Colour, texture, and luminance: Textile design methods for printing with electroluminescent inks

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ABSTRACT

Printable smart materials offer textile designers a range of changeable colours, with the potential to redefine the expressive properties of static textiles. However, this comes with the challenge of understanding how the printing process may need to be adapted for these novel materials. This research explores and exemplifies the properties and potential of electroluminescent inks as printable smart colours for textiles, in order to facilitate an understanding of designing complex surface patterns with electroluminescent inks. Three conventional textile print methods – colour mixing, halftone rasterization, and overlapping – have been investigated through experimental design research to expand the design potential of electroluminescent inks. The result presents a set of methods to create various color mixtures and design complex patterns. It offers recipes for print formulation and documents the outcomes, offering a new design resource for textile surface pattern designers to promote creativity in design, and provides fundamental knowledge for the creation of patterns on textiles using electroluminescent inks.

KEYWORDS electroluminescent printing, smart textiles, textile design, texture, colour mixing

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1. Introduction

Smart materials have been defined as materials capable of changing from one state to many in response to external stimuli (Addington and Schodek, 2005). As raw materials for design, smart materials entered the textile practice decades ago (Braddock and O'Mahony, 1998; McQuaid and Beesley, 2005). Their presence has enriched the material palette traditionally used by textile designers, and the expressive language specific to the field (Kooroshnia, 2017; Mossé, 2014). Light has proven to be a highly valued design material in the form of LEDs, optical fibers, and electroluminescent wires, and has been used to complement the expressive vocabulary of textile design, such as in artistic applications (Bobeck Tadaa, n.d; Layne, 2006; Loop. pH, 2012; Kettley, 2015) and research practices (Jansen, 2015; Taylor and Robertson, 2014; Persson and Worbin, 2010). In these examples, which combine light and textile construction methods, light sources have been embedded in the design of textile structures or added by embroidery to the textile surface, defining a new category of textiles. Accordingly, the intangible materiality of surface design expressed by light combines with the physicality of textiles and produces a hybrid category of expressions resulting from the mixture of these distinct material characteristics: transformative/static, sharp/soft, digital/physical, visual/tactile.

These projects exemplify and expand the potential for textile designers to embed directly light into textile structures. Yet working with light using textile printing methods, which create a flexible light-emitting surface, is still an undeveloped field.

1.1. *Electroluminescence*

Electroluminescence (EL) was discovered in 1907 and named in 1936. Thin film EL (TFEL or ACTFEL) panels, which provided printable light materials for surface applications, were developed in the late 1950s and became commercially available in 1974. In the 1990s, thick dielectric EL (TDEL) was introduced and was shown to be brighter and more reliable, and could be produced using screen-printing (Kretzer, 2015; Deferme and Verboven, 2018).

EL inks work by sandwiching an illuminating layer between conductive and insulating layers: a transparent conductive substrate on which the EL ink is printed, followed by the printing of a dielectric and a second conductive layer. When a high voltage, at least 20V, and typically around 200-250V, is applied to the conductive layers, the device emits a short light pulse from the EL layer. Applying standard alternating current (AC) power allows this process to operate repeatedly, appearing as a continuous light source (Smet, et al., 2010).

The colour range of EL inks is biased towards blues, greens and yellows. The brightness and colour of EL inks may change relative to both voltage and frequency (Song et al., 2018). In industrially-manufactured EL products, the colour range can be extended through the use of dyes to change the colour of the light (Silver et al., 2008).

While there are exemplary works using EL inks in architecture (Kretzer, 2015), interaction design (Franinović and Franzke, 2015), interior design (Loop pH, 2012) and product design (Barati et al., 2018; Olberding et al., 2014), their focus is on the process of creating non-textural and geometrical light-emitting patterns, using a single colour of ink, and/or methods for controlling the light. This leaves space for further research exploring the design potential of the raw material – printed EL ink – in terms of expanding its colour palette and aesthetic range by experimenting with textile design methods – forming diverse colour mixtures, overprinting, and halftones. Thus, this research aims to explore and exemplify the properties and potential of EL inks as printable smart colours for textiles, in order to facilitate an understanding of designing complex surface patterns with EL inks. The methods proposed by this research offer new resources for surface pattern designers to expand their creativity and craftsmanship in the printing design process.

