The influence of colour mixtures on the textural perception of surface design: Deciphering textile methodology in the field of bioplastic design

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Abstract
In textile design, the characteristics of a textured surface are the result of the properties of the materials, the textile techniques used, and the colour mixtures associated with each technique. The perception of colour on textured textiles is dependent on the angles of viewing and incidence of light on the surface. Accordingly, when analyzing the perception of the colour of pile textiles such as velvet, we observe that the orientation of the piles on the surface affects the perception of colour. The perception of colour and its transformation depends on whether the light is reflected off the side or the end of the yarn. By bringing do it yourself (DIY) materials into the textile design field, this research questions how biomaterials such as bioplastic can be further developed using textile surface design methods, and how the relationship between texture and colours can be advanced in the design of complex textured surfaces. The method develops a hybrid strategy for designing a new material category combining DIY and digital tools, which offers a more sustainable alternative to conventional textile materials. Moreover, the method proposed builds on two major aspects: explorations of bioplastic materials and their impacts on colour design and selection, and an analysis of changes in the visual perception of coloured surfaces with regard to differences in texture, the positioning of a light source, and angle of viewing. The results are methods of creating complex colour combinations and textural surfaces using near-adjacent and complementary colours and the intrinsic transparency property of bioplastics.

KEYWORDS
bioplastics, colour mixtures, sustainability, textile methods, texture design

1 | INTRODUCTION

All surfaces have material attributes that influence the characteristics of texture—from uniform and smooth to irregular and coarse—and that interact differently with light and affect our colour perception. Kopacz argues that the quality of the colours that the eye sees are really determined by three conditions in...
combination: “the chromatic characteristics of the subtractive colour, the colour quality of the lighting applied to it, and the surface texture of the material containing the colour.”4(p161) The ways in which light is reflected, absorbed, or transmitted by surface textures causes variation in the amount of light that reaches our eyes, influencing how colour is perceived.5 Although the impact of texture on perceived colour is subtle, it is important to understand this impact and, by making informed decisions in the design process, embrace or modify it.

In textile design, there are three techniques for manipulating colour when producing textiles: “visual mixing through weaving, colour management through the dyeing process, and manipulation of yarn orientation” (Ibid. p167). This occurs by working with the dimensions of the yarn, strength of dyes and pigments, orientation of dyed yarns in the warp and the weft (for weaving techniques), weaving and knotting techniques in carpets, and manipulation of yarns and fibers. By changing the position of coloured yarns in a warp or weft or the dimensions of the yarn during weaving, the perceived colour of the yarn can be changed slightly due to the corresponding change in light reflected by the fiber. With a woven carpet, subtle colour variation can be accomplished in several ways, including twisting as in a frieze, uneven loop height in a loop pile, or a combination of the two in a cut-and-loop pile. In each case, the direction of the yarn is changed to give a more textured effect through the appearance of subtle colour variation.

In knotted carpets such as oriental rugs, the orientation of the fibers and the way the yarns are trimmed create an impression that they are leaning slightly, causing the pattern to be directional even when the graphical pattern is symmetrical. This effect causes the colour of a such a carpet to be perceived as darker when viewed from one end.

