Crafting hybrid workflows for the design of augmented textile artefacts

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Abstract
In the textile field, digital crafting is a relatively unexplored domain that requires further investigation in relation to the tools of the field and the aesthetic consequences of their use on the design. Computer software such as SDS-ONE APEX4 and computerised flat-bed knitting machines made by Shima Seiki are examples of the digitisation of analogue textile processes, and make use of digitally controlled material-fabrication methods. In adopting an exploratory approach to textile digitisation, this research aims to: i) explore methods of digital craftsmanship with a focus on textile materials and tools for the design of smart textiles, and ii) test the aesthetic possibilities of sketching smart textile artefacts using a hybrid workflow.

This paper presents a hybrid workflow composed of methods emerging from the synergy between experiential knowledge of materials and experiments with digital media. One category of experiments addressed the material level. By utilising digital tools for the virtual sampling of colour-changing smart materials, two changes in textiles were explored: from white to coloured in response to UV light, and from bright to dark in light-emitting yarns being recharged by UV light. The different timings of the colour changes and dimming of the smart yarns were documented and digitised, resulting in a library of colour swatches of gradients based on dynamic material behaviour. The swatches were combined with multi-layered textile structures, digital textures, and simulations of smart and conventional yarns to design the surface of textiles using the knit and weave design software SDS-ONE APEX4. In the sketches, every pixel represented a knit stitch or meeting of a warp and weft thread, providing information about material, structure, and colour at a specific point in time. Another category of experiments addressed the relationship between material and form; the colours swatches were further mapped on three-dimensional objects in Blender software to generate new forms and explore how dynamic surface effects influence the perception of form.

The experiments presented in this case study suggest that digitising a process that is based on the physical behaviour of yarns and textile structures offers an alternative medium for exploring smart materials more sustainably, expanding physical experimentation into the digital. This hybrid process enables designers to move between software packages and collaborate across professional knowledge domains, with the potential to develop cross-disciplinary and more sustainable material practices.

Author keywords
Digital crafting; hybrid workflows; smart textile design; sustainable material practices.

Introduction
Digital craftsmanship in the field of textile design has generally been linked to industrial manufacturing processes; it requires work with digital machines that necessitate field-specific technical knowledge of yarn behaviour, textile structures, and programming textile-specific closed-source software. Digital textile environments and manufacturing tools have typically been developed to increase production efficiency, and are optimised for work with conventional materials, rather than being seen as parts of exploratory processes. From this perspective, the design process is technologically assisted and seen as a linear workflow moving smoothly from idea to material production as part of a bottom-up process.

Thus, in the textile field, experimental approaches to digital crafting are forming an emerging design space that requires further investigation in relation to the tools used by practitioners and the aesthetic consequences of their use on the design (Clarke & Harris, 2012).

State of the art
Today, the knowledge of the textile designer has expanded beyond the traditional domain of experimental analogue processes to include digitisation and advanced manufacturing using industrial machines. Thus, digital craftsmanship has begun to make use of exploratory processes that use digital modelling software and digitally controlled fabrication technologies to imagine new material concepts (Harris, 2012). Similar to the 3D-printing technologies used in product and architectural design, computer software such as SDS-ONE APEX4 and computerised flat-bed knitting machines made by Shima Seiki are examples of the digitisation of analogue textile processes, and make use of digitally controlled material-fabrication methods (Taylor & Townsend, 2014). In contrast to conventional digital form-modelling environments used in product design and architecture, the forming process used in SDS-ONE APEX4 relates strictly to textile materiality; the design process requires knowledge of knitting and weav-

ing in terms of yarn structures and qualities, and allows the geometrical principles of forming using textile methodology to be expanded upon.

