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# Colours in a Circular Economy

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## ABSTRACT

*This paper reports on preliminary results on the recycling of coloured cellulose-based textiles using a novel dry-jet wet spinning denoted as the Ioncell-F process. The practical possibility of colour circulation is useful knowledge for colour designers in the industry. The findings can help define further parameters for circular economy products.*

## KEY WORDS

Textile Remanufacturing; Colour Design; Ioncell-F; Dyeing; Fibres; Disposable Textiles; Circular Economy

## INTRODUCTION

The objective of this research is to study the stability and possible modifications of colours during the dissolution and regeneration processes with the intention to avoid dye stripping and further dyeing of recycled fibres. This is essential knowledge for a textile industry that aims to transform its practices towards circularity. A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the “end-of-life” concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models (Ellen McArthur Foundation, 2012).

Recycling should be understood as part of the strategy whole, which aims at building a new kind of society. This society consumes and disposes only the necessary amount of raw materials. A recycling economy has been hindered by, among other factors, lack of systematic strategy wholes (Aarras, 2015). Resources to make primary textile fibres are decreasing and the world population is rising; therefore textile recycling needs to stay on the agenda. It is necessary to develop processes to design textiles that are easy to recycle (Gulich, 2006a). All existing textiles exhibit some colour whether it is achieved by the means of dyeing or being the textile's own natural colour. One of the issues faced by developers will be the presence of finishes and dyes in the textiles. Strategically it is best to have as neutral-coloured fibre in the stock as possible, white or off-white, which could thus be dyed on demand in the desired colour. However, in order to achieve this neutral colour, the dyed textile needs to be bleached and later dyed again, consuming energy, water and chemicals in both processes. Most of the literature is more concerned with purification and decolorisation of the water than with the recycling of the chemicals (Buschile-Diller, 2006). Through colour design, previous dye work applied to the disposable textile could be utilised as such and manifest in the remanufactured fibre as an attractive design element.

Fletcher (2014, 122-124) reports about mechanical fibre extraction technique for fibre reclamation, which involves tearing the fabrics mechanically apart using carding machines. It can be applied to cotton fabrics. For polyester chemical recycling process can be used. In polyester recycling a polymer feedstock is repolymerized to produce a recycled material that is purer and of a more consistent quality than produced by the mechanical method, although more energy intensive to produce (Fletcher 2014, 122). Fibres of both of these reclamation methods can be found on the market but chemical waste recycling of cotton and other cellulosic fabrics seems to be only in development stage.

The paper begins with the test description and results of dyed textile conversion. Based on the achieved results of colours in the remanufacturing process, a concept of colours in a circular economy will be constructed. The colour design concept is intended to contribute to the systemic regenerative nature of a circular economy, and it aims to give guidelines for designers working in a circular economy context. “Colour Library” is a conceptual system for colour design that it based

on disposable textiles and their colours and provides expertise and resources to produce yarns for textiles of desired colour and quality.

## RESEARCH

### Methodology

A set of laboratory experiments were performed using dyed cellulosic materials employing the Ioncell-F technology. According to Michud et. al. (2015) it is an alternative to the viscose and Lyocell process for the manufacture of man made cellulosic fibres, With the solvent used in this process the cellulose solutions could be spun at substantially lower temperatures than in the NMMO-based Lyocell process, which reduces energy consumption and prevents cellulose degradation.

A variety of dyed textiles was collected to test their feasibility in remanufacturing and their colour translation to new fibre. The textiles were a combinations of different kinds of textile made from the same polymer (cellulose) forming single-material composite systems, including cotton and man-made cellulosic fibres such as viscose, modal, lyocell or cupro. Some minor presence of elastane per item (1% - 5%) was accepted. When collecting second-hand textile items, the material information given on their wash tags was trusted. Precise background information about post-consumer textiles as well as industrial cut waste, their dyeing methods and earlier treatments was unavailable; thus some assumptions were made based on general knowledge of textiles. According to Forss (2000) reactive dyes are mostly used to dye cellulosic fibres and they are degraded by chlorine compounds, so the textiles were tested with quick hypochlorite drop test. Because of the popularity of blue jeans, indigo is still one of the most important of all dyes in present use (Broadbent, 2001). Thus cotton jeans along with were assumed to be indigo-dyed.