Over the last decade bioplastics have begun to be used in design disciplines, attracting the attention of design researchers and practitioners who are interested in experimental and conceptual design approaches based on rapidly renewable natural raw materials.6,7 A sea full of possibilities by the textile design researcher Carolyn Raff8 is an ongoing research project that seeks to explore the endless possibilities that red algae-based biopolymers offer in textile design. The agar bioplastics are coloured largely with leftover dye from other textile and fashion processes, the designers of which only use natural dyes in their processes. By using embroidery and textile manipulation, the colourful biodegradable bioplastics are used in textile and fashion design. Another project, entitled Desintegra.me and produced by Talep,9 has also developed an algae-based biodegradable plastic for food packaging. Talep uses natural dyes, which are extracted from fruits and vegetables such as blueberries, purple cabbage, beetroot, and carrots, to create new forms of packaging. Another project has been undertaken by Klarenbeek and Dros10 in which a bioplastic made from algae or other organic raw materials such as mycelium, potato starch, and cocoa bean shells is transformed into 3D-printed objects. These and other experimental research projects in this area have used natural and sustainable ingredients to make strong, flexible, and useful bioplastics that suggest functional objects with various aesthetic qualities. Hence, this research emphasizes the need to question, for example, how this hybrid material territory can be further developed using textile surface design methodology, and how the relationship between texture and colours can be advanced in the design of complex textured surfaces. Accordingly, the project aims to present a hybrid design strategy that can facilitate complex surface designs that expand the aesthetic possibilities of bioplastics when do it yourself (DIY) and digital tools are combined. It addresses two questions: (a) how the character of bioplastic materials impacts colour design and selection, and (b) how the visual perception of coloured bioplastic surfaces changes according to differences in topographical texture, the angle and direction of light sources, and the angle of viewing.

## 2 | METHOD AND DEVELOPMENT

### 2.1 | Material development

In this project, the materials that were used to create DIY bioplastics consisted of three main ingredients: glycerine, water, and either gelatine or agar. Often, all of the ingredients are mixed in a beaker, then heated on a hot plate to above 100°C. The mixture is stirred until the particles are dissolved and the solution becomes a transparent liquid. Finally, colour is added and the mixture is stirred until the solution has an even colour intensity. The solution is then poured onto a non-stick casting frame; after a couple of days, the film has dried and is ready to use. Previous experiments with both gelatine and agar indicated that it is possible to produce thin bioplastic films with different properties depending on the main material used in the solution. Agar resulted in translucency, a texture that was either smooth or had a noticeable grain, and a flexible and stretchy surface. A gelatine-based solution is to be recommended for the production of transparent and even, shiny, hard, and flexible but not stretchy bioplastic. It is noted that the surface texture and transparency of the bioplastic created in this way was affected by the characteristics of the gelatine or agar, the texture of the casting frame, and the string method, for example, creating foam through string.
Based on previous experimentation with gelatine and agar as biopolymers and 1% glycerol as plasticizer, two recipes using gelatine were chosen. The first was a combination of 2.25 g of gelatine and 120 mL of 1% glycerol solution used for making gradient-coloured surfaces; the second was a combination of 10 g of gelatine and 240 mL of 1% glycerol solution used for creating much harder surfaces.\(^{11}\) Both recipes produced a robust film which was thin (1 mm), even, transparent, shiny, hard, and flexible. During the experimental process, smooth acrylic molds (19 × 27.7 cm) were used as a casting frame to create a fine, regular texture pressed into the surface. It was decided to not use a textural casting frame as the casting texture would interfere with the designed three-dimensional texture. To enhance the three-dimensional surface texture, laser-cutting and straight-knife fabric cutting techniques were used to apply complex digital patterns to the surfaces.

## 2.2 Colouring development

In order to find the right types of dyes and pigments for colouring the bioplastic, the bioplastic solution was mixed with different dyes and pigments such as reactive, disperse, acid, food, and natural dyes, and textile pigment paste, thermochromic inks, and glow-in-the-dark pigment. The samples were analyzed in relation to how the types of colourant influenced the transparency of the bioplastic. The results indicated that most of the tested dyes produced bright colours and transparent surfaces, while pigment-based materials such as thermochromic or glow-in-the-dark pigments created dull colours and opaque surfaces (Figure 1). There were subtle differences between the different types of dye in terms of their producing bright and vivid colours, and so it was decided to use red, yellow, blue, green, and black food dyes on the basis that they are organic colouring agents and, in comparison to natural dyes, create more transparent and vibrant colours. The principle of colour mixing was similar to the pigment-mixing methods described by Itten,\(^{12}\) except that in order to make a lighter value colour a very small proportion of colour was added to the solution, rather than mixing white with the desired colour.