Recent research in the textile field has exemplified how analogue and digital knowledge in the textile domain can interact in the design process to open up a greater degree of creativity for textile practitioners. The 'Responsive Knit' research project (Scott, 2018) introduces a new perspective on using analogue knowledge of structural textile behaviour to design a new workflow by exploring shape-changing materials that react to moisture. Informed by knowledge of analogue processes, the result exemplifies how the textile hierarchy of fibre, yarn, and knitted structures can be implemented in a digital material workflow to fabricate new materials inspired by biomimicry. Another research project explores the link between analogue and digital textile knowledge by developing methods for power knitting that are suitable for the design and manufacturing of soft robotics. The workflows include exploration of tendon placement, methods of shaping, and studies of anisotropic textures. The artefacts produced represent an experimental way of exploring the possibilities of digital knitting technology to combine textile qualities with actuation systems, resulting in complex shapes that are able to exhibit smart behaviour such as shape-changing (Albaugh et al., 2019). Similarly, the responsive textile installation *Lumen* (Sabin, 2019) uses a digital form-finding workflow based on the use of architectural tools such as Rhino, Grasshopper, and Kangaroo to fabricate a tensioned, knitted canopy. The knitting strategy used to create the installation was based on the whole-garment method developed for Shima Seiki machines, and uses digitally designed knitted tubular shapes. The diverse range of colours of the UV-reactive yarns is directly embedded in the knitting process, as the striped pattern follows the weft direction of the knitted cones.

Revisiting the role of experimental knowledge and analogue processes in digital workflows, Woolley and Huddleston emphasise the importance of craft in their own process: "For the craftsperson, the retention of some element of direct physical proximity is vital because physical contact underpins the interplay between perception, skill, knowledge and creativity on which practice depends" (2016, p.93). Although digitisation is strongly present in the textile field, the creativity that is the result of the experiential freedom of analogue processes – relating to e.g. knowledge of tactile qualities and material behaviour – is still present, and can be used in a meaningful way to inform digital designs with regard to new material concepts.

Aim and method

Adopting an exploratory approach towards textile digitisation, this research aims to: i) explore new methods of digital craftsmanship with a focus on textile materials and tools for the design of smart textiles, and ii) test the aesthetic possibilities of sketching smart textile artefacts using a hybrid workflow. Two types of light-responsive changes were explored in physical and a digital space: colour change from white to coloured in response to UV light, and colour change from bright to dark in light-emitting yarns being recharged by UV light. This was undertaken in order to establish a hybrid workflow of methods emerging from the synergy between experiential knowledge of materials and experiments with digital media.

Previously, Kooroshnia(2014) developed a method for creating two-phase patterns for print design by mixing glow-in-the-dark and conventional pigments for a coloured pattern in daylight and a pattern of gradation of light in darkness. Her research further stresses the need for new tools that allow for simulation of the effects of the pattern to aid the design process. In this case study, the gradation of colour and lightness is approached from the perspective of the textile structure, by embedding UV-reactive yarns into knit structures. Knit software SDS-ONE APEX4 and 3D-modelling software Blender were used to simulate and visualise the changes in colour and lightness, in parallel with physical experimenting feeding into the digital process by documenting and making knit experiments. In the workflow presented in this case study, three variables for designing UV-responsive colour changing textiles were identified: i. the placement of the UV-reactive yarn, ii. the choice and proportions of materials and iii. shape of the knit (Table 1).

Table 1. The design variables for UV-responsive colour changing knits

Design variable	Function in the design process	Type of sketching
Placement of UV-reactive yarn	Defines the surface texture or pattern of the knit in its coloured or light-emitting states	Hand- and machine-knitting, SDS-One APEX4: Design 64
Choice and Proportions of materials	Defines the texture, tactile properties and behaviour of the knit, and how visible the changes in colour and brightness are	Hand- and machine-knitting, SDS-One APEX4: Design 64
Shape of the knit	Defines what parts of the 3D shape are subjected to UV-light for colour change, or visible when emitting light.	Hand- and machine-knitting, Rhino 3d, Blender and Adobe Photoshop

Experiments

The first experiments addressed the material level. Changes were explored and mapped in UV-reactive yarns to translate their properties into a digital form for further experiments. When the yarns were placed in either sunlight or a dark room, it was noted that both the colour-changing and light-emitting yarns had different reaction times and intensities of colour or light. In order to understand how the expression of the textile might change over time when using these yarns and how, and for how long, the different yarns either change colour or emit light, the changes were documented and translated into digital colour charts. The glow-in-the-dark yarn samples were recharged outside, then placed in a dark space and documented at regular intervals for 3.5 hours, after which time all of them had stopped glowing. Colour charts showing the brightness of the yarns at specific points in time were made. Similar documenting was undertaken of the colour changes in the UV-reactive colour-changing yarns by taking the samples outside and documenting the changes at regular intervals until no further changes occurred (2 minutes after they had been placed outside). The yarns were taken inside, and the changes were documented until they had returned to their original colours. A series of colour charts showing the colours at specific points in time was made, showing when there were notable changes in the colour palette (i.e. a colour appearing or disappearing; Fig. 1).