The textiles were first sorted according to colour or desired colour mixture and cut into small pieces; seams were excluded to minimise the increase of the percentage of non-cellulosic materials, such as polyester. The cut textiles were ground into a fine pulp by means of a Wiley-mill. At this point a certain average colour could be already seen from an optic mixture of multiple colours' "optic average colour" (later as OAC): for example 9 different shades of yellow pulped together formed optic average yellow. If the pulp was formed of two different colour sources, for example 50% pink and 50% yellow, the OAC of that was orange. At this point the first glimpse of the direction of the end fibre colour was observed. Homogenous pulp of ground colour components was subjected to treatment in 3% H<sub>2</sub>SO<sub>4</sub> solution at various temperatures, for various periods of time in order to reach a particular viscosity level suitable to form spinnable cellulose solutions. Intrinsic viscosity values of all of the final spinning pulp blends were targeted to be 450 ml/g, which was achieved by either one successful treatment or with treating two parts of the same pulp in different conditions and mixing them in a defined calculated ratio. The intrinsic viscosity of the resulting mixture was also tested and adjusted on demand by remixing before preparing the final spinning dope. Ready pulps were pre-mixed by hand with the ionic liquid solvent and then dissolved in a vertical kneader within 90 min at 90°C. Dissolved cellulose was filtered and spun using a customized laboratory piston spinning unit.

The success of colour translation of the end fibre was defined in relation to the OAC of the ground untreated materials. The colour difference evaluation was done visually and employing CIELab spectrophotometry. The optical appearance of the final fibre was compared to the pulp sheets prepared from the mixture of the ground waste textiles. All sheets of pre-remanufacturing average optic textile pulps were prepared in the following manner: ground, untreated textile pulp was measured in amounts of 200g/m<sup>2</sup> with added compensation of dry matter content, disintegrated in water and turned into a sheet of even thickness. The sheets were later pressed and dried, folded to form pieces of four layers and, because of their instability, measured through glass with an L&W Elrepho spectrophotometer. The fibres were measured by arranging them under the spectrophotometer aperture covering the background completely and placing them under the same glass as the pulp sheets, thus making the presence of glass relative and insignificant. Eleven samples were tested, and they were categorized according to their success in translation to the fibre of second generation.

- Successfully translated colour. This category refers to fibres that preserved their lightness, saturation and hue relatively well and visually could have been connected to their OAC.
- Colours that were altered in translation only slightly. This category refers to fibres that changed their lightness, saturation or/and hue resulting in a visually noticeably different colour, yet that still could have been connected to their OAC.
- Colours that were altered in translation rather noticeably. This category refers to fibres that changed their lightness, saturation or/and hue resulting in a visually noticeably different colour, yet other than white.
- Drastic loss of colour. This category refers to the fibres that lost their saturation, hue and rose on the lightness scale towards white after the dissolution process.