Two methods were used to colour the bioplastics, which resulted in some monochromatic-coloured surfaces and some gradient-coloured surfaces. The gradient movements differed based on the angle from which the colour started and flowed into the next colour. The most common types of movement in this context are parallel, concentric, and zigzag.\(^{1(p79)}\) In order to make soft,

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**FIGURE 1**  A combination of 2.25 g of gelatine and 120 mL of 1% glycerol solution was used to make the bioplastic samples. Sample A was made with 5 g of food colouring, B with 5 g of reactive dye, C with 5 g of disperse dye, D with 5 g of acid dye, E with 5 g of textile pigment paste, and F with 5 g of thermochromic ink.

**FIGURE 2**  A selection of colour gradient; the bioplastics facilitated the production of clearly defined visual boundaries between the colours.
transitional gradients, the base colour was poured first; immediately after, drops of the second and third colours were slowly added. To determine which colours would be used for each type of gradient, a digital gradient palette was created. The colours were based on the natural transition from primary to secondary colours; later, some contrasting colours were added. The results indicated that the softest transitional gradients are not easily achieved using bioplastics. By comparison, it was observed that bioplastics produce more clearly defined visual boundaries between colours. colours such as yellow and red were used to define hard or distinct boundaries, while blue and green created juxtapositions at soft boundaries (Figure 2).

2.3 | Three-dimensional texture surface development

In order to enhance the surface texture of the bioplastic, different repeated units were composed and applied to the bioplastics using laser cutting, and both engraving and cutting were tested. The results indicated that the impact of an engraved texture on perceived colour is subtle, while the impact of a cut texture on perceived colour is obvious. Three design strategies were used to achieve generative pattern gradations and enable various cutting possibilities, that is, to obtain a variety of gradated three-dimensional textures with multiple angularities in small, medium, and large sizes. The directionality of the cutting of the patterns determined the diversity of the angularity of the light and surface expression. The surfaces designed exhibited between two and four intersecting faces, creating three-dimensional surfaces with an angularity of between 30° and 60°.

The first type of pattern was a linear composition with gradation which was cut in the x direction. The composition is an example of proportional gradation in size and position in the x and y directions of the faces. The three-dimensionality of the surface built on two intersecting faces, meaning that light was re-directed by one of them. The second gradation of rectangular shapes was obtained using proportional gradation, which simultaneously affected both the size and rotation of the basic motifs in the x direction. The cut pattern divided the rectangular repeating shape into two identical triangular geometries. The three-dimensionality of the surface texture built on three intersecting faces, meaning that light was re-directed by two of them. The third type of pattern was a gradation of hexagonal shapes organized around one attracting point using proportional gradation, which affected the size and arrangement of the basic motif in the x and y directions. The final design was cut in three directions parallel to the hexagon’s sides. The three-dimensionality of the surface texture built on four intersecting faces, meaning that light was re-directed by three of them.

2.4 | Documenting the impact of angle of light source, as well as angle of view on the motifs

In order to explore how the three generative pattern gradations described above behaved in relation to the light source, one motif from each pattern category was cut on a green piece of transparent bioplastic. The sample was placed on a table at an angle of 90° to the viewer at a distance of 50 cm. The light source was daylight; the sun was at an angle of 143.97°E with a solar altitude of 12.49°, and the experiment was held in Borås, Sweden. An incandescent lamp (12 V/10 W) was also used, and emitted a warm light. The incandescent lamp was positioned at 10° increments between 10° and 180° to the samples (Figure 3).

Next, and as in the previous part of the experiment, the sample was placed on a table and the light source was daylight; the sun was at an angle of 143.97°E with a solar altitude of 12.49°; the experiment was held in Borås, Sweden and the angle of the viewer was at 10° increments between 10° and 180° to the samples at a distance of 50 cm (Figure 4).