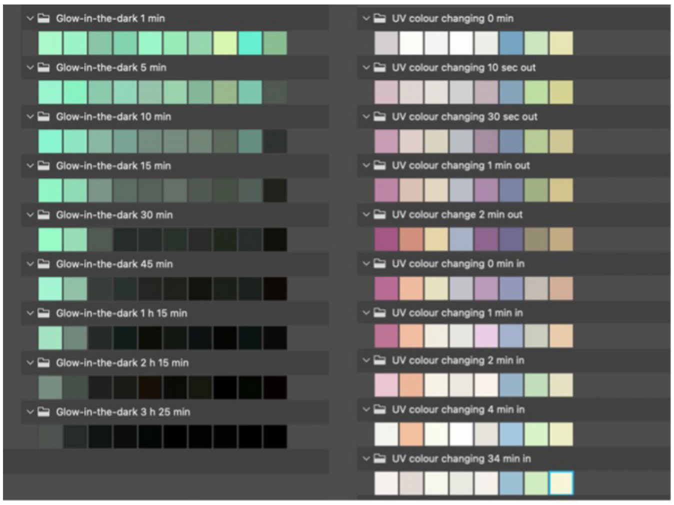

Figure 1. Colour charts mapping the changes over time in the brightness of the glow-in-the-dark yarns (left) and colours of the colour-changing yarns (right).

The colour charts were then used to produce several series of gradients (Fig. 1). In the gradients, every pixel represented a knit stitch or the meeting of a warp and weft thread, providing information about material, structure, and colour at specific points in time. Two series gradients of the glow-in-the-dark yarns were made, visualising how the expression of textiles changed over 3.5 hours, i.e. the time taken for the yarns to go from fully recharged to no longer emitting light (Fig. 1). The colour charts for the UV-reactive colour-changing yarns were also used to create gradients to explore how the colours changed over the 34-minute period during which the yarns changed from white to coloured and back to white (Fig. 1). However, the UV-reactive colour changing yarns have a range of different colours, and they appear and disappear at different rates, unlike the glow-in-the-dark yarns, which primarily change in the intensity and duration of light. This gave the resulting gradient a striped expression.

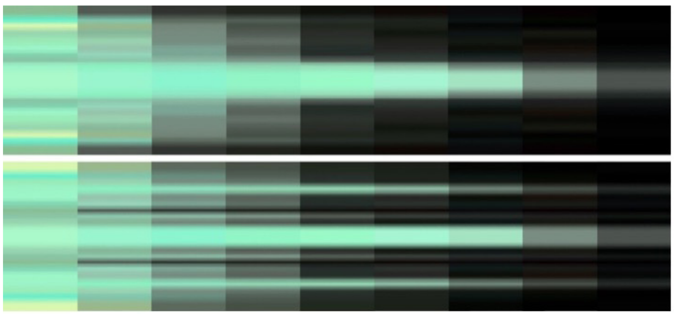

Figure 2. Two gradients showing changes in the colour of the light being emitted by glow-in-the-dark yarns over a 3.5-hour period: from bright to dark (above) and contrasting stripes (below).

Samples were knitted out using Dubied hand-knitting machine. Experiments combined a white single-jersey structure with floats in the colour-changing and glow-in-the-dark yarns, organised in a gradient from the most intense and longest-lasting to the lightest, fastest-dimming colour or glow. Different proportions in the placing and materials in the floats were tested, and one in which the distance between the floats was gradually increased as the gradient progressed from more to less reactive yarns produced a clear gradient in a dark room. The colour effect, however, was not particularly visible. To make the colour changes more visible, two threads of colour-changing yarn were plated together with a thicker white wool in a single-jersey structure (Fig. 3). The glow-in-the-dark yarn floats were organised as a striped pattern that mixed brighter and dimmer glowing yarns, creating a fabric with two different faces with contrasting changes.

Figure 3. A gradient in UV-responsive colour changing yarns over a 55-minutes period first outside (images 1-4 from left), then inside (images 5-11 from the left). Single jersey with plating and floats on the reverse side.

