## Shapeshifting

Full paper submission

## Title

Repeatless: transforming surface pattern with generative design

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## Abstract

Much of the initial use of digital technology within the printed textile industry has focused on the particular advantages that it has over previous fabric printing methods. Examples include simplifying workflow, producing relatively cheap short runs, or allowing designers to work with photographic imagery and unlimited colour palettes. This paper firstly identifies that digital fabric printing has a fundamentally different possibility in relation to its forerunners. Formerly, printing was essentially the ability to reproduce the same image (or text) over and over again. Digital printing, however, does not have to work from static information; it can print a design that changes as it is being printed.

Secondly, the research demonstrates that digital technology can provide the content with which to do this, creating a design that not only changes as it is being printed, but that never repeats. This is achieved by a generative software application. The resulting code is based on cellular automata, a method of mathematical modelling that allows the elements within a system to evolve in relation to each other. In this case, the elements are the individual motifs or other visual components and the system is the overall design. The rules that govern how the motifs arrange themselves are based on methods used by printed textile designers to ensure the eye can roam freely over a design, balancing the arrangement and scale of the motifs, for example, or the negative space between them.
The degree of complexity possible with cellular automata allows the qualitative design process to be modelled with a richness that maps the skills of creating pattern into code. The output is a non-repeating design of infinite length that can be saved section by section to be streamed to a digital printer, exploiting the technology in an entirely novel fashion. Seen individually, digital design and digital printing technology present a large number of new possibilities for the printed textile industry. This paper shows a way that interdisciplinary, practice-led research can integrate them and offer a method to shift the paradigms of what pattern is and the way in which it can be reproduced.

## Keywords

generative design
digital fabric printing
printed textiles
surface pattern
non-repeating pattern
cellular automata
complexity

## 1.0 Introduction

The application of digital technology provides a novel method of transforming one of the paradigms of surface pattern and printed textile design. Combining software and hardware offers the possibility of creating any length of pattern, without the need for the design to repeat. Pre-digital textile printing processes employed in mass production mechanically reproduce the same design again and again down a length of fabric. Indeed, this is the desirable characteristic; it enables an expanse of fabric to be covered with the same design on an industrial scale. Whether the method is the wood block or the prevalent rotary screen print method (Ujiie, 2006: 338), the pattern has to be designed so it repeats identically down the substrate. A physical form of the design is a part of the technology and hence has to be pre-determined before printing starts; the design cannot be altered during the print process. This paper will firstly identify why this is no longer the case with digital fabric printing: the technology permits the printer to receive data that is constantly changing and output it as a design that never needs to repeat. The process can continue indefinitely and hence work for any length of substrate.

This then raises the question of how to actually create an infinite, non-repeating pattern. The second proposal answers this, using a generative software application. In the field of print and pattern design, practitioners seek to arrange the motifs or other visual elements within a design so that the eye can roam freely over it. This paper suggests that such strategies, used to create good quality repeat designs, can be applied to non-repeating pattern. In a non-repeating context, similar compositional methods could be used to ensure a well-balanced design. The research here submits that design methods can be modeled to a sufficient degree to develop algorithms which can be used to create the pattern-producing software application. At this point, the work becomes inter-disciplinary. A complex system of cellular automata is used to structure the modeling of the design principles. In such a system, each element within it responds to its surroundings based around a series of rules. For example, an element might die of overcrowding if there are too many other elements in its neighbourhood. Cellular automata have a particular characteristic that renders them particularly useful in this instance; very simple rules can produce richly complex results. The proposition here is that the rules could be based on those methods used to create well-balanced print and pattern designs. The techniques that designers have developed over centuries of working with repeat pattern can be transformed into a complex system that generates potentially infinite lengths of repeatless pattern. Digital fabric printing allows such pattern to then be transferred to any textile length, or indeed other suitable substrate. The framework described here offers a new way to integrate the possibilities offered by digital hardware and software to shift the paradigms of how lengths of pattern can be designed and produced.