When the incandescent lamp was at 90° to the sample, the hue was maximally intensified. As the incandescent lamp moved from 10° to 180°, the three-dimensional surface cast a shadow, which was itself coloured due to the transparent quality of the bioplastic. The shape and size of the shadow changed at different angles. It was also observed that both the angle of the light and colour of the shadow influenced the colours of the surface, enhancing the sense of volume.

It was observed that for the first type of pattern (linear), as the incandescent lamp moved from 10° to 180° only the length of shadow changed; for the second type of pattern (square), as the incandescent lamp moved from 70° to 90° and 140° to 180° the shadows cast on the square created a new shape. For the third type of pattern (hexagon), as the incandescent lamp moved from 10° to 70° and 150° to 180° the shadow cast created not only new shapes in addition to the hexagons but made one side darker, appearing to divide the hexagons into two parts.

Changing the angle of viewing altered the appearance of the surface textures. By viewing the samples from the side (at 10°-40° and 140°-170°) rather than
above, the three-dimensional surface textures appeared to have changed from flat surfaces to ones increasingly articulated by colour and texture. This finding was used during the documenting of the final samples to capture the most mixed colours and three-dimensional surface textures.

FIGURE 3  Top left; the photography setup. Top right and below; the interactions between the colour of the surface and the cast shadow at different lighting angles

FIGURE 4  On top left, shows the photo shooting setup. On top right and below shows the complexities of the interactions between the colour of the surface and the cast shadow when angle of view is changing
3  |  FORMING DIVERSE COLOUR MIXTURES: HOW THE VISUAL PERCEPTION OF COLOURED BIOPLASTIC SURFACES CHANGES ACCORDING TO DIFFERENCES IN TOPOGRAPHICAL TEXTURE, THE ANGLE AND DIRECTION OF LIGHT SOURCES, AND THE ANGLE OF VIEWING

3.1  |  Colour selection

A gelatine-based solution was used for the production of the bioplastic, creating a transparent, even, shiny, hard, and flexible material. When two transparent layers overlap or obscure one another, areas of overlap have the combined characteristics and colours of the two. By stacking two layers of transparent, coloured bioplastic, the colours of the two layers mixed and made the eyes move between them.

It was also observed that stacking two coloured layers affected not only the colour relationships between the layers but the design’s visual weight and balance. For example, yellow on a yellow background tends to dissolve into the background producing a lighter visual expression, whereas yellow on a contrasting colour such as blue creates a dark and heavy expression.

Adding three-dimensional texture to the top layer of coloured, transparent, even, and shiny bioplastics affected not only the combined colours of the two but also highlighted the spatial behavior of colour at the cut parts; this is defined as a function of how intense or bright a colour appears to be when juxtaposed with another colour. For example, a fully saturated yellow; when placed against a gray colour it shares the same spatial plane, but when it is placed against a dark blue it appears to be slightly larger and stands out from the surface.

A digital colour palette was created and printed onto transparent films to illustrate different colour combinations in relation to overlapping, as well as to demonstrate interactions between colours at the boundaries between two colours.

3.2  |  The influence of colour mixtures on the perception of textural surfaces

Following reflection on the results achieved, with a focus on colour rather than enhancing the three-dimensionality of the textures, it was decided to view the samples from above at 90° (from a height of 50 cm) in daylight; the sun was at an angle of 143.97°E with a solar altitude of 12.49°; the experiment was held in Borås, Sweden, and an incandescent light was also used at an angle of 150°. For the first type of pattern, transparent, magenta-cyan-pink gradient pieces of bioplastic were laser cut and placed on top of a transparent, violet-cyan gradient piece of bioplastic. The colours of the two layers were near-adjacent, creating a subtle colour combination and gradation between the colours. Because of the adjacency of the hues and closeness of the values, soft boundaries were created at the cut areas and the overall appearance became “flatter” (Figure 5).