In order to be able to digitally sketch changes in colour and amount of light emitted in a medium connected to textile materiality, the colour charts were transferred into the knit and weave software SDS-ONE APEX4. Exact shades of each colour chart, depicting the colours of the yarns at a specific point in time, were input as their own custom colourway. This made it possible to see how the expression of the textile would change over time by viewing it in relation to different colourways (Fig. 4). The software allows yarns that have similar sizes, weights, and textures to the physical UV-reactive yarns to be chosen, making it possible to translate the properties of these yarns into digital form and combine the changes in colour and amount of light emitted with textile structures, materials, and textures. Thus, it was possible to simulate what the textiles would look like at different stages of change.

Figure 4. SDS-ONE APEX4 simulation using the colourways of colours of the UV-reactive colour-changing yarns over a period of 34 minutes. Single-jersey structure with plating.

Two simulations were undertaken used knitted gradients with ten colourways to cover all of the increments in the colour changes of the yarns over a period of 34 minutes. The first simulation was undertaken using a single-jersey structure with a single thread of the colour-changing yarns. The second simulation was also a single-jersey structure but for this the colour-changing yarns were plated on a thicker wool yarn (Fig. 4). This created a heavier, denser fabric similar to one of the experiments undertaken using the hand-knitting machines (Fig. 3). The gradients of both experimental results were striped.

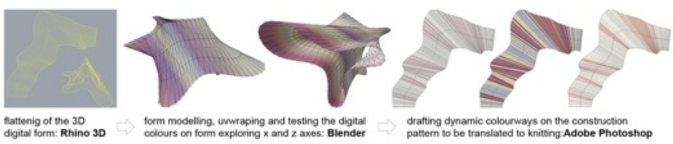

Figure 5. An example of flattened surface patterns prepared for knit construction; a simulation of a dynamic colour gradient created by applying colour gradients on the form in Rhino 3D.

In order to test the impact of different colours on form, an organic form was generated using Rhino 3D and Grasshopper (Fig. 5). These software packages allow three-dimensional objects to be flattened, which is necessary to translate the digital form to the physical knitting process. The form of the construction pattern was used to plan the sequence of colours and select yarns in terms of their quality when designing the knit forms. The same construction pattern could then be translated in the knitting software and fabricated using a partial knitting technique which allows direct shaping in the machine. Digital colour samples in the Blender software were mapped on the object to explore the effect of dynamic colour and texture on perception of form. The sizes of the stripes and direction of colour gradation and contrast were important to consider when planning colour placement on the form to emphasize its curvature and helped to plan the succession of colours on the construction pattern to be translated to the knitting program.

Conclusion

Smart materials react to various stimuli, which means that the designer needs to understand the textile's expression in multiple stages and consider how placement, heat, and light, for example, can influence the changes in expression that can occur. Three-dimensional modelling software packages such as Rhino 3D and Blender facilitate exploration of smart materials and changeable expressions in different contexts, as they allow parameters such as colour, form, space, and intensity and direction of light to be tweaked. Thus, the workflow presented in this paper explored the relationship between analogue and digital craftsmanship with a focus on colour, textile construction methods, and proposing tools for designing smart-textile artefacts. Similar to the research of Scott and Albaugh et al., it was found that navigating between various digital software packages allows the designer to fabricate and flexibly include dynamic variables, design variations, and smart-material agency in customised workflows for knitting design. In a comparable way, the hybrid workflow used in the creation of *Lumen* (Sabin, 2019) demonstrates that digital form-finding can be influenced by the limitations of the chosen knitting technique, and that such processes can be accurately translated into knitting technology. In addition, this research expands on these previous works by exploring the digitalization of smart colourways and their application on 3D forming process for knitting. Software packages such as SDS-ONE APEX4, which simulate conventional materials, allow the development of alternative workflows that are customised by the designer to function with colour-changing yarns, allowing changes in colour over time to be planned, predicted, and visualised directly on textile structures and digital artefacts. To further develop the method, the accuracy of colour expressions could be improved by documenting changes in yarn samples in a more controlled manner by using a colour scanner.

Generally, the introduction of digital sampling and form-finding supports the development of sustainable textile practices by reducing the need for material testing and consumption. However, software packages such as SDS-ONE APEX4, as well as Scotweave, TexGen, and Blender, should not be seen purely as means of recreating smart yarns in digital form in order for them to then be produced as physical textiles. Instead, they can be approached as alternative ways of working with smart materials and customised workflows, allowing the designer to develop sustainable and innovative practices relating to the Industry 5.0 model (Xu et al. 2021): they can facilitate exploration of values, expressions, materials, structures, and scenarios that might not yet be possible, or relevant, to realise in physical form.

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