## 2.0 Transforming the paradigms of printing

In essence, the print process is a method of doing the same thing over and over again. In a surface pattern or textiles context, the design is printed again and again down a fabric or other substrate. Meller and Elffers (1991: 13) suggest that 'it is the nature of a textile pattern… to duplicate itself endlessly, so that the basic image is lost in a sea of repeats.' With this type of design, any section of the fabric can be cut into any size or shape to then make the product. This is desirable in manufacturing terms as it helps reduce wastage, which lowers costs. Indeed, 'repeated patterns are the norm in industrialized traditional textile printing' (Bowles and Isaac, 2012: 12). When creating a repeat, a designer will generally attempt to produce a pattern that makes it hard to identify that it is doing the same thing over and over. The more difficult it is to spot the repeat, the more the design will appear to flow seamlessly over the surface of the substrate. To give a practical example, the bottom edge of one instance of a design has to fit exactly into the top edge of its next instance down; similarly, its right edge has to fit exactly into the left edge of its next instance across. In most cases, the designer will try to conceal the join, generally by avoiding an obvious horizontal or vertical gap. Viewed from any distance, the eye would naturally be drawn to such a gap and the design would appear as a series of panels rather than an evenly spread pattern. A well-concealed join 'ensures good design continuity from one repeat to the next' (Clarke, 2011: 43). It is important to note two things at this point. Firstly, the notion of a design ideal where all content is balanced by ensuring that nothing within the pattern stands out. Secondly, that some steps in the process of creating a repeat design might be quantifiable; objectively outlining the design process will become very significant later in the paper.

Once the design is finished, it can then be printed. With pre-digital printing, some part of the printer was a physical manifestation of the design; the engraved surface of a copper roller, for example, or the areas of open screen mesh that allow the dyestuff to be pushed through onto the fabric. In simple terms, digital fabric printers work by spraying the dyestuff onto the fabric. While in itself this is a mechanical process, the means by which the spray is controlled is not: there is no physical version of the design within the printer. As the print head moves over the surface of the fabric, the flow of each colour is switched on or off digitally. Cumulatively, the application or non-application of colour over the fabric results in the final design. The print is controlled by data. If the design repeats, so will the data. If the data never did the same thing twice, the design would never repeat.

The notion that digital fabric printing could remove the need for repeating pattern was identified by Briggs and Bunce (1995). Further discussion has taken place in subsequent surveys of the field around the notion that non-repeating designs could be digitally printed (Bowles and Isaac, 2012: 12; Braddock-Clarke and Harris, 2012: 163; Briggs-Goode, 2013: 112). These recognize that with all pre-digital printing methods, there is a limit on how large the repeat design can be, dictated by a physical constraint such as the circumference of a rotary screen, and propose that this constraint might no longer be an issue with digital printing.

However, very large designs, particularly those that are raster-based, require very large amounts of memory; once this goes beyond a certain size, it becomes very difficult for the computer or printer hardware to process it. Schofield (2012: 336-7) proposes a system of working with large-scale designs in which the designer creates a scaled down version of the final image using little visual elements called patches. Once finished, this is then divided into sections and rendered as a series of much larger scale images that tile together to form the final print.

What, however, if there was a method of creating a design that didn't have a fixed size, a design that changed indefinitely in real time? Setting aside for a moment the issue of whether this is practically possible, this paper's first proposal is that digital technology would allow it to be printed. Data controls the print in a digital system, not a pre-determined mechanical translation of the design. Rather than cycle to give a repeat, the data can be changing all the time. Instead of the treating a design as a static, finite entity that is created and sent to print as a finished outcome, the digital print process would be able to work with a dynamic design that was being generated as it was being printed.

Surveys of the use of digital technology within the fashion and textiles industries suggest that its advantages are currently seen as improvements over the existing capabilities of the previous printing technologies, particularly the rotary screen method. For example, Ujiie (2006) examines how it simplifies workflow and Tallon (2011) notes the reduced cost of producing short print runs of fabrics. From a design perspective, Bowles and Issac (2012) recognize the ease of working with photographic imagery and unlimited colour palettes that the new technology affords. As the design process has become digital, the capabilities of software packages have reflected the need for repeat. Bowles and Issac (2012: 180) and Clarke (2011: 66) outline the uptake by designers of both general image editing software, such as Adobe Photoshop, and specialist textile design packages, such as those produced by Nedgraphics and Lectra Systems. All offer methods to retain the process of designing in repeat. Figure 1 shows a design produced using Photoshop that features photographic imagery and a wide range of colour, yet remains in repeat.

Figure 1: 'aram1006' (Russell, 2005), a repeat design for digital printing.

However, this research proposes that digital printing can do something altogether different from the previous technologies. It could output an ever-changing design, shifting the paradigm that the print process is about doing the same thing over and over again.