2. Set up for the experimental work

The technique of silkscreen printing by hand was used to print the EL inks directly onto a transparent, conductive surface (polyester film coated in indium tin oxide (ITO film); Gwent F2071018D1). The size of the silkscreen mesh was 43 threads per inch. The EL ink was covered by a white dielectric insulator print layer (Gwent D2070209P6), followed by a silver conductive print layer (Gwent C2180423D2), producing an EL device with a standard build per the manufacturer's guidelines. This produces an EL light emitted through the transparent substrate, meaning layers printed first sit at the top of the print when illuminated (Figure 1). The print cannot be illuminated to assess the design outcome until all layers have been printed and dried. To see the light range, samples were illuminated within a range of 8VDC to 20VDC through a DC/AC inverter and viewed in darkness. Colour measurements were also made in darkness, with a Datacolor Spyder5 colorimeter, using DisplayCAL 3.8.7.1 software. Five measurements of each sample were made, and outliers were calculated and discarded before the mean L*a*b* figures were calculated for each sample. It should be noted that the photos taken in a dark room were colour-managed to match as closely as possible the perceived appearance of the print when viewed in darkness.

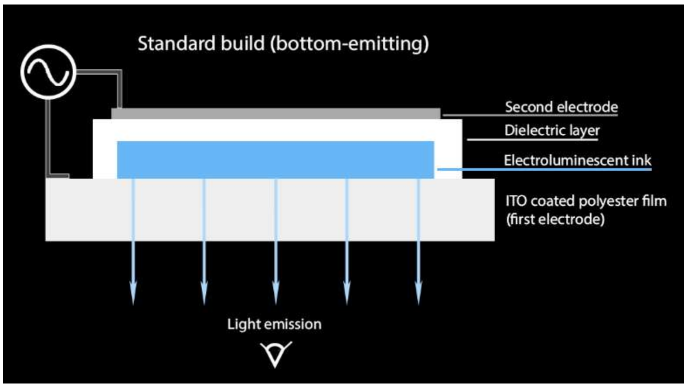

Fig. 1: The standard build illustrated as printed. When illuminated, the device is turned upside down, and the light emits from the bottom, throught the transparent film.

3. Design Methods

3.1. *Colour mixing*

Experiments were conducted using blue (Gwent C2061027P15), green (Gwent C2070209P5) and orange (Gwent C2070126P4) print pastes. The colour palette was obtained with mixes of two-colour blends in 10% increments. Each colour was also printed unmixed (100%), and a 1:1:1 (33% each colour) swatch was printed to test three-colour mixing. The result in daylight was a white print, however, once illuminated with an inverter at 20VDC and viewed in darkness, the effects were different coloured lights similar to mixtures of RGB lights: 80% green and 20% blue produced cyan, 20% green and 80% orange produced yellow light, and 80% orange and 20% blue produced magenta. The other mixes produced a smooth coloured light gradation. The 1:1:1 swatch appeared as a blue-green light and not white light. This is because white light is produced by the proper mixture of red, green and blue light. The green EL ink is perceived as more toward turquoise, while the orange is far from red (Figure 2).

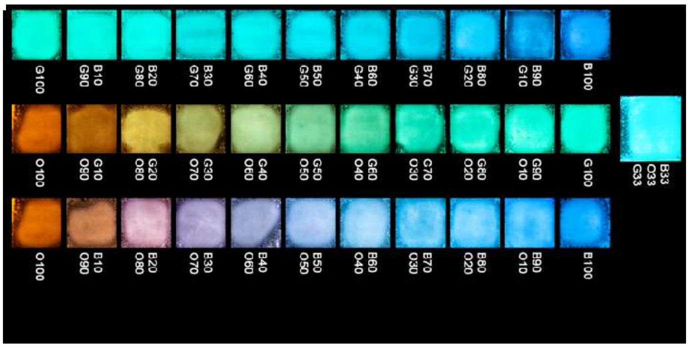

Fig. 2: Three colour scales produced by mixing two colours of EL inks using blue, green and orange, illuminated with an inverter at 20VDC and viewed in darkness.

