Tanja Nuša Kočevar, Krste Dimitrovski
Oddelek za tekstilstvo, Naravoslovnotehniška fakulteta, Univerza v Ljubljani

The possibility of creating visually one-coloured fabric simulations from differently coloured yarns

Original Scientific Paper

Received *October 2007* • Accepted *January 2008*

Abstract

*The following lecture presents research in which the possibility of creating a visually one-coloured fabric from a warp and a weft in two different colours was investigated. Colours of warp and weft floating points on a fabric's surface optically mix into a unique colour sensation if they are small and set closely one to another. If the deviation of colour values of warp and weft threads from the origin is approximately the same for both colours with regard to the CIE L*a*b* colour space, the perceived colour of the fabric's surface can theoretically remain constant.*

*Fabric simulations were created using the CAD system Arahne. The warp and the weft colours were the variables which changed throughout the research, while the parameters of fabric construction remained unchanged. The colours of the simulated fabrics were then measured using a spectrophotometer and analyzed. Three initial colours were chosen. In the cases where the first two chosen colours were changed, the shades of the warp and weft did not pass into other quadrants of the CIE L*a*b* colour space, whereas with the third Initial colour, the colour shades produced passed into other quadrants too.*

Vodilni avtor/corresponding author:
dr. Tanja Nuša Kočevar
tel.: +386 1 200 32 49
e-mail: tanja.kocevar@ntf.uni-lj.si

Možnosti ustvarjanja vizualno enobarvnih simulacij tkanin iz različno obarvanih niti

Izvirni znanstveni članek

Poslano *oktober 2007* • Sprejeto *januar 2008*

Izvleček

V članku je predstavljena raziskava možnosti izdelave vizualno enobarvne simulacije tkanine iz različno obarvanih niti osnove in votka, katere barva naj bi bila enaka simulaciji enobarvne tkanine, stkane iz osnove in votka v enaki barvi. Pri opazovanju površine tkanine, na kateri so osnovne in votkovne točke majhne in tesno druga zraven druge, se namreč barve v očesu opazovalca optično mešajo in zlijejo v enoten barvni vtis. S spremembo barv osnove in votka se zaznana barva, torej optična mešanica, spremeni. Ker barva tkanine, ki je rezultat optičnega mešanja, nastane po principu aditivnega mešanja barv, lahko teoretično predvidevamo, da pri enakomerni spremembi barv osnove in votka zaznana barva površine tkanine ostane enaka oziroma le deloma spremenjena. S pomočjo CAD-sistema Arahne smo izdelali simulacije tkanin, narejenih v vezavi platno, ki smo jim spreminjali barve osnovnih in votkovnih niti. Barve osnove in votka smo spreminjali na dva načina. Izbrani konstrukcijski parametri tkanin so pri tem ostali nespremenjeni. Barve simulacij tkanin smo izmerili s spektrofotometrom in analizirali rezultate. Izbrali smo tri izhodiščne barve simulacij tkanin. Dve sta bili izbrani tako, da spremenjene barve osnove in votka niso prehajale v sosednje kvadrante barvnega prostora CIE L*a*b*, pri tretji izbrani izhodiščni barvi pa so spremenjene barvne komponente prehajale tudi v druge kvadrante. Rezultati so pokazali, da lahko v primerjavi s simulacijo enobarvne tkanine, ki je narejena iz enake preje v osnovi in votku, dobimo vizualno enako ali zelo podobno simulacijo enobarvne tkanine iz dveh različnih ustreznih barvnih komponent (osnova in votek), tudi če se skupna barvna razlika med barvo osnove in barvo votka precej poveča.

Ključne besede: barva, tkanina, optično mešanje barv, barvne razlike, simulacije tkanin.

Tekstilec, 2008, letn. 51, št. 1–3, str. 55–73

The results showed that when two noticeably different colours are used for the warp and weft, a visually very constant colour can be produced in the fabric, even when compared with a one-coloured fabric made from a warp and a weft of the same colour.

Key words: Colour, woven fabric, optical colour mixing, colour difference, fabric simulations.

1 Introduction

For the production of one-coloured fabric, warp and weft yarns of the same colour are regularly used. The phenomenon of optical colour mixing, which under the certain observation conditions causes the blending of various colour sensations into one unique colour, allows for the possibility of creating a visually uniform colour on the fabric's surface, although it is made from various colours of warp and weft threads. In the case where two yarn colours are used to weave a visually one-coloured fabric, the colour surfaces on the fabric's face must be very small and close together so that they can optically mix into a uniform colour sensation. The phenomenon of optical colour mixing on the fabric's surface enables the creation of a number of various colours from two or more warp and weft colours. This is frequently used in the creation of multi-coloured jacquard and dobby fabrics. Parameters of fabric construction contribute because they define the size, position and arrangement of colour surfaces on the fabric's face.

Fabric designers are often interested in how to create a desired colour for a fabric's surface from two different colours of warp and weft. It frequently happens that larger amounts of a certain yarn remain after a weaving process. This yarn can also be used for the production of one-coloured fabric if it can be added to a corresponding yarn as a second component using appropriate fabric construction parameters. Additionally, mistakes can happen in the dyeing process of yarns for a warp or a weft, and the incorrectly dyed yarn can be supplemented with an appropriate colour for the other component (warp or weft), and with the phenomenon of optical colour mixing, the mistake can be corrected [1].

1 Uvod

Za izdelavo enobarvne tkanine uporabljamo osnovo in votek v enaki barvi. Pojav optičnega mešanja barv, ki pri določenih pogojih opazovanja povzroči zlitje različnih barvnih vtisov v enotno barvo, pa dopušča možnost ustvarjanja vizualno enobarvne tkanine tudi iz osnovnih in votkovnih niti različnih barv. Če uporabimo pri tkanju dve različno obarvani niti z željo, da dobimo vizualno enobarvno tkanino, morajo biti barvne ploskve na površini tkanine zelo majhne in tesno skupaj, tako da se optično mešajo v eno barvo – v enovit barvni vtis. Optično mešanje barv na površini tkanine omogoča ustvarjanje množice različnih barvnih vtisov iz dveh ali več uporabljenih barv osnove in votka. Uporablja se pri izdelavi barvno pestrih žakarskih tkanin, prav tako pa tudi pri izdelavi listnih tkanin. K temu pripomorejo konstrukcijski parametri, s katerimi določimo dolžino in položaj flotiranja niti na površini tkanine ter na ta način površino in obliko določene barve na površini tkanine.

Oblikovalci tkanin se pogosto znajdejo pred vprašanjem, kako želeno barvo površine tkanine ustvariti iz dveh različnih barv osnove in votka. Pogosto se tudi dogaja, da pri procesu tkanja nastajajo večje količine ostankov različno obarvanih prej, iz katerih lahko z ustreznimi konstrukcijskimi parametri in dodajanjem primerne barvne komponente druge niti dobimo želeno enobarvno tkanino. Kot uporabna pa se kaže tudi možnost odpravljanja napak, do katerih pride pri barvanju preje za osnovo ali votek, in sicer tako, da napačno obarvani preji dodamo drugo prejo ustrezne barve ter s pomočjo optičnega mešanja barv popravimo storjeno barvarsko napako [1].

Cilji raziskave, predstavljene v članku, so bili naslednji:

- ugotoviti, če je mogoče ustvariti vizualno enobarvno tkanino z enako ali zelo podobno barvo, kot jo ima izhodiščna enobarvna tkanina, kljub temu da spremenimo barvi osnove in votka; pri tem je bil naš namen oceniti, kakšna je lahko razlika med barvama osnove in votka, pri kateri še vedno lahko ustvarimo tako barvo vizualno enobarvne tkanine, ki je enaka ali zelo podobna izhodiščni barvi tkanine;
- glede na zgoraj opisani cilj ugotoviti, če je takšno barvo tkanine mogoče doseči, tudi če se barvi osnove in votka spreminjata tako, da prehajata v druge kvadrante prostora CIE L*a*b*, oziroma če gre za veliko spremembo barvnega tona osnove ali votka.