## 3.0 Transforming the paradigms of surface pattern design

### 3.1 Transforming repeat into non-repeat

In detailing how the digital print process could output an ever-changing pattern, the ability to actually create such a design was assumed. What follows is a proposal for a practical method of doing this, showing how generative design processes could provide a method of creating dynamic surface pattern. Such processes are defined as 'the generation of designs by a set of rules or an algorithm, usually using computers' (Bruton and Radford, 2012: 166). In other fields of design, generative methods have been explored fairly widely; for example, in graphics (Maeda, 2000 and 2004) or architecture (Fraser, 1995). By comparison, they are not as established in printed textiles. Carlisle's research (2002) considers how randomness could create non-repeating design. McDonald (2013) examines the use of generative methods to improve user experience in working with mass customisable product, specifically in the employment of interaction and fabrication technologies within a digital textile printing context. Paramanik (2013) also explores generative design for printed textiles, developing a method of exploring digital craft processes using motion capture technology. The collaborative design practice of Reas and Reas

(2014) demonstrates the use of generative design in a fashion context, using fabric digitally printed with generative imagery to make garments. In a broader textile field, there has been some consideration of a generative approach to tapestry based applications (Moallemi and Wainer, 2008) and Miller discusses with Sutton (1981) the possibility of using patterns from number theory as floor covering. Richardson (2009) has used generative processes and interaction to create animated pattern. Although the work is projected rather than printed, it draws inspiration from the wallpaper designs of William Morris. Häberle's [mustercode] project (2013) explores the use of generative design for the mass customization of textile products and raises the 'potential solution' of 'altering patterns over tens of thousands of … meters.' She suggests that natural form of a leaf might be modeled generatively and that data relating to leaves might also be visualized. Schofield (2012: 343) imagines a system where an algorithm might arrange the 'patches' (visual elements) that make up the designs referred to earlier to generate 'limitlessly big images', suggesting that 'such a system would go some way towards the notion of generating endless-non repeating surface designs.'

What differentiates the work in this paper from this previous research is twofold. Firstly, it outlines a practical method of creating generative pattern using any type of content, no matter what the style or medium. Secondly, as the patterns it creates are dynamic and never repeat, it exploits the fundamental shift of the boundaries of print that digital technology, thus integrating the new possibilities offered by software and hardware.

The desired outcome here is a dynamic surface pattern surface pattern that takes advantage of the prospect of printing a repeatless design. A model is required that that allows the design to evolve continuously, yet remain recognisably a pattern. Furthermore, if the output is to be commercially viable, the model should ensure that the design quality is consistent over all parts of the printed result.

Earlier in this paper, the practice of creating well-concealed joins in repeat designs was outlined. The ability to do this is part of the skills-base that a professional designer would use to create good quality designs. Whilst it is part of a creative process, it is one that can be explained in fairly objective terms – in this instance, avoid the join between repeats being an obvious vertical or horizontal gap. If a number of other criteria in the process of pattern design could be defined as instructions, then it might be possible to form a model to ensure the quality of the design.

Returning to the notion that a designer will try to ensure that the eye can move freely over a design, the desired balance of motifs is achieved by a number of different methods, most of which seek to ensure that no one part of the design dominates. If something does stand out, wherever it repeats will stand out, making the underlying structure very noticeable.

> This problem, known as "tracking"... can be resolved by scattering copies or variations of noticeable elements in a design in such a way that they appear to be randomly placed and equally balanced with other similar motifs or coloured areas.' (Bowles and Isaac, 2012: 88).

Whilst the goal here is a non-repeating design, it is proposed that methods such this could produce models that might be used in a generative design process. Furthermore, they could ensure the design quality of the output is always industrially usable.

At the start the generative process is the notion that a pattern is made up of a number of visual elements: 'patterns are composed of motifs that interrelate with each other as repeated, varied, alternating, symmetrical or asymmetrical shapes' (Newall and Unwin, 2011: 6). A series of principles that model how such motifs might effectively interrelate within a design are then defined. Crucially, these principles apply to the structure of the pattern, not to its content. Although part of the interaction process that will subsequently be described includes an awareness of whether any one element is similar to its neighbours, this research focuses on the strategies used to arrange the elements. Whatever the content of an all-over design, the methods by which the pattern is composed tend to be fairly similar; it is these that this research seeks to model. The example developed here can work with any imagery, which is of vital importance if the work is to have industrial applications. For example, the brief might request a hand-drawn floral design. A series of drawings of flowers could be made and scanned; the generative process would then create a non-repeating pattern from them. If the brief required a digital, geometric design, the individual elements could be created using proprietary design software and then converted to a repeatless pattern by the  computer application. Indeed, the content could be generative; there are many practice-led examples of generative design processes being used to create imagery that intentionally or not would fit well within the aesthetics of printed textile design - Ignac's *Cindermedusae* (2010) for example, or Brown's *Flowers* (2012-13). Whilst it is anticipated that at some point in the future that the research introduced here will investigate the use of generative content, this paper focuses on the use of programming to create the structure of the pattern, not its content, precisely so that any content can be used. Using the finished application, other designers could create their own repeatless designs with their own motifs and the resulting outputs could be applicable to industry.