The emitted light of each mixed colour was measured using the colorimeter, resulting in CIE L*a*b* values for each colour (Figure 3). While this provided useful information about the gamut and range of colours available through this method, the low L* (lightness) values of the colours did not represent them as they are perceived by the eye. In order to enable simulation as a design tool when using mixed EL ink colours, an RGB value for each colour was sampled from the photograph of the colour mix print. These RGB figures have been given alongside the measured L*a*b* values in table 1. These can be used in graphic design software such as Photoshop when designing and preparing patterns for EL prints. This provides a visual representation of the colours achievable with particular combinations and gives the designer the ability to predict the result before starting to print.

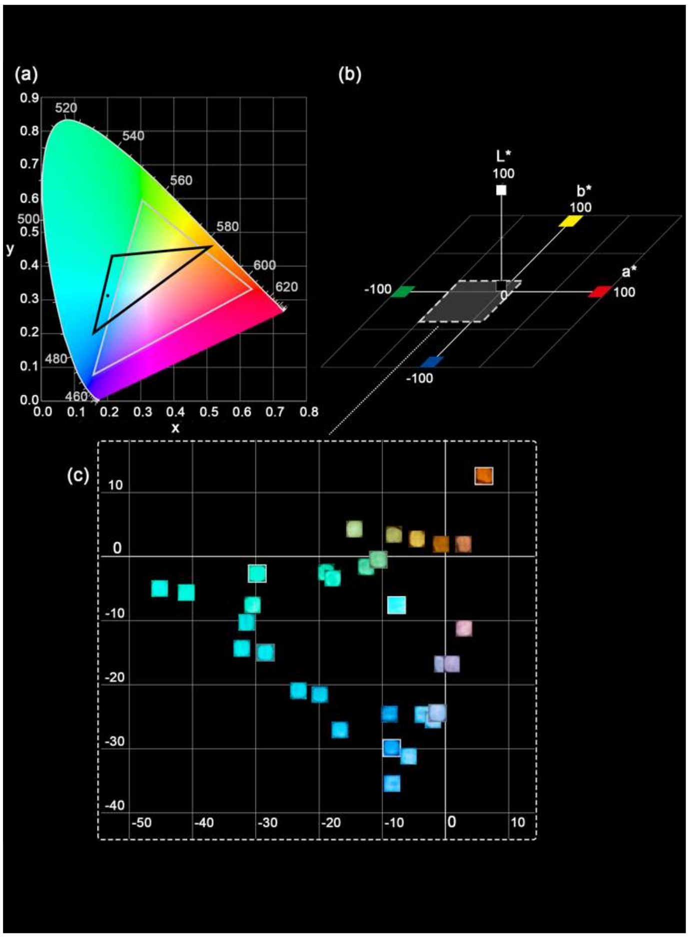

*Fig. 3: (a) the black triangle shows the gamut of the EL colour mixture palette, with the dot indicating the 1:1:1 colour mixture. The sRGB gamut is included (in grey) for comparison, and shows that the blue and green EL colours and their mixes cannot be fully represented in an sRGB environment (e.g., on-screen). (b) the CIE L*a*b* colour system, used to measure the colour palette values. (c) the EL colour palette mapped against *a and *b values (indicated in figure b by the gray square).*

Colour	L*	a*	b*	R	G	B
B100	12.47	-8.51	-29.9	167	208	253
B90G10	8.79	-9.02	-24.62	157	213	251
B80G20	15.53	-16.83	-27.02	154	219	248
B70G30	13.71	-19.99	-21.43	139	220	242
B60G40	15.97	-23.35	-20.92	131	221	236
B50G50	16.92	-28.59	-15.04	137	229	237
B40G60	17.83	-32.38	-14.34	136	236	234
B30G70	15.44	-31.54	-10.26	139	238	235
B20G80	23.18	-45.33	-5.03	147	244	232
B10G90	19.77	-41.13	-5.67	137	243	225
G100	11.63	-29.94	-2.64	90	227	194
G90O10	13	-30.73	-7.49	96	219	188
G80O20	8.55	-18.02	-3.3	100	207	176
G70O30	8.52	-18.83	-2.36	111	200	166
G60O40	6.05	-12.5	-1.62	92	144	114
G50O50	5.58	-10.63	-0.43	99	138	108
G40O60	8.25	-14.34	4.21	112	129	97
G30O70	6.08	-8.11	3.4	116	121	90
G20O80	4.58	-4.69	2.82	147	133	89
G10O90	1.6	-0.53	1.95	160	115	69
O100	7.64	6.2	12.46	209	113	0
O90B10	6.98	2.92	1.94	202	146	150
O80B20	14.66	2.88	-11.04	201	162	186
O70B30	11.16	0.88	-16.56	181	169	211
O60B40	10.29	-0.33	-16.8	177	175	219
O50B50	14.2	-1.37	-24.36	172	183	230
O40B60	15.31	-2.01	-25.37	174	194	238
O30B70	12.26	-3.62	-24.91	168	197	244
O20B80	17.68	-5.86	-31.21	169	201	247
O10B90	17.4	-8.37	-35.45	173	209	252
B33G33 O33	5.12	-7.73	-7.67	83	131	140