2 Teoretični del

2.1 Barva

Barva je subjektivna čutna zaznava, ki je odvisna od vrste svetlobe, sestave in oblike objekta, ki ga opazujemo, ter od fiziološke in psihološke sposobnosti opazovalca. Zavestna zaznava barve nastane v možganih pod vplivom svetlobe, ki pade na mrežnico očesa. Temeljni dejavniki za nastanek barve so: svetlobni vir, ki oddaja

The aims of this research are as follows:

- *To ascertain the possibility of creation of a visually one-coloured fabric using different colour warp and weft, having the same or very similar colours as a preselected fabric produced from a warp and weft of a single colour. We also hoped to evaluate the magnitude of the difference between the reference colour and the warp and the weft colours that can still be used to create a visually one-coloured woven fabric that is the same or it is very similar to the reference colour.*
- *Regarding the aim mentioned above, we also intended to establish if it is possible to produce visually one-coloured fabric, if the warp and the weft colours change in the way to pass on to the areas of other quadrants of CIE L*a*b* colour space, respectively if hues of the warp and the weft colour differ a lot.*

2 Theory

2.1 Colour

Colour is a subjective perception that depends on light, as well as the shape and composition of an observed object, and on the physiological and psychological capabilities of an observer. A conscious perception of a colour arises in the brain and is influenced by the light that hits the retina. There are three basic elements that influence the perception of colour: the light source, the coloured object – which partly reflects and partly absorbs the light – and the observer, who has the capability to perceive the reflected light. A colour spectrum that reaches the eye can be created with the addition or with the subtraction of light. This characteristic is called aditivity. The process is called additive colour mixing and it means the addition of new light [2].

Colours that originate from the optical mixing of colours are also the result of the process of additive colour mixing. Optical colour mixing is created in our eyes and our brains because of a combination of physiological and psychological effects. When small dots of colour are placed adjacent to each other, the eye will combine the colours into one blended colour.

There are three perceptible colour dimensions that help us to describe the quality of colour. These are lightness, hue and saturation.

svetlobo, obarvan objekt oziroma predmet, ki delno odbije, delno pa absorbira vpadlo svetlobo, in opazovalec, ki ima sposobnost zaznati odbito svetlobo.

Spekter svetlobe, ki pade v oko, lahko nastane z dodajanjem ali pa z odvzemanjem svetlobe. To lastnost imenujemo aditivnost. Dodajanje je mogoče le s prištevanjem nove svetlobe – proces se imenuje aditivno mešanje barv svetlobe [2].

Tudi barve, ki jih dobimo pri optičnem mešanju, nastanejo po zakonitostih aditivnega mešanja. Optično mešanje nastane v očesu ali možganih zaradi fizioloških in psiholoških učinkov. O optičnem mešanju barv govorimo, ko iz dveh ali več barv zaradi slabe ločilne sposobnosti očesa dobimo novo barvo.

Barvi lahko določimo tri zaznavne dimenzije, s katerimi jo tudi najlažje opišemo. Te dimenzije so: svetlost, pestrost in nasičenost.

- Svetlost (lightness) je edina lastnost, s katero ločimo nepestre barve. Definiramo jo kot lastnost vizualnega dojemanja, s katero razlikujemo, koliko (več ali manj) svetlobe oddaja (seva ali odbija) kakšna površina. Svetlost je prav tako ena od lastnosti kromatičnih barv. Nekatere pestre barve so svetlejše od drugih, na primer rumena je svetlejša od rdeče ali modre.
- Barvni ton, pestri ton (hue) je osnovna lastnost pestrih barv. Ta pove, za kakšno barvo gre, in je določena z imenom barve. Pestrost je tudi lastnost, s katero ločimo posamezne dele spektra, in osnovna lastnost, s katero ločimo pestre barve od nepestrih. Definirana je z razporeditvijo barv v barvnem krogu.
- Nasičenost (saturation) barve pove, kako je kakšna barva razredčena s sivo ali belo barvo. Najbolj čiste in nasičene so barvne svetlobe v spektru. Barve, ki jim zmanjšamo nasičenost, so bolj blede, bele ali sive. Popolnoma nenasičene so nepestre barve (bela, sive in črna).

*2.2 Barvni sistem CIE L*a*b* in barvne razlike*

Najbolj izpopolnjen in tudi najpogosteje uporabljen sistem za numerično opredelitev barv je sistem CIE L*a*b*. Ta sistem predstavlja matematično kombinacijo pravokotnega koordinatnega sistema in cilindričnega koordinatnega sistema. Zajema vse dimenzije barve, ki numerično prikažejo barvne vrednosti, na podlagi katerih lahko določimo lego barve v tridimenzionalnem prostoru: [3]

- L* pomeni svetlost barve in zavzema vrednosti od 0 (absolutno črna) do 100 (absolutno bela),
- a* določa lego barve na rdeče-zeleni osi,
- b* določa lego barve na rumeno-modri osi,
- C* predstavlja kromo oziroma delež čiste barvne komponente v neki barvi (C* ≥ 50 – izraziti oziroma čisti barvni toni),
- h pomeni pestrost oziroma razporeditev barv v barvnem krogu (0°–90° – rdeče-rumeno področje, 90°–180° – rumeno-zeleno področje, 180°–270° – zeleno-modro področje, 270°–360° – modro-rdeče področje).

Vsaka barva ima torej določeno mesto v barvnem prostoru; njena lega je določena s pomočjo vrednosti a* in b*, ki predstavlja-

- *Lightness is the only property of a colour that can differentiate achromatic colours. It is defined as a characteristic of visual comprehension that corresponds to how much light is emitted from a surface (radiated or reflected). Lightness is also a characteristic of chromatic colours. Some colours are fundamentally lighter than others, for example yellow is lighter than red or blue.*
- *Hue is the fundamental characteristic of chromatic colours. It is that aspect of a colour described with names. Hue is also the characteristic which distinguishes particular parts of the spectrum and it is the main attribute that distinguishes chromatic colours from achromatic ones. Hue is defined with the arrangement of colours on the colour wheel.*
- *Saturation describes how a colour is diluted with grey or white colour. The purest and most saturated are colour lights in the spectrum. Colours for which saturation is decreased are paler, whiter or greyer. Unsaturated colours are achromatic ones (white, greys and black).*

2.2 CIE L*a*b* Colour system and Colour Differences

*One of the most improved and most frequently used systems for numerical colour evaluation is CIE L*a*b* system. The system represents a mathematical combination of right-angled and cylindrical coordinate systems. It contains all colour dimensions which show colour values numerically. On this basis, it is possible to define the position of a colour in a three-dimensional space: [3]*

- *L* – colour lightness, which takes values from 0 (absolute black) to 100 (absolute white).*
- *a* defines position of a colour on the red – green axis,*
- *b* defines position of a colour on the yellow – blue axis,*
- *C* represents chrome, a part of pure colour component in a colour (C* = 50 – distinctive, pure colour shades),*
- *h – hue, represents the arrangements of colours on the colour wheel (0°–90° – red-yellow area, 90°–180° – yellow-green area, 180°–270° green-blue area, 270°–360° blue-red area).*

ta komponenti v kartezičnem koordinatnem sistemu, ter s kotom h in razdaljo od središča C*, ki sta del cilindričnega sistema. Komponenta, ki govori o svetlosti barve (L*), pa leži v barvnem prostoru pravokotno na osi a* in b*.
Iz številčnih vrednosti a* in b*, ki pripadata določeni barvi, lahko izračunamo barvne vrednosti za kromo (C*), ki predstavlja delež čiste barvne komponente v neki barvi, in barvni oziroma pestri kot (h), ki pomeni razporeditev barv v barvnem krogu.

$$C^* = (a^{*2} + b^*)^{1/2} \quad [1]$$

$$h = \arctan (b^*/a^*): +a^* = 0°; +b^* = 90°; -a^* = 180°; -b^* = 270° \quad [2]$$

Za ocenjevanje barvnih razlik lahko uporabljamo dve metodi, in sicer vizualno ter numerično. Vizualno ocenjevanje zahteva različne, natančno določene pogoje opazovanja, vendar ocene niso objektivne. Objektivno primerjavo dveh obarvanih površin nam omogoča numerično ocenjevanje.
Barvne razlike med dvema vzorcema v prostoru CIE L*a*b* lahko izračunamo iz razlik koordinat v vseh treh smereh barvnega prostora. Celotno barvno razliko pa označimo z ΔE*. [3]

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad [3]$$

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta C^*)^2 + (\Delta H^*)^2]^{1/2} \quad [4]$$