**Table 1: Samples of remanufactured fibres, their colours and origins**

	Colour and total consistency	Origin	Colour components	Dyeing method (certain or estimated)	Success of translation from average optic colour in regenerated fibre
1.	Yellow 55,4% Cotton 43,5% Viscose 1,1% Elastane	Flea market, mostly post-consumer source materials	All various shades of yellow	Most components were dyed with presumably reactive dyes	- Visually rather similar to source material - darker than OAC, reduced chroma in red, increased chroma in yellow Successfully translated colour
2.	Blue 49,4% Cotton 19,8% Viscose 4,8% Cupro 10,2% Modal 4,6% Lyocell 1,1% Elastane	Flea market, mostly post-consumer source materials	All various shades of blue	Most components were dyed with presumably reactive dyes	- Visually hue change noticeable from royal blue to purple - darker than OAC, increased chroma in red, reduced chroma in blue OAC was altered in translation
3.	Blue Denim 50% Cotton 50% Lyocell	½ of the material from post-consumer item. ½ of the material from pre-consumer item.	Two shades of denim blue	Components were dyed with presumably indigo dyes	- Visually hue change noticeable from light blue to rather dark, dull petrol - darker than OAC, increased chroma in green, reduced chroma in blue OAC was altered in translation
4.	Red 50% Viscose 42% Cotton 8% Modal	Fabrics were bought from fabric store and dyed for testing purposes. Pre-consumer materials.	All red	Reactive dyed. All components dyed in the same pot.	- Visually drastically lightened - Lighter than OAC, reduced chroma in red, reduced chroma in yellow. Drastic loss of colour
5.	Optic Orange 50% Cotton 30% Viscose 20% Modal	Fabrics were bought from fabric store and dyed for testing purposes. Pre-consumer materials.	50% Red 50% Yellow	Reactive dyed. Red components dyed in the same pot.  Yellow components dyed in the same pot.	- Visually hue change noticeable from bright orange to wheat yellow COMMENT: Red colour component from the same pot as in sample 6, thus loss of red parent colour foreseeable. - Lighter than OAC, reduced chroma in red, increased chroma in yellow. OAC was altered drastically in translation
6.	Optic Purple 50% Cotton 30% Viscose 20% Modal	Fabrics were bought from fabric store and dyed for testing purposes. Pre-consumer materials.	50% Red 50% Blue	Reactive dyed. Red components dyed in the same pot.  Blue components dyed in the same pot.	- Visually hue change noticeable from deep purple to cold violet COMMENT: Red colour component from the same pot as in sample 6, thus loss of red parent colour foreseeable. - Lighter than OAC, reduced chroma in red, increased chroma in blue. OAC was altered in translation
7.	Emerald Green 100% Cotton	Industrial cut waste from local knitting factory. Pre-consumer materials.	All green from single source	Presumably reactive dyed	- Visually slight change in lightness and hue noticeable from emerald green to slightly colder green - Darker than OAC, reduced chroma in green, no chroma change in blue OAC was slightly altered in translation - Colour in translation still green, but slightly colder and darker
8.	Peony Pink 50% Cotton 30% Viscose 20% Modal	Fabrics were bought from fabric store and dyed for testing purposes. Pre-consumer materials.	All pink	Vat dyed. All components dyed in the same pot.	- Visually colour slightly brighter than source material - Darker than OAC, increased chroma in red, increased chroma in yellow OAC was slightly altered in translation - Colour in translation still pink, but slightly more intense in chroma
9.	Turquoise 49,18% Cotton 29,51% Viscose 19,67% Modal 1,64% Elastane	Flea market, post-consumer source materials.	All various shades of turquoise	Most components were dyed with presumably reactive dyes	- Visually rather similar to source material - Darker than OAC, increased chroma in green, reduced chroma in blue Successfully translated colour
10.	Mint Green 52,26% Cotton 36,48% Viscose 9,86% Modal 1,39% Elastane	Flea market, mostly post-consumer source materials.	50% All various shades of turquoise 50% All various shades of yellow	Most components were dyed with presumably reactive dyes	- Visually rather similar to source material - Darker than OAC, increased chroma in green, reduced chroma in yellow Successfully translated colour
11.	Light Orange 60% Viscose 32% Cotton 8% Modal	Fabrics were bought from fabric store and dyed for testing purposes. Pre-consumer materials.	50% All various shades of yellow 50% All various shades of peony pink	Yellow components were dyed in the same pot with reactive dyes.  Pink components were dyed in the same pot with vat dyes.	- Visually colour slightly brighter than source material - Darker than OAC, increased chroma in red, reduced chroma in yellow Average optic colour was slightly altered in translation - Colour in translation still orange, but more chromatic in red

## Results

This experiment opened a certain phenomenology associated with the chemical remanufacturing of dyed cellulosic textiles.

- The OAC of ground textiles, while manifesting in optical form as one colour, can alter after dissolution and the colour of the fibres will be different. This can apply to pre- and post-consumer fabrics.
- The OAC of textiles, while manifesting in optical form as one colour, can be preserved rather well after dissolution and the colour of the fibres will be corresponding. This can apply to pre- and post-consumer fabrics. Successful translations can be found among presumably reactive dyed textiles as well as vat dyed textiles.
- It was observed that colour theory can be applied to textiles of two differing colours in order to form fibres of a new colour. This works with both pre- and post-consumer fabrics. The feasibility of this exercise depends on how well the parent colours endure the dissolution process.
- The accurate application of colour theory fails if the parent colour cannot withstand the dissolution process.
- Textiles that were vat dyed in documented circumstances preserved their colour through dissolution very well, even adding slightly to the chroma intensity of the new fibre.
- Denim textiles shifted slightly towards a more green hue.
- A case of reactive dyed textiles altering from their OAC manifestation by exhibiting drastic loss of colour was observed.

In Figure 1 the process of material transformation is shown in three stages: source material textiles, pulp sheets formed from the ground textiles and spun fibres.