*Table 1: Measured L*a*b* values, and suggested RGB values, for the EL ink colour palette.*

3.2. *Overprinting*

An overprinting experiment was conducted to test the potential for blending colours through overprinting the three unmixed, 100% EL orange, green, blue inks. All possible two-colour overprints, including inversion of each overlap order, were tested, waiting for each layer to dry before printing the next. It was expected that the effect obtained by the overprinting of two different colours would result in a similar effect as if they were mixed equally and then printed. However, the results indicated that the printing order had a significant impact on the resulting colour when overprinting, with the top layer colour (printed first) dominating the resulting blended colour (Figure 4). When the EL prints were activated, they showed some errors such as unwanted particle gathering and uneven paste distribution that occurred during the hand-screen printing process. Careful fabrication is thus important when planning and producing high quality designs. The results of this experiment guided the research towards exploring rasterization.

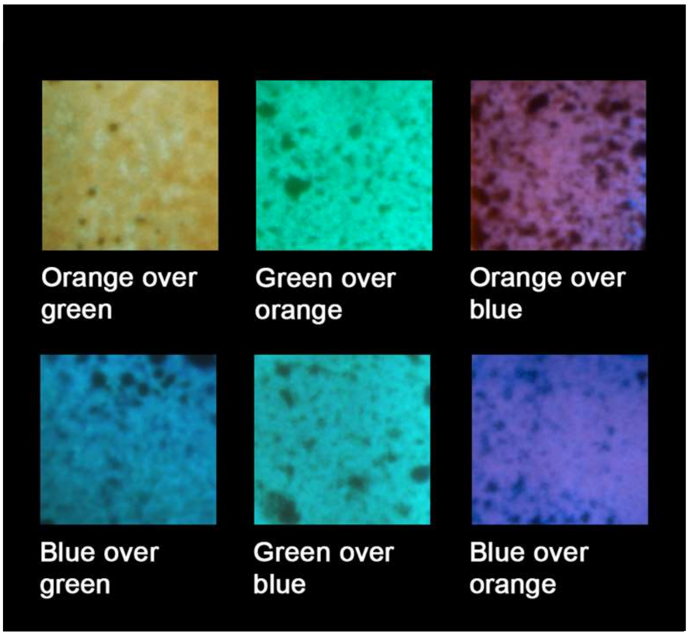

Fig. 4: There was a perceivable difference in green on top of orange and orange on top of green, for example; both combinations of orange and green resulted in a different coloured lights.

3.3. *Rasterization*

An experiment was conducted to determine the best resolution for rasterizing when printing with EL inks. A stepped gradient, of 10% to 90% density, in 10% increments, was used to create ‘dot’ and 45° ‘line’ halftones, using 30, 25, 20, and 15 lines per inch (lpi). The result after activating the print indicated that the dot halftone had clear definition at low densities, across the range of resolutions from 30 lpi to 15 lpi. The 45° lines, however, were only clear at 20 and 15 lpi, even at low densities. The results of this experiment suggest that coarser resolutions of 15 or 20 lpi are more effective for producing detail, and that either only two or three densities should be used, or lower densities than were tested, to ensure visible differences between areas (Figure 5).