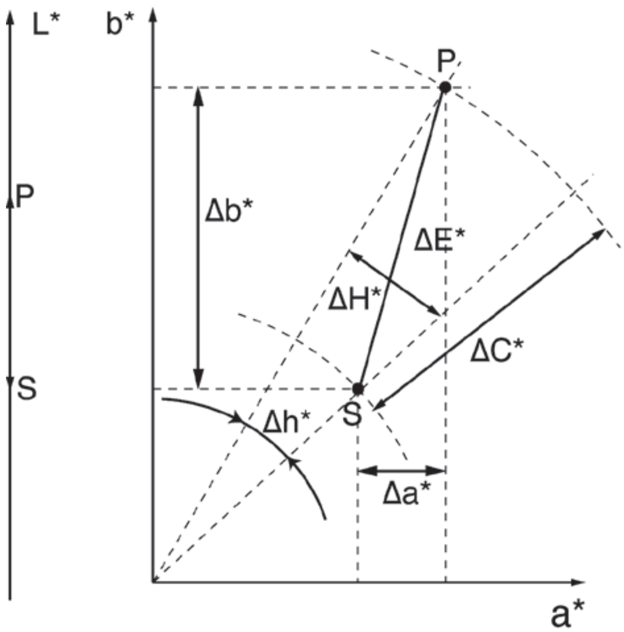

*Figure 1: Colour difference in CIE L*a*b* colour space.*

2.3 Skladnost vezav in barv na tkaninah

Tkanina je rezultat postopka tkanja in jo dobimo s prepletanjem niti, ki potekajo v dveh med seboj pravokotnih smereh, in sicer v

Every colour has a defined place in the colour space. Its position is defined by values a and b*, which represent components in the Cartesian coordinate system, and with an angle h and a distance from the centre C*, which are the part of the cylindrical system. The component L* lies perpendicular to a* and b* axis.*

- *From the numerical values L*, a*, b*, which belong to a certain colour, it is possible to calculate colour values for chrome (C*), which represents a part of a pure colour component in a certain colour and hue (h), which means the arrangement of colours on the colour wheel.*

For evaluation of colour differences, two methods can be used, namely visual and numerical. Visual evaluation should be done under specific conditions; however, it cannot be objective. Objective comparison of two coloured surfaces is possible by numerical evaluation.

*Colour differences between two samples in CIE L*a*b* space can be calculated from differences of coordinates in all three directions of colour space. The whole colour difference is indicated with ΔE* [3].*

2.3 Harmony of weaves and colours on a fabric's surface

The result of a weaving process is that threads interlace as a fabric in two right–angled directions, namely in vertical (warp) and in horizontal (weft). The yarns of a warp and a weft combine to form a plane – woven fabric. There are many different methods of interlacing the threads, which are called weaves.

A weave defines an arrangement of warp and weft interlacing points. Regarding the fabric's colour, every interlacing point consists of three components in the same or various colours. The size and the shape of an interlacing point depend on the fabric's construction parameters.

The most important parameters are:

- *the yarn fineness in warp and weft (tex),*
- *the warp set (number of threads/cm) and weft set (number of threads/cm),*
- *the weave (the pattern of interlacing of warp and weft in a woven fabric).*

The above mentioned constructional parameters influence the perceived colour of the fabric. The yarn fineness has an influence on the

vertikalni (osnova) in horizontalni (votek). Preji osnove in votka se združita v ploskovno tvorbo – tkanino. Poznamo več načinov križanja osnovnih in votkovnih niti, ki jih imenujemo vezave.

Vezava je določena na podlagi razporeditve osnovnih in votkovnih veznih točk. S stališča barve je vsaka vezna točka sestavljena iz treh komponent pravokotnih oblik – enakih ali različnih barv. Velikosti in oblike komponent, ki sestavljajo vezno točko, so odvisne od konstrukcijskih parametrov. Najpomembnejši konstrukcijski parametri tkanine so:

- finost ali titer preje (tex) v osnovi in votku,
- gostota osnovnih niti (g_o – niti/cm) in votkovnih niti (g_v – niti/cm),
- vezava (način prepletanja niti).

Zgoraj navedeni konstrukcijski parametri imajo velik vpliv na barvo tkanine. Od finosti preje je odvisna velikost posameznih barvnih površin, od gostote niti pa je odvisna razdalja med posameznimi barvnimi površinami. Če pri tkanju uporabimo prejo velike finosti ter tkemo z veliko gostoto v osnovi in votku, se barve, ki so na površini tkanine, optično mešajo. Tretji pomemben konstrukcijski parameter je vezava, ki vpliva na barvo površine s količinskim razmerjem barv ter z velikostjo in obliko barvnih površin, ki se pri izbrani vezavi tvorijo na licu tkanine [4].

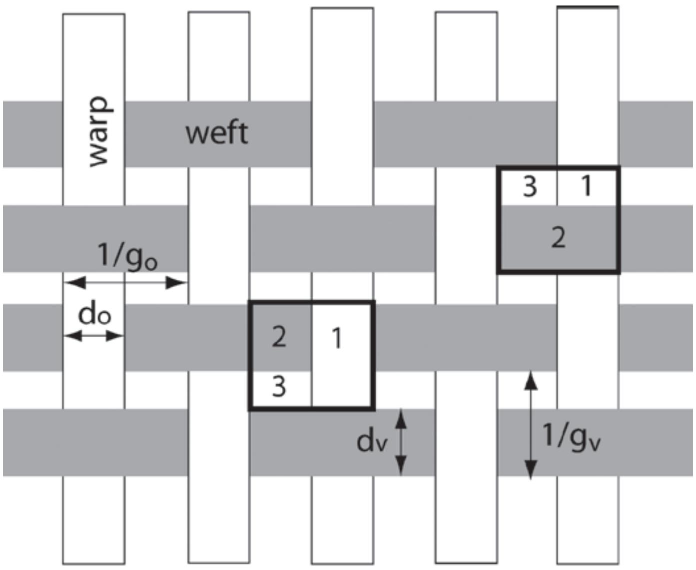

Figure 2: Schematic review of a fabric in plain weave (d_o and d_v – warp and weft diameter, $1/g_v$ – distance from the beginning of one to the beginning of another weft thread, $1/g_o$ - distance from the beginning of one to the beginning of another weft thread).

Barvo vezne točke sestavljajo torej tri barvne komponente, in sicer barva osnovne in votkovne niti ter barva podloge (slika 2). Pri vzorčenju predpostavimo, da je barva osnovne vezne točke enaka barvi preje, iz katere je ta točka, tako da lahko zanemarimo drugi dve komponenti [5]. Poleg konstrukcijskih parametrov na rezultat *size of the individual colour surfaces and the set of a fabric has an influence on the distances between colour surfaces. When a very fine yarn is used for the weaving process and the warp and weft set is high as well, colours on the fabric's surface optically mix together into a new colour sensation. The third important parameter of a fabric's construction is the weave, which influences the colour of the fabric's face by setting the proportion, size and shape of each colour surface that comprises the face of the fabric [4].*

The colour of one interlacing point consists of three colour components: a warp colour, a weft colour and a background colour (figure 2). When designing a woven fabric we presume that a warp interlacing point is the same as a warp colour, therefore other two components can be neglected [5]. Beside the constructional parameters of the fabric, there are other factors that influence the optical colour mixing, such as a distance of an observer from the observed fabric and also the lightning of the fabric's surface.

3 Experiment

In the experiment, the colours of visually single colour fabric simulations made of two colour components were researched. Fabric simulations are visually one-coloured while colour surfaces on the fabric face are so small that at the reading distance (around 30 cm) they optically mix into one-coloured sensation because of the chosen fabric parameters. The initial colour of a fabric is made up of a warp and a weft in the same colour, the rest of the colours are the result of systematic change of warp and weft colour. In this research, the colours of both components gradually and equally changed with the same step size, one from another. The change of fabric colour was evaluated regarding the mutual distance of warp and weft colour in the colour space, in comparison to the initial fabric colour.

3.1 Methods

The experimental work was accomplished using computer simulations of woven fabrics that enabled precise changing of yarn colours and preservation of constant fabric construction parameters. Fabric simulations were printed on

mešanja vplivajo tudi drugi dejavniki, na primer oddaljenost opazovalca od opazovane tkanine in osvetlitev površine tkanine.

3 Eksperimentalni del

V eksperimentalnem delu smo raziskovali barve simulacij vizualno enobarvnih tkanin, narejenih iz osnove in votka v različnih barvah. Simulacije tkanin so vizualno enobarvne, ker so barvne površine na licu tkanine zaradi izbranih parametrov konstrukcije tako majhne, da se pri opazovanju z razdalje branja (okoli 30 cm) optično mešajo v enobarven vtis. Izhodiščna barva tkanine je rezultat prepletanja osnove in votka, ki sta v enaki barvi, druge barve tkanine pa so rezultat sistematičnih sprememb barv osnove in votka. Barve obeh komponent se v raziskavi spreminjajo oziroma se v barvnem prostoru postopno in enakomerno oddaljujejo druga od druge. Pri tem smo ugotavljali spremembo barve tkanine v odvisnosti od medsebojne oddaljenosti barv osnove in votka v barvnem prostoru glede na izhodiščno barvo.