### 3.2 Transforming design with science

The research now turns to complexity, a field of science and mathematics. Mitchell defines the investigation of complex systems as 'research that seeks to explain how large numbers of relatively simple entities organize themselves, without the benefit of any central controller, into a collective whole that creates patterns, uses information and in some cases, evolves and learns' (2009: 4). If the dynamic surface pattern sought here is thought of as the collective whole, then the motifs or other elements within a design can be thought of as the simple entities within it. An example of a complex system is a cellular automaton, defined as

> a lattice of discrete individual sites, each site taking on a finite set of, say integer values. The values of the sites evolve in discrete time steps according to deterministic rules that specify the value of each site in terms of the values of neighboring sites. (Wolfram, 1994: 412)

In this context, the lattice can be thought of as an imaginary grid covering the design, with each site as a square of the grid. The values of the sites correspond to their content; either empty or containing a design motif or element. The deterministic rules are the algorithms that have been developed from the principles of pattern design. It is these that dictate how the motifs interact and, as a result, how design evolves down the fabric. Whilst the printed output can be thought of as a final design, it is also a documentation of the way the motifs dynamically interact.

It is not only the structure of cellular automata that makes them ideal for pattern design. Even with very simple rules, they can 'engage in unpredictable, nonlinear, relational behavior' (Tierney, 2007: 82). In other words, even though the interaction between the motifs is governed by rules, the way they will actually arrange themselves cannot be determined in advance. Simple rules can give rise to complex results. The design will follow the rules, but the likelihood that it will do the same thing twice is negligible. It will be identifiable pattern, but it won't repeat.

Putting all this together provides the model. Motifs or other design elements interact with each other according to rules derived from the established methods of creating pattern. Rather than produce repeat designs, however, the result is a complex system of dynamic surface pattern. Once the model is established, it can be tested by its application to design practice. The algorithms that derive from the model are translated into computer programming language. In this instance, the coding environment Processing is used.

> It was developed as an open source project (initialled by Casey Reas and Benjamin Fry …) … [and is] built on a much more complex and powerful language, Java, but greatly simplified and applied. (Pearson, 2011: 14)

Its initiators describe it as 'specifically designed to generate and modify images' (Reas and Fry, 2007: 1).

## 3.2 Transforming models to design outcomes

The following example demonstrates practically how the process outlined above produces design outputs. A software application entitled 'Cloth of Gold' (Russell, 2013-4) is used. This was written to show how a cellular automaton with rules derived from traditional design methods could work with any imagery to create endless lengths of non-repeating pattern. The application arranges a library of pre-determined motifs to form the output. The library can of any size and can include any imagery that can be digitized.

The 'Cloth of Gold' code works in two stages. The first stage is the cellular automaton. A two dimensional grid is set up that corresponds to a finite area of the design. Here, the grid is 35 cells wide and 28 high. These dimensions were derived from practical experimentation; they essentially strike a balance between getting sufficient complexity and making it easy to quickly test the visual quality of the output. Each cell of the grid has data assigned to it that will subsequently determine whether or not it will contain a motif, and if so, what the motif's characteristics will be. In this instance, these characteristics include which motif is to be used and it's size, transparency and degree of rotation. Each time step involves three processes. Initially, a number of the cells in top row of the grid are randomly set to contain motifs. Then all the cells in the grids interact, based on the rules derived from traditional pattern design practice. For example, one rule dictates that the motifs should not form strong vertical lines, thus avoiding the tracking issues raised earlier. This can result a number different consequences for each motif; this might be that it moves, changes scale or is removed completely. Finally, the data in every cell of the grid moves down a row; the top row is now empty and the bottom row of the grid passes onto the next stage. These processes cycle for as long as the programme runs; as in this instance the grid has 28 rows, the cellular automaton's rules are applied to each motif 28 times before it passes to the second stage. This stage is shown in Figure 2.