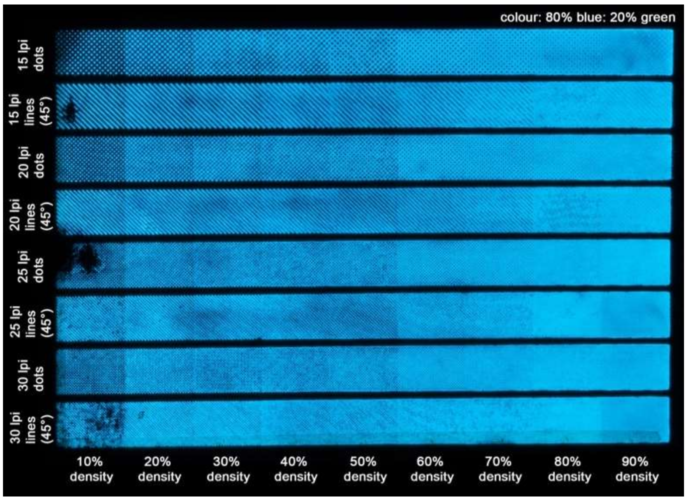

Fig. 5: The result of the rasterization experiment.

Two experimental sets were conducted to evaluate colour mixing through halftone rasterization, again using the three print paste colours unmixed at 100%. These were split into two colour groups: analogous colours – blue followed by green – and complementary colours – orange followed by blue. The first set (Figure 6, prints 1 and 2) was made using the 20 lpi dots, 15 lpi lines, and 15 lpi dots, each at 10% and 20% density, with the screen slightly offset so the two colours did not overlap and would mix optically. The second set (Figure 6, prints 3 and 4) used the same rasterizations for the first colour layer, however, the second colour layer was printed with 30% and 40% density, turning the screen 180°, so the 15 lpi dots were covered with 20 lpi dots and vice versa. The result indicated that colour mixing using rasterization is different to colour mixing through overprinting the two colours or mixing the two colours. For instance, the colour mixing of 10% blue and 40% green in print number three appeared equivalent to the 20% blue and 80% green (B20G80) mixture in Figure 2, and these were equal in terms of colour proportion but they represented two different coloured light mixtures (Figure 6).

4. Result

4.1. *Designing surface patterns using EL*

After understanding how El inks behave and how this may impact the design process, a set of surface patterns inspired by a twill woven fabric and two knitted textiles featuring patterns of dots and lines were designed, with the aim to exemplify how the different methods for colour mixing developed by this research can be used when forming a design. The surface patterns were designed as two-screen prints using Photoshop consuming data from table 1, and aware that the colours of positive and negative spaces were reversed in darkness (Kooroshnia, 2014).

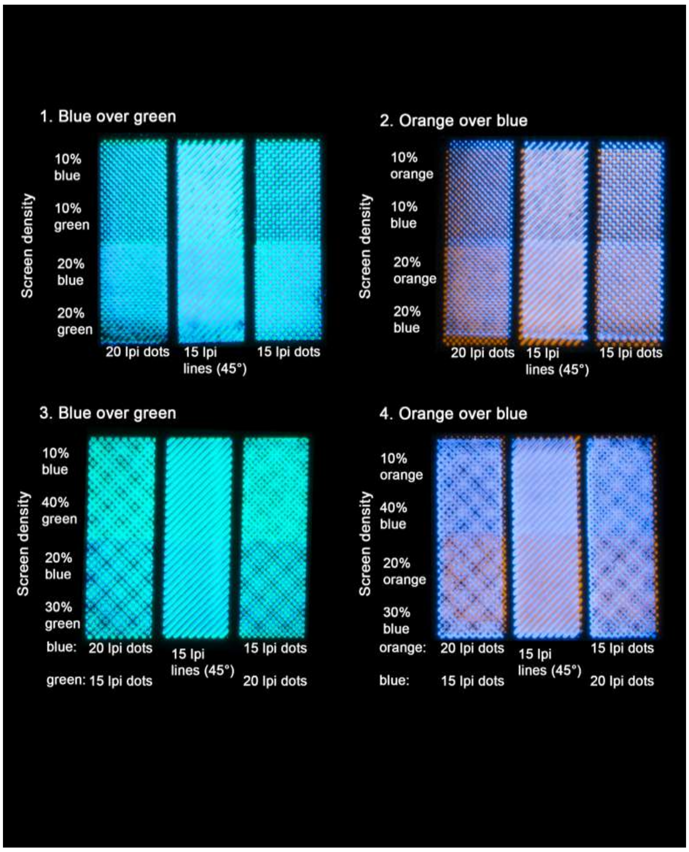

Fig. 6: three-dimensional effects were observed in all the prints. In prints 3 and 4 moiré effects were created due to the interaction of the different rasterization lpi values for the two overlapping colours.