3.1 Materiali in metode dela

Eksperimentalno delo smo izvedli s pomočjo računalniških simulacij tkanin, kar nam je omogočilo natančno spreminjanje barve in ohranjanje enakih parametrov konstrukcije tkanin. Izdelane simulacije smo natisnili na bel papir in barvo dobljenih natisov izmerili s spektrofotometrom. Za izdelavo simulacij tkanin smo uporabili CAD-sistem Arah podjetja Arahne, d. o. o., oziroma integrirani program ArahWeave, ki je namenjen za načrtovanje listnih in žakarskih tkanin.

Konstrukcijski parametri tkanin, katerih barve smo analizirali, so naslednji:

- finost preje v osnovi in votku je 25 tex,
- gostota osnovnih niti (g_o) in votkovnih niti (g_v) je 30 niti/cm,
- vezava platno.

Po pričakovanjih so se pri izbranih konstrukcijskih parametrih tkanin barve osnove in votka optično mešale v vizualno enobarvno tkanino.

Izdelane simulacije tkanin smo natisnili s kapljičnim tiskalnikom Epson Stylus Photo 870. Tiskalnik poleg štirih običajnih uporablja še dve dodatni barvi, in sicer svetlo cian in svetlo magenta barvo (CcMmYK), ki povečata barvni prostor tiskalnika. Tiskalnik, ki smo ga uporabljali za natis, tiska z ločljivostjo 720 dpi (pik na palec). Natis smo naredili na bel, gladek, premazan papir.

Nato smo izmerili CIE L*a*b*-vrednosti natisnjenih simulacij osnovnih in votkovnih niti ter tkanin, in sicer s spektrofotometrom Eye-One podjetja Gretag Macbeth. Pogoji merjenja s spektrofotometrom so bili naslednji:

- kot merjenja 2°,
- geometrija merjenja 45/0,
- standardizirana dnevna svetloba D65,
- vrednosti merjenja: L*, a*, b* ter C* in h.

white paper and the colour of the prints were measured with a photo spectrometer. The simulations were performed using an Arah CAD system and the integrated programme Arah Weave, which is intended for design and creation of dobby and jacquard fabrics.

The constructional parameters of the fabrics, whose colours were analyzed are as follows:

- *fineness of yarns in the warp and in the weft: 25 tex,*
- *warp and weft set: 30 yarns/cm,*
- *plain weave.*

As was anticipated, at the chosen constructional parameters of the fabrics, colours of the warp and the weft optically mixed into visually one colour.

The designed fabric simulations were printed with an Epson Stylus Photo 870 ink-jet printer. Besides the four usual printing colours, the printer uses two additional colours, light cyan and light magenta (CcMmYK), which increase the printer's colour space. The simulations were printed on white, smooth coated ink jet paper with a resolution of 720 dpi.

*CIE L*a*b* values of printed simulations of warp and weft yarns and fabrics were measured using Gretag Macbeth's Eye–One spectrophotometer.*

The measuring conditions were the following:

- *observer: 2°,*
- *measuring geometry 45/0,*
- *standard light source D65,*
- *measured values: CIE L*, a*, b*, C* and h.*

The printed simulations were measured on a black background and every sample was measured three times.

The yarn colours were the variables on which the experimental work was based. Values a and b* of the warp and the weft colours were changed throughout the research. The same CIE L*a*b* values were allocated in the CAD system to the initial colours which were named "1" for the warp and "a" for the weft colours. The a* and the b* values for the warp and the weft colours which follow, were changed in the two manners which are shown in figure 3 (L* value is constant for all colours).*

Method 1

Changing of warp colour:

a→ +a* (increasing of value a*)*

Na papir natisnjeno simulacijo tkanine smo položili na črno podlago, za vsak merjeni vzorec smo izvedli tri meritve.

Barva niti je bila spremenljivka, na kateri je temeljilo naše eksperimentalno delo. Barvam osnovnih in votkovnih niti smo spreminjali vrednosti a* in b*. Izbrana izhodiščna barva simulacije tkanine pomeni barvo „1" osnove in barvo „a" votka. V CAD-programu smo torej izhodiščni barvi osnove in izhodiščni barvi votka dodelili enake L*a*b*-vrednosti. Vrednosti a* in b*, ki so sledile, smo spreminjali na naslednja dva načina, ki sta prikazana na sliki 3 (L* je v vseh primerih konstantna vrednost):

– 1. način

Spreminjanje barve osnove: a* → +a* (večanje vrednosti a*)
b* → –b* (zmanjševanje vrednosti b*)

Spreminjanje barve votka: a* → –a* (zmanjševanje vrednosti a*)
b* → +b* (večanje vrednosti b*)

– 2. način

Spreminjanje barve osnove: a* → +a* (večanje vrednosti a*)
b* → konstantna vrednost

Spreminjanje barve votka: a* → –a* (zmanjševanje vrednosti a*)
b* → konstantna vrednost

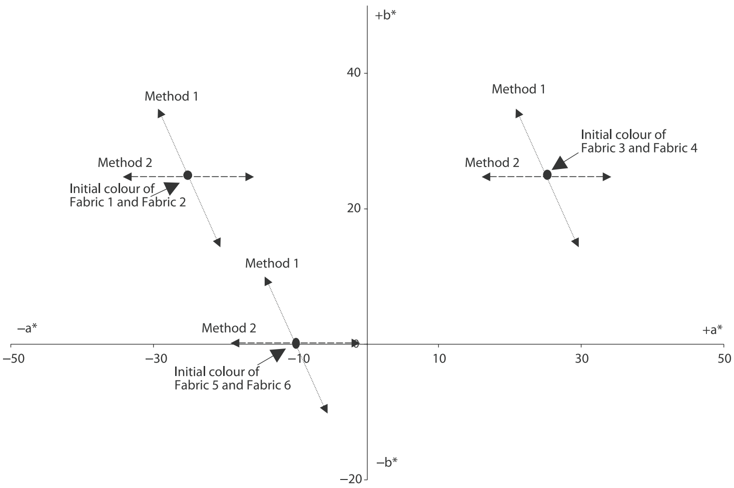

*Figure 3: Schematic review of both methods of research and of three initial colours in the CIE a*b* diagram.*

Barvne vrednosti osnove in votka smo spreminjali s konstantno vrednostjo koraka, ki je znašal 3 in je določal spremembo vrednosti a* in b*. Pri izdelavi simulacije tkanine smo definirali tudi barvo podlage, ki je prav tako pomemben parameter, saj ima velik vpliv na izmerjene vrednosti barv tkanine [1]. Podlagi simulirane tkanine smo določili enake vrednosti L*, a* in b* kot izhodiščni barvi osnove in votka. Za analizo barv smo izdelali simulacijo tkanine, pri kateri smo v določenem zaporedju spreminjali barvo osnove in barvo votka. V vzorcu snovanja in tkanja je 6 oziroma 12 različnih barv osnove in 6 oziroma 12 različnih barv votka, pri čemer sta prva barva osnove in prva barva votka enaki. Na ta način je na površini tkanine na-

b→ –b* (decreasing of value b*)*
Changing of weft colour:
a→ –a* (decreasing of value a*)*
b→ +b* (increasing of value b*)*
– *Method 2*
Changing of warp colour:
a→ +a* (increasing of value a*)*
b→ constant value*
Changing of weft colour:
a→ –a* (decreasing of value a*)*
b→ constant value*

Colour values of the warp and the weft were changed by a constant step value of three, which defines the change in the values of a and b*.*

The colour of the simulation background was also defined, and it had a big influence on the measured values of fabric colours [1]. The background colours of the fabric simulations have the same L, a* and b* values as initial colours of warp and weft.*

For the colour analysis, a fabric simulation was carried out, which had warp and weft colours as shown in figure 3. In the weave pattern, there are six colours, in two fabrics 12, different colours of the warp and the weft, and the first colour of the warp and the weft are equal. In such a manner there are 36 (in two fabrics 144) squares on the fabric's face in various colours. The manner of the fabric simulation construction, where 6 various colours of warp and weft are used is shown in figure 4.

The warp colours are indicated by numbers (1, 2, 3, 4, 5, 6, and for Fabrics 5 and 6 also 7, 8, 9, 10, 11 and 12) and for the weft colours, small letters are used (a, b, c, d, e, f, and for Fabrics 5 and 6 also g, h, i, j, k, and l). The squares on the fabrics are denoted by which warp and which weft colour they are made from. Warp colour "1" and weft colour "a" are identical or very similar; therefore square "1a" is a one-coloured fabric, which is in the analysis described as the reference square or the reference colour.