**Figure 1: Textile source materials (rectangle pieces), optic pulp sheets of average colour (round pieces), remanufactured fibres in upper part of the picture. (photo Eeva Suorlahti)**

## CONCEPT DEVELOPMENT

### Colour library

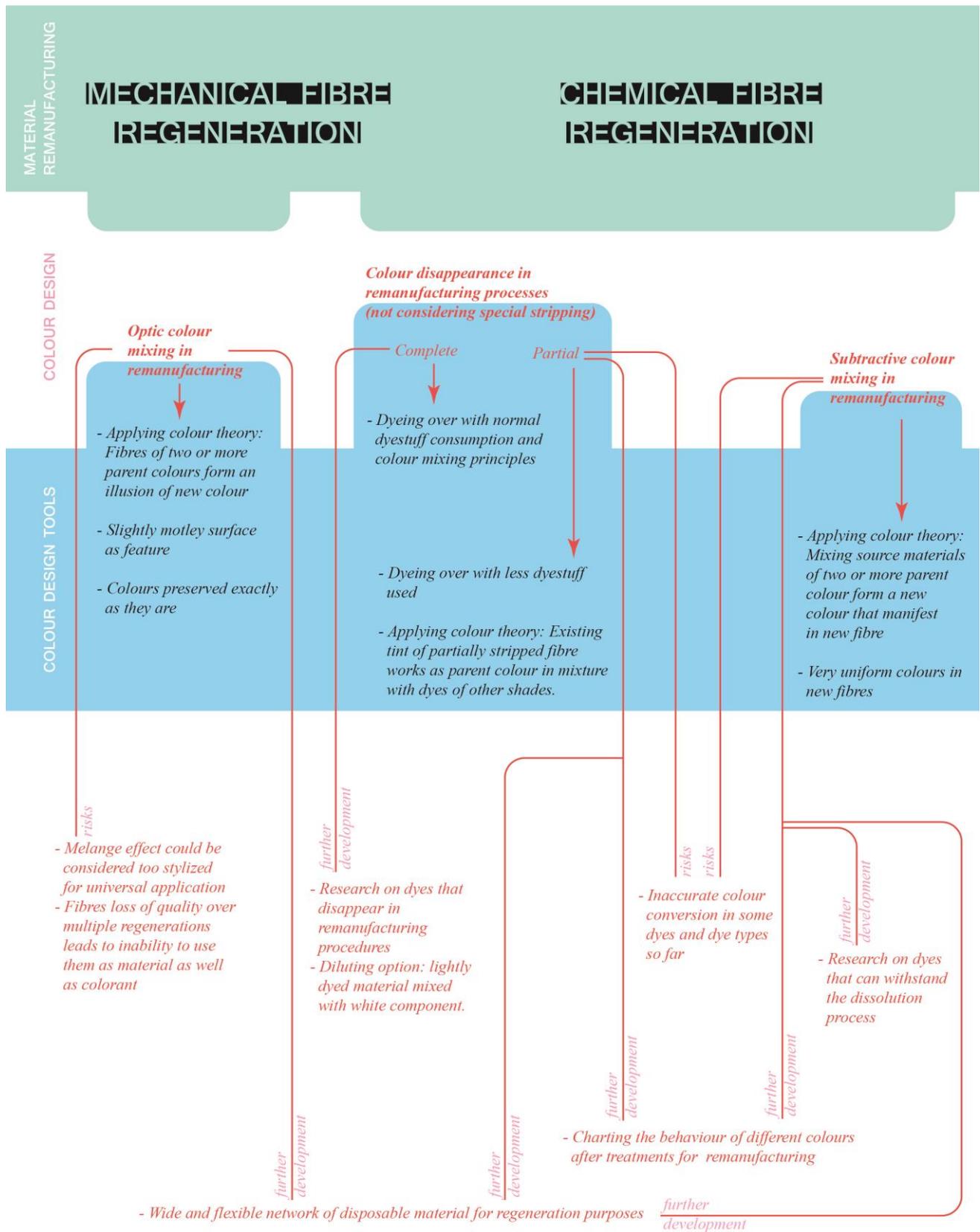
Some important benchmarking for a colour design could be taken from former or current practices, such as mechanical fibre regeneration. According to Prato Textile Museum didactic tables (2016) reclaimed wool was the principal product of Prato's textile industry (Italy) from the mid-19<sup>th</sup> to the mid-20<sup>th</sup> century. It is made from fibres of shredded used textiles and textile industry off-cuts which are subsequently re-spun and rewoven. Selected and sorted rags were delivered to the factory in bales classified according to two criteria: type of fibre and colour or rather the prevalent shade. The rag sorter, a man whose experience and sensitive touch enabled him to classify fibres with amazing accuracy was an important professional figure in that industry. The sorting resulted in creation of piles of rags which are named after their colour: 'aviator' (shades of blue similar to the Air Force uniforms); 'camel' (beige), 'railwayman' (dark grey), 'flag' (bright green) and multicoloured. (ibid.)