For the second type of pattern, transparent, orange-white gradient pieces of bioplastic were laser cut and placed on top of a transparent, green-cyan gradient piece of bioplastic. The combination of the orange, green, and green-cyan colours created a desaturated brown at the bottom and a desaturated green at the top. At the cut areas, especially from the left to the middle, where the orange was mixed with green and green-cyan, vibration occurred where the two adjacent complementary colours with equivalent values met. Both of the colours seemed to move forward and beyond the surface, and as the contrast effect intensified, they came to vibrate at the mutual edge. This resulted in a sense of visual depth, enhancing the volume. On the right side, as there was no colour contrast or combination between the layers, soft boundaries that diminished the volume were created (Figure 6).

For the third type of pattern, transparent, green pieces of bioplastic were laser cut and placed on top of a transparent, orange-red-magenta-violet-blue gradient piece of bioplastic. This piece was more complex as the colours of the two layers were mostly complementary, except at the bottom where near-adjacent green and blue colours met. The green of the top layer mixed with orange, red, magenta, and violet to create a desaturated brown, which contrasted with the colourful bottom layer. Thus, hard boundaries were created at the cut areas, while vibration occurred at the mutual boundaries; these phenomena were the result of two adjacent complementary colours with equivalent values meeting. In addition, soft boundaries occurred when the blue and green were placed next to each other (Figure 7).

In comparison with the surfaces of the smooth, flat, and shiny bioplastics which reflected light more uniformly and had less influence on perceived colour than that of the three-dimensionally textured ones, the three-dimensionally textured bioplastics in all three sizes caused light to interact with the bioplastic in different ways through a combination of reflecting and transmitting, redirected light in various directions, and created surface variation and pockets of shadow with value differences. The original colours appeared to be darker and less saturated when it was in shadow.
3.3 | The influence of topographical texture, light sources, and angle of viewing on perception of coloured bioplastic surfaces

As with the pile textiles, orientation was important. The three-dimensionally textures that reflected light directly into the eye seemed to be lighter in colour. This can be explained by the fact that the light that reflected off the surface caused the colour of the surface to appear lighter, increasing the intensity of the surface colour. The shiny parts of the surface of the bioplastic combined with the orientation to increase the brightness of the surface. The colours of the opposite side were in shadow and thus, became darker. This phenomenon facilitated the creation of complex three-dimensional surface textures; in the third pattern series, for example, which consisted of four intersecting faces, some parts of the texture reflected the light, brightening the colours and enhancing the volume, while other parts of the texture created shadow and desaturated the colours of the bottom layer. This resulted in a sense of visual depth and an ambiguous expression (Figure 7).

Another effect noted was that the gradation of the three-dimensional surface texture created movement on the surface as a whole. This effect was more visible when the size of three dimensional texture was smaller (Figure 7).

4 | DISCUSSION

Josef Albers\(^\text{17}\) studied how the perceived colour of a surface is affected by the colours of its surroundings in a
two-dimensional plane. Unlike Albers, Swirnoff explored the interaction between light and colour in three-dimensional space. In the context of field of depth, the interplay of light and its projection and scale in terms of colour cause fascinating transformations of volumes in space. The research presented in this article exists at the intersection between the two approaches in that it described colour interactions and explored the interactions between colours, light, and shadow that occurred on three-dimensional transparent surface textures. For all of the three-dimensional surface textures, the colour variables of hue, saturation, and value, along with light, shadow, and angle of viewing, interacted to a great extent. Manipulation of these variables produced or altered the perception of the three-dimensional surface textures.

The creation of the samples involved a hybrid method that has the potential to allow textile designers to design complex textures at the intersection of DIY methods and digital tools for surface fabrication. As compared to other fabrication processes such as moldings and casting, straight-knife cutting is a robust strategy for embedding new layers of digital textures on flat surfaces, or to create gradated effects on monochromatic sheets. Moreover, this technology enables designers to apply accurately intricate patterns designed using complex digital processes to surfaces. Additional three-dimensional effects could emphasize the curvature of a surface, and enhancing a change in the planarity of a surface could be achieved through changes in the size and colour of planes. In this way, detailed expressions can be added to create an endless variety of surface patterns, which can be used as flexible
partitions in interior design in a manner similar to textiles.