Two pairs of colours were selected from the colour mixing experiments. Design 1 used 100% blue (B100) EL ink in the first layer and a mix of 20% green with 80% orange (G20O80) for the second layer. Design 2 used 100% green in the first layer (G100) and a mix of 20% blue with 80% orange (B20O80) for the second layer. Design 3 was printed with a mix of 20% blue with 80% green (B20G80) in the first layer, and a mix of 20% blue with 80% orange (B20O80) in the second layer.

To enhance the textural expression of the printed EL patterns the technique of halftone rasterization was used with the aim to mimic the visual effect of surface patterns printed on textiles. Likewise, to enhance the colour palette, the technique of overprinting was used to create complex colour mixtures as visual effect in both the foreground and background of the designs (Figure 7). The results were compared to the sketches made in Adobe Photoshop. The printed EL patterns demonstrated that visual effects such as complex color mixtures, form intervals, perception of movement, and spatial illusion can be achieved through printing with EL materials.

These effects occured mainly because a combination of dim and bright coloured lights resulted from the overprinting.

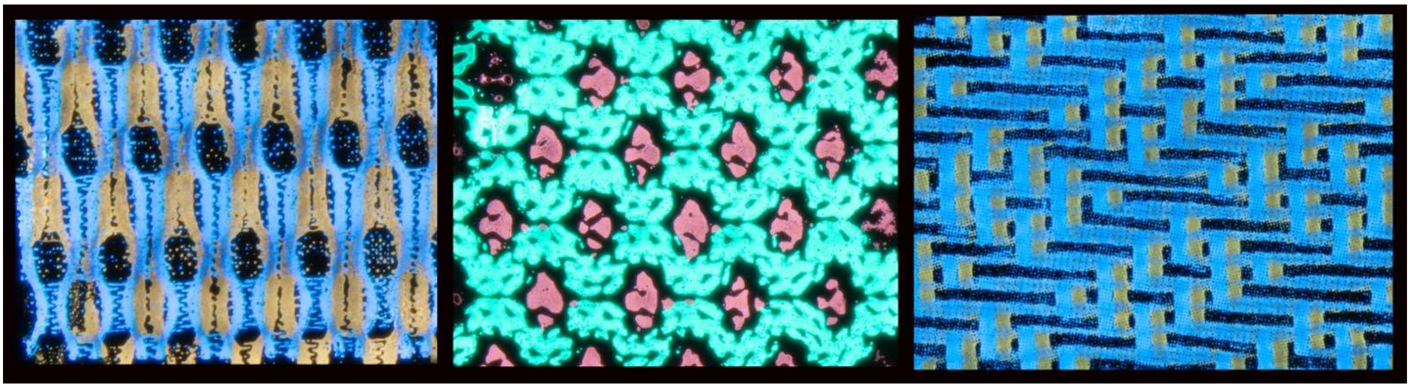

Fig. 7: Designers can use EL inks to print light-emitting surface patterns, using the same methods used for surface pattern pastes. From Left to right: designs 1, 2 and 3.

5. Discussion

By demonstrating the potential of EL inks when approached using textile design methods for printing such as colour mixing, overprinting, and halftone rasterization, this research expands the design possibilities of EL crafted displays in producing a novel, coloured, rich textural character to light as a material for surface design. We suggest digital RGB values for mixed colours, enabling computer simulation of designs, removing some of the risks from this technique, and freeing designers from the flat, monochromatic designs that characterize current EL offerings.

The experiments were evaluated in a dark room using an AC/DC inverter supplied with a variable direct current (DC) power supply to illuminate the prints. Stepping the DC voltage through 20V, 16V, 12V, and 8V dimmed the coloured lights, creating an illusion of space in the surface pattern (Figure 8).