*For the analysis of the results, the colours of squares which are on the diagonal of the fabric were observed (1a, 2b, 3c, 4d, 5e, 6f and for Fabrics 5 and 6 also 7g, 8h, 9i, 10j, 11l). The squares which are on the fabric's diagonal have warp and weft colour which are approximately equally distant from the initial colour in the a*b* diagram.*

stalo 36 oziroma 144 kvadratnih polj različnih barv. Na sliki 4 je prikazan način izdelave tkanine, pri katerem je uporabljenih 6 različnih barv osnove in votka. Za označevanje barv osnove smo uporabili številke (1, 2, 3, 4, 5, 6, pri Tkanini 5 in Tkanini 6 pa tudi 7, 8, 9, 10, 11 in 12), za označevanje barv votka pa male črke (a, b, c, d, e, f, pri Tkanini 5 in Tkanini 6 pa tudi g, h, i, j, k, l). Polja tkanine so označena s številko in črko – glede na to, iz katere barve osnove in katere barve votka so narejena. Barva osnove „1“ in barva votka „a“ sta enaki oziroma zelo podobni, zato je polje „1a“ enobarvna tkanina, ki je v analizi predstavljena kot referenčno polje – referenčna barva.

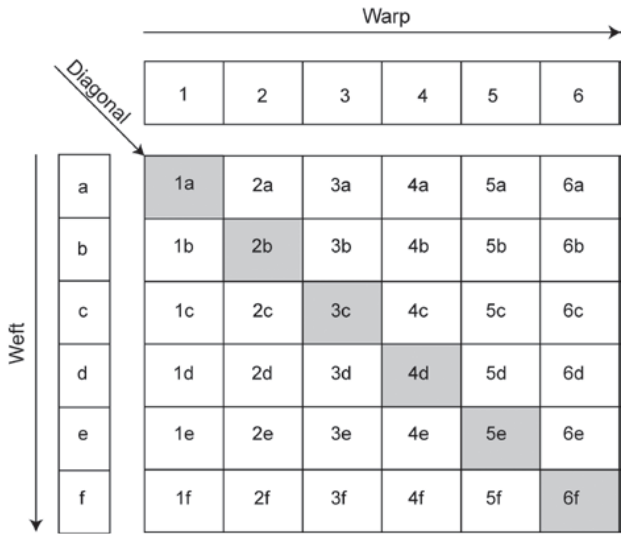

Figure 4: The scheme of a printed fabric's simulation with the review of signs for the warp, the weft and the indicated squares on the fabric's diagonal.

Pri analizi rezultatov smo opazovali barvne vrednosti polj na diagonali tkanine (1a, 2b, 3c, 4d, 5e, 6f, pri Tkanini 5 in Tkanini 6 pa tudi 7g, 8h, 9i, 10j, 11k, 12l). Kvadratki, ki ležijo na diagonali tkanine, imajo namreč barvo osnovne in barvo votkovne niti v a*b*-diagramu približno enako oddaljeni od izhodiščne barve.

3.2 Rezultati in razprava

Izbrali smo tri izhodiščne barve, ki smo jih spreminjali po prej opisanih načinih. Pri prvi in drugi barvi so položaji spremenjenih barv ostali v osnovnem kvadrantu CIE L*a*b*-prostora, in sicer pri prvi barvi v 2. kvadrantu (Tkanina 1, Tkanina 2) ter pri drugi barvi v 3. kvadrantu (Tkanina 3 in Tkanina 4). Tretjo barvo pa smo izbrali tako, da so spremenjene barvne komponente prehajale tudi v območja drugih kvadrantov CIE L*a*b*-prostora: pri Tkanini 5 iz drugega v tretji in v četrti kvadrant ter pri Tkanini 6 iz drugega v tretji in v prvi kvadrant. Pri obeh načinih smo v CAD-sistemu med barvo osnove in barvo votka večali razliko v nasičenosti in v barvnem tonu, svetlosti barv pa so ostale nespremenjene

3.2 The results and their analysis

*Three initial colours were chosen, and they were changed using the methods described above. For the first and the second colour, the positions of changed colours remained in the initial quadrant of CIE L*a*b* space, namely first colour in the 2nd quadrant (Fabric 1, Fabric 2) and second colour in the 3rd quadrant (Fabric 3 and Fabric 4). The third colour was chosen in such a manner that changed colour components also pass on to the areas of other quadrants of CIE L*a*b* space: for Fabric 5 from the second on to the third and to the fourth quadrant and at Fabric 6 from the second quadrant on to the third and the first quadrant. For both methods, the difference between warp and weft colours was increased in saturation and in hue values in the CAD system, lightness of colours remained unchanged (the results of measured colours of fabric simulations show that the colour values of the printed simulations differ a little, in which can be seen in the tables). While the colour values of printed colours deviate slightly from values defined in the programme, only the measured colour values were used for the analysis.*

*The colour difference between the initial colour of the fabric and the colour of the fabric that is created from warp and weft colours that are approximately equidistant from the initial colour in the CIE L*a*b* space was investigated. In all cases the colour of the fabric was in between the warp and weft colours on a virtual straight line that runs through all three colours. Results of the measured colours and the calcu-*

(pri merjenju barv simulacij tkanin smo ugotovili, da so se te pri tisku minimalno spreminjale, kar je razvidno iz podatkov v tabelah). Ker se vrednosti natisnjenih barv nekoliko razlikujejo od vrednosti barv, določenih v programu, smo za analizo uporabili le izmerjene vrednosti barv.

Ugotavljali smo skupno barvno razliko med izhodiščno barvo tkanine in barvo tkanine, ki je narejena iz osnove in votka, katerih barvi sta v CIE L*a*b*-prostoru približno enako oddaljeni od izhodiščne barve. V vseh primerih pa barva tkanine na navidezni premici, ki poteka skozi barvni komponenti, leži med komponentama. Rezultati meritev barv in izračunov skupnih barvnih razlik so prikazani v tabelah in na grafih.

Razlike smo ocenjevali tudi vizualno. Zanimalo nas je, pri kateri barvi oziroma pri katerem polju diagonale tkanine je razlika med to barvo in izhodiščno barvo vizualno opazna.

3.2.1 Tkanina 1 in Tkanina 2

Izhodiščna barva je zelena. Pri Tkanini 1 smo spreminjali barvo osnovnih in votkovnih niti po 1. načinu. Barvi osnovnih niti se je nasičenost manjšala, barva votkovnih niti pa je postajala vedno bolj nasičena. Med barvama „6“ in „f“ je nastala dokajšnja razlika v nasičenosti, in sicer $\Delta C^*_{6-f} = 23{,}56$. Sprememba kota barvnega tona med barvama je majhna in znaša $\Delta h_{6-f} = 3{,}76$.

Rezultati so pokazali, da se zadnja barva diagonale „6f“ od izhodiščne referenčne barve „1a“ najbolj razlikuje ($\Delta E^*_{1a-6f} = 2{,}70$), kar lahko vidimo na sliki 5. Sprememba barve, ki nastane med omenjenima barvama, je relativno majhna, če jo primerjamo z razliko med „1“ in „a“ ($\Delta E^*_{1-a} = 4{,}44$) ter med „6“ in „f“ ($\Delta E^*_{6-f} = 23{,}73$). Med navedenima barvama „1a“ in „6f“ je največja sprememba v kotu barvnega tona ($\Delta h_{1a-6f} = 2{,}5$) in prav tako tudi največja razlika v nasičenosti ($\Delta C^*_{1a-6f} = 1{,}6$). Barva diagonale postaja zaradi večjega vpliva votkovnih niti bolj nasičena zelena. Sprememba nasičenosti je pri barvi votka namreč večja ($\Delta C^*_{a-f} = 14{,}75$) kot pri barvi osnove, ki počasneje prehaja v manj nasičeno zeleno barvo ($\Delta C^*_{1-6} = 13{,}03$).

Table 1: Values L, C*, h of warp and weft colours of Fabric 1 and colour differences ΔE* between individual colours.*

	Warp						Weft					
	1	2	3	4	5	6	a	b	c	d	e	f
L*	52.88	54.28	54.86	55.07	55.39	55.81	53.28	52.98	53.60	54.01	54.23	54.54
C*	42.37	39.32	37.29	34.89	32.18	29.34	38.15	42.64	44.93	47.78	50.81	52.90
h	138.66	137.00	137.29	137.50	136.70	134.70	136.87	137.06	137.28	138.07	138.75	138.46
	Difference between warp colours						Difference between weft colours					
	2–1	3–2	4–3	5–4	6–5	6–1	b–a	c–b	d–c	e–d	f–e	f–a
ΔE*	3.57	2.10	2.42	2.77	3.05	13.57	4.53	2.37	2.96	3.09	2.13	14.88

lated colour differences are shown in the tables and in the figures.