Furthermore, exploring the pliability of surfaces under natural or artificial lighting produced changes in the overall expression of the colour due to changes in the angularity of the surface. Thus, the flexibility and robustness of the textural qualities of bioplastics could be further explored at the level of the built environment in relation to fluid geometries. Similarly, the transparency of the colours and angularity of the layers of the knife-cut patterns offer great possibilities for designers to create spatial dividers that could interact with the light conditions in an environment. Specially, the near-adjacent colours which create a subtle colour combination and smooth gradation between the colours offer an interesting-coloured shadow in the space. The effect on colour perception and the smooth, reflective surfaces of bioplastics enable the design of rich, colourful expressions that would be possible to view from multiple angles and introduce a multitude of colour gradients to a space.

Bioplastics are natural materials that react differently to heat and moisture as compared to plastics. This versatile aspect of the material could be further developed, as could complex colour strategies for the design of kinetic façades or interior wall partitions. In this context, the design variables resulting from atmospheric conditions such as moisture, heat, and air flow can trigger further changes in the overall formation of colour mixtures, redirect light in a dynamic way through the opening of the surface, and affect the perception of the colour of a textured surface and shadows cast in a space.
5  |  CONCLUSION

Following on from the initial premise that there currently exist three techniques for manipulating colour when producing textiles, this article suggests a fourth; using straight-knife cutting technology to work with the intrinsic properties of bioplastics—transparency, smoothness, and flexibility—in order to create complex, coloured, and textured surfaces in textile design. Whereas the visual mixing of colours on pile textiles is based on the angularity of opaque fibers and light directionality, the three-dimensional textures created during the research presented in this article introduced the element of transparency. These material properties together with the intricate topography of the surface resulted in a more gradual change in colour and more extensive colour interactions on the surface, which depended not only on the position of light sources but on the angle from which a texture was viewed.

The method presented in this article expands the design possibilities of DIY bioplastics by taking advantage of the intrinsic properties of the material, such as transparency, smoothness, and flexibility, to create complex, coloured textural surfaces. The significance of this is related to the development of a methodology to assist designers in seeing possibilities, understand how the three-dimensional surface textures, the colour, shadow, and angle of viewing, interacted to a great extent. Manipulation of these variables produced or altered the perception of the three-dimensional surface textures.

DATA AVAILABILITY STATEMENT
Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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Marjan Kooroshnia is a colour researcher and senior lecturer in textile design at the Swedish School of Textiles, University of Borås, Sweden. Her research area is colour and light, with a focus on how they affect the process of designing dynamic surface patterns. In her PhD project, she explored the design properties and potentials of smart colours when printed on textiles in order to expand the range of colour-changing effects offered, as well as to facilitate communication regarding, understanding of, and design with smart colours.

Delia Dumitrescu is Professor in textile design at the Swedish School of Textiles, University of Borås. Her research focuses on the development of smart textiles design methods and aesthetics using industrial textile manufacturing and digital technology. Her cross-disciplinary approach to the textile field, knowledge in structures and digital tools enabled her to develop new textile design methods for diverse applications, for example, from the body to interiors and space.

Jessica Rijkers is a fashion and textile designer. She is currently studying toward a master's degree in textile design at the Swedish School of Textiles in Borås. Jessica wants to reframe the way we look at textiles by modifying production methods and replacing
conventional ingredients, for example, cotton, wool, and synthetic fibers, with alternatives such as bioplastic and materials sourced from waste streams. A clean and modernist approach is her signature in terms of design, and is combined with sustainable details through which she strengthens the identity of materials, re-empowering the textiles.

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