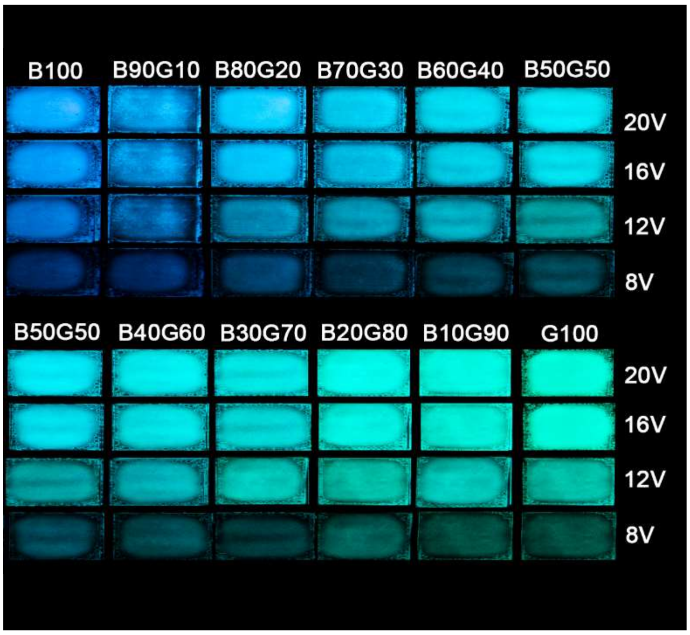

Fig. 8: Illuminating the prints with 8V creates the dimmest coloured lights and 20V creates the brightest coloured light.

In addition, while EL printing typically produces static colour, it can be used in the design of segmented displays to produce transformative digital textiles with temporal variations through changes in brightness (i.e., through variable voltage sequencing) and as such offers an alternative to complex multi-LED arrays, or the linear restrictions of optical fibre. It has the potential to open new territory in textile design for flexible, luminous, and dynamic textile displays with complex textures and surface patterns and temporality.

Recent research in material engineering has proved it is possible to print basic EL inks directly onto textiles, maintaining their intrinsic flexible properties to create functional lighting surfaces (Verboven, et al., 2018). From a design perspective, the replacement of plastic substrate with textiles demonstrates more expressive potential by enhancing the haptic perception of the printed patterns. However, more cross-disciplinary research is needed to be able to combine the two perspectives into the development of aesthetic and functional products. This research mirrors the LED-based work of Mueggler Zumstein et al. (2016), in providing colour reference tools to enable textile designers to approach designing with smart materials.

In daily life, we are used to communicating and being surrounded by visual and haptic displays which are hiding complex technologies. By proposing methods to create complex surface patterns with enhanced colours and textures, the result of this research suggests more creative ways to express smart technologies for the automotive or home environments when designing displays with tactile and visual feedback. Likewise, EL printing as applied in product design or architecture offers as a design asset the familiar expression of textiles. This could provide an interface for lighting technology which might enable alternative ways to experience peripheral information or adapt interior atmospheres to ensure well-being.

6. Conclusion

The experiments conducted during this research suggest that the print potential of EL inks is wider than has been explored in art, design and research so far. Even with the limited colour range of commercially available EL inks, broader aesthetic and textural expressions are possible than the typical flat blue of the technology to date. Textile craftsmanship and design methods such as colour mixing, halftone rasterization, and overprinting may be applied to electroluminescent inks, and the design potential of these techniques can be used to produce light-emitting smart textiles, where the intangibility of light combines with the physicality of textiles to define a hybrid category of expression.

7. Conflict of interest declaration

No financial/personal interests have affected the authors' objectivity(s).

8. Funding source declaration

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9. Short biography of the author(s)

Delia Dumitrescu is Professor in Textile Design at the Swedish School of Textiles. Her research focuses on the development of smart textile design methodology and how smart textile design methods can be expanded to related design fields with the aim of developing cross-disciplinary practices.

Marjan Kooroshnia is a colour researcher and associate professor at the Swedish School of Textiles. Her PhD research explored the design properties and potentials of thermochromic colours printed on textiles in order to expand the range of colour-changing effects and to facilitate communication regarding, understanding of, and designing with, these smart materials.

Erin Lewis is a PhD researcher in Textile Interaction Design at The Swedish School of Textiles. Her research explores electromagnetic textile expressions in the form of interactive, wearable, and ambient textile prototypes.

Kathryn Walters is a PhD researcher in Textile Design at The Swedish School of Textiles. Her research area includes complex woven structures and changeable textile materials.

Licensing terms

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