Differences were also estimated visually to evaluate at which square the colour difference is already visually noticeable.

3.2.1 Fabric 1 and Fabric 2

The initial colour is green. For Fabric 1 the colours of the warp and weft yarns were changed using Method 1. The colour of the warp gradually became less saturated and the weft colour became more saturated. Thus there was a considerable difference between colours "6" and "f" ($\Delta C^*_{6\text{-}f}$ = 23.56). The change of the hue angle between the two colours is small and it amounts to $\Delta h_{6\text{-}f}$ = 3.76.

The results show that the last colour of the diagonal "6f" differs the most from the reference colour "1a" ($\Delta E^*_{1a\text{-}6f}$ = 2.70), which is also shown on the figure 5. The colour change that originates between the two mentioned colours is relatively small, compared to the difference between "1" and "a" ($\Delta E^*_{1\text{-}a}$ = 4.44) and between "6" and "f" ($\Delta E^*_{6\text{-}f}$ = 23.73). The biggest change in the hue angle is found between the two colours "1a" and "6f" ($\Delta h_{1a\text{-}6f}$ = 2.5) as well as the biggest difference in saturation ($\Delta C^*_{1a\text{-}6f}$ = 1.6). The colour of the diagonal became more saturated green because of the bigger influence of the warp colour. The change of the weft colour saturation is bigger ($\Delta C^*_{a\text{-}f}$ = 14.75) in comparison with the change of warp colour saturation ($\Delta C^*_{1\text{-}6}$ = 13.03).

For Fabric 2, the colours of warp and weft were changed using Method 2. The difference in the saturation between the last warp colour "6" and the last weft colour "f" is $\Delta C^*_{6\text{-}f}$ =14.37. The hue angle between the two colours is big, compared with the saturation difference, and amounts to $\Delta h_{6\text{-}f}$ = 21.34.

The biggest common colour difference on the fabric's diagonal is between the reference colour, "1a" and the last colour on the diagonal "6f" ($\Delta E^*_{1a\text{-}6f}$ = 1.86). This colour change is small compared with the colour difference between "1" and "a" ($\Delta E^*_{1\text{-}a}$ = 3.78) and between "6" and "f" ($\Delta E^*_{6\text{-}f}$ = 20.48). Although the biggest colour difference is between the last and the reference colour of the diagonal, what is also shown on the figure 6, the biggest saturation

Table 2: Values L, C*, h of colours that are on the diagonal of Fabric 1 and colour differences ΔE* between warp and weft colours and between colours on the diagonal.*

	Diagonal					
	1a	2b	3c	4d	5e	6f
L*	54.27	54.91	55.72	55.79	56.27	55.60
C*	38.66	39.47	39.12	39.71	39.45	40.26
h	135.40	136.37	135.90	136.83	135.60	137.90
	Difference between warp colour and weft colour					
	1–a	2–b	3–c	4–d	5–e	6–f
ΔE*	4.44	3.57	7.73	12.93	18.73	23.73
	Difference between colours on the fabric's diagonal					
	–	2b–1a	3c–1a	4d–1a	5e–1a	6f–1a
ΔE*	–	1.22	1.56	2.09	2.15	2.70

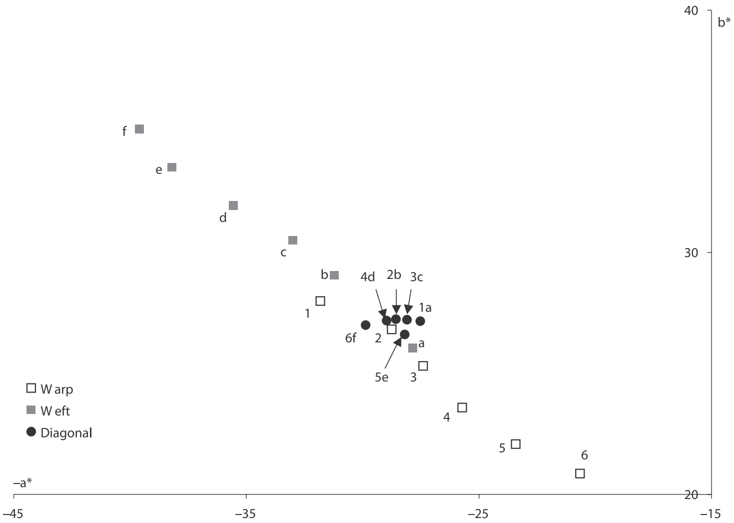

Figure 5: The review of colour values of Fabric 1

Pri Tkanini 2 smo spreminjali barvo osnovnih in votkovnih niti po 2. načinu. Razlika v nasičenosti med barvama „6" in „f" je $\Delta C^*_{6\text{–}f}$ = 14,37. Sprememba kota barvnega tona, ki je nastala med tema barvama, je v primerjavi s spremembo nasičenosti zelo velika, in sicer znaša $\Delta h_{6\text{–}f}$ = 21,34.

Največja skupna razlika v barvi je na diagonali tkanine med referenčno barvo „1a" in barvo zadnjega polja diagonale „6f" ($\Delta E^*_{1a\text{–}6f}$ = 1,86). Ta sprememba je majhna, če jo primerjamo s spremembo barve med „1" in „a" ($\Delta E^*_{1\text{–}a}$ = 3,78) ter med „6" in „f" ($\Delta E^*_{6\text{–}f}$ = 20,48). Čeprav se je po analizi barv diagonalnih polj tkanine zadnja barva najbolj razlikovala od referenčne barve, kar je razvidno tudi s slike 6, smo dobili največjo razliko nasičenosti med prvo in

Table 3: Values L, C*, h, of warp and weft colours of Fabric 2 and colour differences ΔE* between individual colours.*

	Warp						Weft					
	1	2	3	4	5	6	a	b	c	d	e	f
L*	52.81	53.28	53.58	54.26	54.31	54.43	53.84	53.56	53.61	53.18	52.92	52.20
C*	38.80	37.96	36.67	35.67	34.14	32.39	37.01	39.12	40.77	43.69	50.81	52.90
h	141.85	140.31	137.42	134.29	130.43	127.84	137.07	140.55	142.34	145.05	138.75	138.46
	Difference between warp colours						Difference between weft colours					
	2–1	3–2	4–3	5–4	6–5	6–1	b–a	c–b	d–c	e–d	f–e	f–a
ΔE*	1.41	2.29	2.32	2.80	2.31	10.88	3.14	2.07	3.56	2.13	2.49	13.23

difference is between the first and the fifth colour (ΔC^*_{1a-5e} = 0.87). The biggest change of hue angle is between the first and the last colour on the diagonal (Δh_{1a-6f} = 2.51). The colour of the diagonal becomes more saturated green, while the change of the weft colour saturation is bigger (ΔC^*_{f-a} = 9.75) than the change of the warp colour saturation (ΔC^*_{6-1} = 6.41).

3.2.2 Fabric 3 and Fabric 4

The initial colour is orange. For Fabric 3, colours of warp and weft were changed using Method 1. The warp colour thus proceeds from orange to reddish colour and weft colour proceeds from orange to yellowish. The difference in colour saturation between the last warp and the last weft is small ΔC^*_{6-f} = 0.7. The change of a hue angle between the two colours is large, compared with the change of saturation (Δh_{6-f} = 38.51).

The analysis of colours on the fabric's diagonal indicates that the colour difference between the reference colour "1a" and first four colours is small, as can be seen in figure 7. The last colour of the diagonal "6f" differs more from the reference colour. The common colour difference between them is ΔE^*_{1a-6f} = 3.55, what is also visually noticeable. The colour difference is relatively small, regarding the colour change between "1" and "a" (ΔE^*_{1-a} = 4.26) and between "6" in "f" (ΔE^*_{6-f} = 27.95). Among all the fabrics, where the changed colours of warp and weft don't pass on to the other quadrants, in Fabric 3, there is a biggest colour difference between the last colour of the warp "6" and last colour of the weft "f".

