computer-aided-designs which will be based upon the results of the colour reference book analysis. These methods will be tested through the production of a series of prints designed specifically for the research project, using an Interwar colour palette of smoky, dark colours, neutrals, pastels and strong earth colours, and exhibited as part of the research project's dissemination.

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[53] The toolkit link will be available through the research project blog, once the website has gone live https://digitaltextileprintingblog.wordpress.com/

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