As Gulich (2006b) argues raw materials and waste disposal are becoming more and more expensive. When looking for suitable raw materials to make reclaimed fibres, household textile waste as well as industrial waste should receive more attention. Mechanically recycling textiles into fibre that can be spun into a good quality yarn is a more difficult proposition, and rather than using post-consumer waste, the best results come from using clean pre-consumer textile waste of the same colour and fibre type (Payne, 2015). When pre-consumer textile waste is mechanically recycled (e.g. denim offcuts), being of the same fabric allows a yarn to be produced with a consistent staple length and thus of a quality suited to textiles for apparel. However, with clean pre-consumer textile waste, the mechanical recycling process will still result in shorter fibre lengths. For this reason, recycled fibres are frequently blended with virgin fibres for apparel applications (Payne, 2015).

The Finnish clothing company Pure Waste also employs mechanical reclamation technique in its fabrics. The company's production manager explains that in their process the fibres are obtained from cotton cut waste provided by selected sewing factories. A small unevenness in colour is a result when recycled polyester from PET bottles are combined with cotton. The cotton colours of their tricot and sweatshirt fabrics originates directly from the colour of the raw material. Melange grey is mixed from grey cut waste and fibres of differing tones so there is a showcase of forming a new tint by optical mixture of fibres. Pure Waste does have an occasional seasonal colour besides their basics like blue or red, their choice of special colour is mainly dependent on its current popularity and thus on the abundance of raw material (Pesola, personal communication, 23.2.2016).

Both mechanical and chemical methods of fibre reclamation are employed in following concept. Mechanical fibre regeneration provides a good start, since the colours of single fibres could remain as they are with little to no alteration. By combining fibres of two or more colours in one yarn they can optically form totally new colour. In a chemical regeneration process, blended colours could produce fibres of new colour. Managing existing colours as parent colourants for the purpose of creating new colours gives a good space for manoeuvre on the trend-sensitive textile market. The methods and tools considered apt for this concept are presented in Figure 2.

# COLOUR LIBRARY



**Figure 2: Colour design concept: methods and tools**

In a colour design method suitable for mechanical fibre regeneration, a motley, melange surface could be considered as a certain visual hallmark for the method. However, even though an interesting aesthetic, it might be considered somewhat too stylised for universal use, thus limiting the interest of customers to a seasonal basis. Another downside of this method is the fact that the fibres are shortened when subjected to mechanical regeneration and form yarns of lower quality. Thus the fibre and the colour it manifests can be recycled only for a limited number of rounds. In addition, if optical mixing of the material is done, it needs to be considered in further colour design when the colour mixture becomes the parent colour itself. In a chemical regeneration process of cellulosic materials the length of the fibre can be as long as needed, the colour is uniform and various behaviour of dyes could be used to further employ in colour design purposes or production disciplines.

## DISCUSSION

The wide range and uncertainty of dyes and dyeing methods applied to existing textiles worldwide will pose challenges to the colour conversion via the Ioncell-F remanufacturing method. However numerous successful examples of colour translation to the fibre of the second generation demonstrate that colour conversion is possible and with dyes designed for remanufacturing this development could be refined. Development in accuracy of colour translation could create a tool for dyeing professionals to achieve colours demanded by the market. Alternatively, the results of decent but not precisely accurate colour conversion from OAC to the new fibre suggest there could be some increase of tolerance to minor colour shifts in future industry as well as by the future consumer.

Two successful samples show that colour theory works under the condition that both parent colours endure the dissolution process. Thus in the future this could be one of the hands-on tools for colour designers to research new hues by mixing existing disposable textiles. Samples that altered their colour after dissolution represent a wild card tool for designers to use in their search for new colours. Some dyes' inability to withstand the dissolution process could be considered as an alternative for dye stripping. Partial disappearance of colour can contribute to reducing the amount of dyes applied to textiles of remanufactured fibres and thus achieve full coloured fabrics with minimised consumption of dyestuff. Colour design is also relevant in this case since textiles with partially preserved colours could be dyed in the conventional way with other hues.

Earlier described options could be applied to post-consumer textiles as well as pre-consumer textiles such as industrial cut waste or surplus fabrics. This study suggests that disposable cellulosic textiles be brought back into circulation as raw material through colour design, considering them not only as material but also as a colorant thus leading to more careful use of manifesting colour qualities of the existing materials.

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