Table 4: Values L, C*, h of colours that are on the diagonal of Fabric 2 and colour differences ΔE* between warp and weft colours and between colours on the diagonal.*

	Diagonal					
	1a	2b	3c	4d	5e	6f
L*	55.24	55.07	55.19	54.56	55.55	54.55
C*	37.47	37.80	38.27	37.42	38.34	38.01
h	136.98	137.30	136.96	138.94	137.08	139.49
	Difference between warp colour and weft colour					
	1–a	2–b	3–c	4–d	5–e	6–f
ΔE*	3.78	1.20	5.27	10.96	15.83	20.48
	Difference between colours on the fabric's diagonal					
	–	2b–1a	3c–1a	4d–1a	5e–1a	6f–1a
ΔE*	–	0.43	0.80	1.44	0.94	1.86

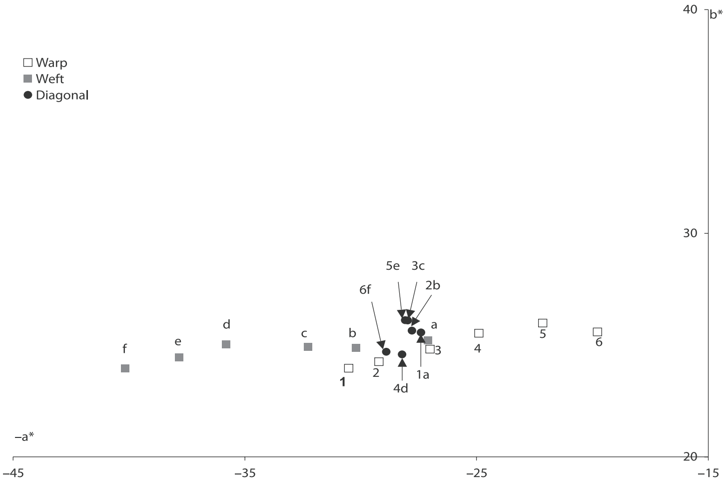

Figure 6: The review of colour values of Fabric 2.

The colour "6f" differs the most from the reference colour, regarding colour saturation (ΔC^*_{1a-6f} = 3.47), the biggest change of hue angle is between the reference and the fifth colour of the diagonal "5e" and is Δh_{1a-5e} = 1.17.
In Fabric 4, warp and weft colours were changed using Method 2. The colour moves from a less saturated orange to a more saturated red area of the colour space. The colour of the weft changes from orange to less saturated yellow. The difference in the saturation between the last warp colour and the last weft colour is ΔC^*_{6-f} = 15.67. Change in the hue angle between the two colours is big (Δh_{6-f}= 25.96) in comparison with the saturation difference.

peto barvo (ΔC^*_{1a-5e} = 0,87), največjo spremembo kota barvnega tona pa smo dobili med prvo in zadnjo barvo (Δh_{1a-6f} = 2,51). Barva diagonale postaja bolj nasičena zelena, saj je sprememba nasičenosti barve votka večja (ΔC^*_{a-f} = 9,75) kot pri osnovi (ΔC^*_{1-6} = 6,41).

3.2.2 Tkanina 3 in Tkanina 4

Izhodiščna barva je oranžna. Tkanini 3 smo spreminjali barvo osnovnih in votkovnih niti po 1. načinu. Barva osnove tako prehaja iz oranžne v rdečkasto barvo. Barva votkovnih niti prehaja iz oranžne v rumenkasto barvo. Razlika v nasičenosti barve med zadnjo osnovno nitjo in zadnjo votkovno nitjo je majhna, ΔC^*_{6-f} = 0,7. Sprememba kota barvnega tona, ki je nastala med omenjenima barvama, pa je v primerjavi s spremembo nasičenosti precej velika, in sicer Δh_{6-f} = 38,51.

Table 5: Values L, C*, h, of warp and weft colours of Fabric 3 and colour differences ΔE* between individual colours.*

	Warp						Weft					
	1	2	3	4	5	6	a	b	c	d	e	f
L*	55.81	55.56	55.62	55.11	55.81	55.53	55.51	55.44	54.75	55.35	56.40	56.64
C*	41.85	40.92	41.76	41.52	41.17	41.97	41.22	40.73	41.67	41.99	42.79	42.67
h	54.51	49.76	45.72	41.54	38.76	32.65	48.71	53.82	58.56	62.71	67.49	71.16
	Difference between warp colours						Difference between weft colours					
	2–1	3–2	4–3	5–4	6–5	6–1	b–a	c–b	d–c	e–d	f–e	f–a
ΔE*	3.56	3.03	3.05	2.04	4.50	15.90	3.69	3.54	3.04	3.63	2.74	16.40

Analysis of the colours on the diagonal of Fabric 4 established that the biggest colour difference is between the reference colour and the last colour of the diagonal. The common colour difference between colours "1a" and "6f" is ΔE^*_{1a-6f} = 3.05 and it is relatively small compared with the difference between "1" and "a" (ΔE^*_{1-a} = 2.68) and between "6" and "f" (ΔE^*_{6-f} = 23.56). The colour difference between the reference and the last colour is visually noticeable. Between these two colours we also find the biggest difference in colour saturation (ΔC^*_{1a-6f} = 1.80) and the biggest change in hue angle (Δh_{1a-6f} = 2.36). Colour changes on the fabric's diagonal are also evident in figure 8.

3.2.3 Fabric 5 and Fabric 6

In Fabric 5 and Fabric 6, the position of the initial colour is moved to the a axis, therefore the*

Table 6: Values L, C*, h of colours that are on the diagonal of Fabric 3 and colour differences ΔE* between warp and weft colours and between colours on the diagonal.*

	Diagonal					
	1a	2b	3c	4d	5e	6f
L*	56.46	56.94	56.20	56.51	57.21	56.31
C*	40.43	40.92	40.84	40.36	40.64	36.96
h	49.72	49.19	49.80	50.48	50.89	48.63
	Difference between warp colour and weft colour					
	1–a	2–b	3–c	4–d	5–e	6–f
ΔE*	4.26	2.91	9.37	15.34	20.91	27.95
	Difference between colours on the fabric's diagonal					
	–	2b–1a	3c–1a	4d–1a	5e–1a	6f–1a
ΔE*	–	0.78	0.49	0.53	1.14	3.55

*changed colour components pass on to other quadrants of CIE L*a*b* colour space. The chosen initial colour is unsaturated green with following values: L* = 60, a* = –10, b* = 0. Besides that colours of the warp and of the weft are changed in the way that they pass on to other quadrants, in these fabrics we included 12 changes of the warp colour and 12 changes of the weft colour.*

*For the Fabric 5, the colours of the warp and the weft were changed using Method 1. The warp colours proceed through three quadrants of CIE L*a*b* colour space, namely from the second to the third and to the fourth quadrant, as shown in figure 9. The warp colour becomes blue-violet, and the weft colour becomes more saturated green and remains in the initial, second quadrant of CIE L*a*b* colour space. The difference in colour saturation between the last warp colour and the last weft colour is* $\Delta C^*_{12\text{–}l}$ *= 34.73. The change of the hue angle between the two colours is relatively big compared with the change of colour saturation (*$\Delta_{12\text{–}l}$*= 142.33).*

The biggest common colour difference is between the initial colour "1a" and the last colour of the diagonal "12l" ($\Delta E^*_{1a\text{–}12l}$ *= 6.99). Between the two mentioned colours is also the biggest difference in hue angle (*$\Delta h_{1a\text{–}12l}$ *= 10.39) and the difference in colour saturation (*$\Delta C^*_{1a\text{–}12l}$ *= 6.46). Colour difference between the initial colour and the last colour on the diagonal is relatively small in comparison with the difference between colours "1" and "a" (*$\Delta E^*_{1\text{–}a}$ *= 11.07) and colours "12" and "l" (*$\Delta E^*_{12\text{–}l}$ *= 57.89). Differences between the reference col-*

Pri analizi barv diagonalnih polj tkanine smo ugotovili, da se prve štiri barve od izhodiščne oziroma referenčne barve „1a" zelo malo razlikujejo. To je vidno tudi na sliki 7. Zadnja barva diagonale „6f" pa se od referenčne barve že precej razlikuje, in sicer znaša skupna barvna razlika med njima $\Delta E^*_{1a\text{–}6f}$ = 3,55. Razlika je tudi vizualno precej opazna. V primerjavi s spremembo barve med „1" in „a" ($\Delta E^*_{1\text{–}a}$ = 4,26) ter med „6" in „f" ($\Delta E^*_{6\text{–}f}$ = 27,95) pa je relativno majhna. Pri tej tkanini je med vsemi tistimi tkaninami, pri katerih spremenjena barva osnove in votka ne prehaja v druge kvadrante, nastala tudi največja barvna razlika med zadnjo barvo osnove „6" in zadnjo barvo votka „f".

Barva polja tkanine „6f" se od referenčne barve najbolj razlikuje po nasičenosti ($\Delta C^*_{1a\text{–}6f}$ = 3,47), največja sprememba kota barvnega tona pa je nastala med referenčno in peto barvo diagonale „5e" in znaša $\Delta h_{1a\text{–}5e}$ = 1,17.