Figure 2: A graphic representation of a section the first grid, showing the a single time step of the cellular automaton.

In the second stage of the process, another grid is used. The width is the same as the first grid; the twenty cell height allows a large enough area of the design to be seen to ensure the design quality can be checked, but gives sections small enough to stream or easily save. This time, as each time step passes, the data associated with each cell is converted to imagery, using the pre-determined library. The result is a section of the endlessly changing whole that fits seamlessly into the sections before and after it. The sections can either be saved as a sequence of images, or streamed to a printer. This stage is shown in Figure 3.

Figure 3: A graphic representation of a section the second grid, showing the data being converted into the output pattern using imagery from the library.

An example of the output can be seen in Figures 4a and 4b. These show sections of repeatless pattern produced by 'Cloth of Gold' (Russell, 2013-4). In the example, the software application works with a library of 80 images, combining photographic, hand-drawn and digitally created motifs to generate the design. A video of the code in action can be viewed online at http://repeatless.blogspot.co.uk/.

Figures 4a and 4b: Two sections of pattern produced by the “Cloth of Gold” version of the Repeatless code.

The printer would interpret the design simply as a sequence of images to be printed seamlessly, one below the other. Eventually either the fabric or the dyestuff would run out, but the design generation or streaming could just be paused at this point and restarted once the new substrate or colour was in place. The outcome is a design of any length that draws on the traditions of pattern, yet never repeats. From an industrial standpoint, it is of value as a mass-customizable product that can use any imagery (that might include content uploaded by the customer). Furthermore, the removal of the need for repeat adds value as far richer, more complex patterns are able to be manufactured that was previously possible on an industrial scale.

## 4.0 Conclusions

The integration of digital design and printing technologies provides a method of profoundly rethinking the design and manufacture of surface pattern and printed textiles. Because the digital print process is driven by data rather than the physical properties inherent in the previous mechanical technologies, a digital printer can output dynamically interacting imagery that evolves in real time. Such imagery can be generated by computer programming, using a model derived from the techniques traditionally used by designers to create well-balanced, good quality print and pattern. The techniques form the rules by which the elements within the design interact, using a complex system of cellular automata. Any type of content can be used; the generative software application arranges the motifs or other elements within the design into a potentially infinite repeatless pattern. This could be saved or streamed section by section to a digital printer, the size of the output being only restricted by the length of the substrate or the printer’s dyestuff capacity. The work presented in this paper not only proposes these ideas, but demonstrates a practice-led method of achieving them.

This research shows how the boundaries of repeat can be fundamentally shifted. The rich heritage of techniques developed by designers to create repeat can be transformed into algorithms that allow the production of non-repeating pattern on an industrial scale. The compositional skills used to conceal the mechanical limitations of pre-digital printing technology metamorphose into a method of ensuring the design quality of an output free from such restrictions. The output becomes a visual documentation of how the content of the design evolves over a period of time, yet draws on the appeal of its pre-determined, static predecessors. The paradigm of repeat has been transformed; pattern can now be repeatless.

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## Biography

Alex Russell studied BA and MA Textiles in Manchester (U.K.), graduating in 1992. Following this, he worked as a freelance designer and part-time lecturer, before lecturing full time at Nottingham Trent University (U.K.) from 1994 to 2001. After this, Alex set up a freelance design studio in Brussels (Belgium) and then Amsterdam (The Netherlands) before moving back to the U.K. in 2006. He has lectured at Manchester School of Art since 2007, is currently doing a practice-led PhD and continues to work as a designer.

Alex's design practice covers a wide range of printed textile design, surface pattern, graphics, art direction, illustration and other creative services for fashion, interiors, trend prediction and editorial/publishing. He has an extensive international client list and his designs been featured worldwide in books and other publications surveying contemporary pattern and print. Alex's 2011 book, *The Fundamentals of Printed Textile Design* (Lausanne: AVA Academia), has been translated into French and Spanish.

His research is practice-led. It is based in printed textiles and surface pattern, but in the last few years has taken a more interdisciplinary approach, incorporating programming and mathematical/scientific modelling techniques. In general terms, it considers the impact of digital technology on the field, with particular reference to print and pattern design and manufacture, the use of complex modelling models to produce generative design and the re-contextualisation of traditional pattern.