Tkanini 4 smo spreminjali barvo osnovnih in votkovnih niti po 2. načinu. Barva osnovnih niti prehaja iz manj nasičenega oranžne-

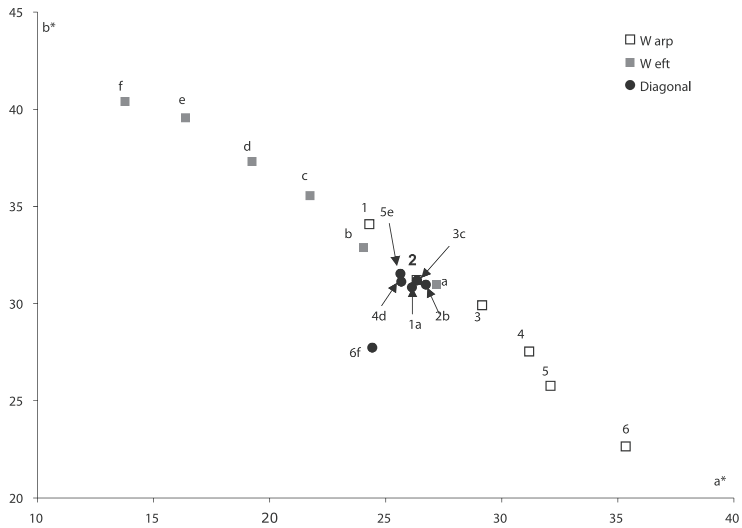

Figure 7: The review of colour values of Fabric 3.

Table 7: Values L, C*, h, of warp and weft colours of Fabric 4 and colour differences ΔE* between individual colours.*

	Warp						Weft					
	1	2	3	4	5	6	a	b	c	d	e	f
L*	55.81	55.56	55.62	55.11	55.81	55.53	55.51	55.44	54.75	55.35	56.40	56.64
C*	39.47	41.25	41.90	45.21	44.56	47.71	41.63	39.33	37.73	35.61	34.36	32.04
h	51.34	49.24	45.53	43.17	42.38	38.81	49.16	52.69	56.22	59.21	62.39	64.77
	Difference between warp colours						Difference between weft colours					
	2–1	3–2	4–3	5–4	6–5	6–1	b–a	c–b	d–c	e–d	f–e	f–a
ΔE*	2.35	2.99	4.23	0.54	4.31	12.64	3.42	2.86	2.87	2.32	2.99	13.82

our and between first eight colours on the fabric's diagonal ("2b"–"9i") are relatively small. The biggest difference is between colours "1a" and "5e" (ΔE^*_{1a-5e} = 1.66), as shown in figure 9. These colour changes are not visually noticeable. Colour changes between the reference colour and the last three colours of the diagonal ("10j", "11k" in "12l") are bigger, and are also visually observable.

*For Fabric 6, the warp and weft colours were changed using Method 2. The warp colour passed from the 2 to the 1 quadrant of the CIE L*a*b* colour space, corresponding to hue changes from green to reddish. The weft colour changed from less saturated to more saturated green colour. The difference in colour saturation between the last warp and the last weft is ΔC^*_{12-l} = 25.57. The change of hue angle between the two colours is relatively big compared with the change of colour saturation Δh_{12-l} = 172.92. This is the biggest change of hue angle between the warp and the weft colours that were analysed in the research.*

The results show that the biggest common colour difference is between the initial colour and the last colour on the diagonal (ΔE^*_{1a-12l} = 5.53). The difference is relatively small in comparison with the difference between the warp and the weft colours "1" and "a" (ΔE^*_{1-a} = 9.14) and between colours "12" and "l" (ΔE^*_{a-l} = 49.70). Also, the last colour has a noticeable visual difference from the initial colour. In the case of Fabric 6, the first ten colours of the diagonal ("2b"–"11k") don't differ substantially from the initial colour as shown in figure 10. Between the mentioned colours there is the biggest common colour difference between the reference colour "1a" and colour "11k", which is ΔE^*_{1a-11k} = 2.71. The biggest change in hue angle is between colours "1a" and "8h" (Δh_{1a-8h} = 8.88) and the biggest difference in colour saturation is between colours "1a" and "12l" (ΔC^*_{1a-12l} = 4.68).

4 Conclusion

From this research it was established that using two suitable colours for the warp and the weft, it is possible to create a simulation of visually one-coloured fabric that has the same or

Table 8: Values L, C*, h of colours that are on the diagonal of Fabric 4 and colour differences ΔE* between warp and weft colours and between colours on the diagonal.*

	Diagonal					
	1a	2b	3c	4d	5e	6f
L*	56.87	56.80	56.27	55.21	55.94	55.05
C*	41.82	41.51	41.13	41.21	40.39	40.02
h	49.60	48.90	48.63	49.46	48.64	47.24
	Difference between warp colour and weft colour					
	1–a	2–b	3–c	4–d	5–e	6–f
ΔE*	2.68	3.09	8.55	14.74	17.01	23.56
	Difference between colours on the fabric's diagonal					
	–	2b–1a	3c–1a	4d–1a	5e–1a	6f–1a
ΔE*	–	0.60	1.14	1.76	1.83	3.05

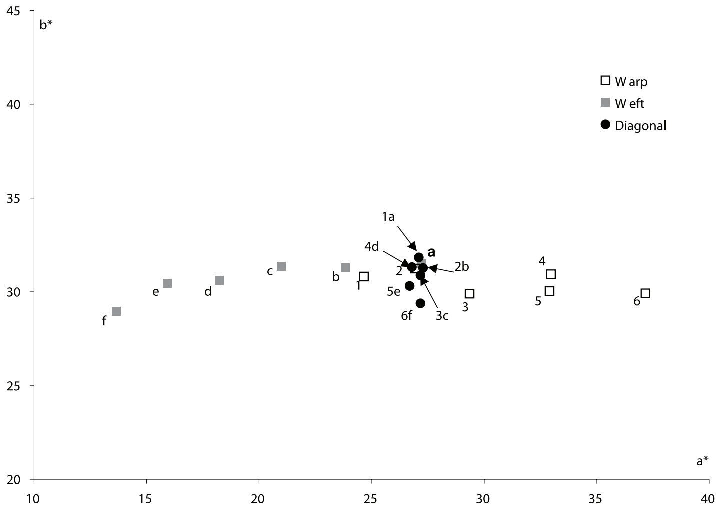

Figure 8: The review of colour values of Fabric 4.

ga območja v bolj nasičeno rdeče območje barvnega prostora. Barva votkovnih niti pa prehaja iz oranžne barve v manj nasičeno rumeno.

Razlika v nasičenosti barve med zadnjo osnovno nitjo in zadnjo votkovno nitjo je ΔC^*_{6-f} = 15,67. Sprememba kota barvnega tona, ki je nastala med barvama „6" in „f", je v primerjavi s spremembo nasičenosti velika, in sicer znaša Δh_{6-f} = 25,96.

Pri analizi barv na diagonali Tkanine 4 smo ugotovili, da se od referenčne oziroma izhodiščne barve najbolj razlikuje zadnja barva diagonale. Skupna barvna razlika med barvama „1a" in „6f" znaša ΔE^*_{1a-6f} = 3,05 in je relativno majhna v primerjavi s spremembo barve med „1" in „a" (ΔE^*_{1-a} = 2,68) ter med „6" in „f" (ΔE^*_{6-f} = 23,56). Razlika med referenčno barvo in zadnjo barvo diagonale *very similar colour as a simulation of one-coloured fabric produced from the warp and the weft of a single colour. Furthermore, the difference between the warp and the weft colours can be considerable.*

*It was also established, that the colour change of the fabric's simulation is not very big, regardless of whether the change of the warp and weft colours is in the saturation or in the hue values. This is also true in the cases where changed colours passed onto the other quadrants of CIE L*a*a* colour space, and where the difference in hue between the warp and the weft colours was pretty big.*

*The intention was to ascertain the colour difference between the initial colour of fabric simulation and colour of the fabric simulation that is produced from warp and weft colours that are approximately equally distanced from the initial colour in the CIE L*a*b* colour space. In all the cases, the colour of the fabric lies on the virtual straight line that runs through the colour*

je vizualno opazna. Med referenčno barvo in zadnjo barvo diagonale je nastala tudi največja razlika v nasičenosti (ΔC^*_{1a-6f} = 1,80) ter največja sprememba kota barvnega tona (Δh_{1a-6f} = 2,36). Spremembe barve na diagonali tkanine so vidne tudi na sliki 8.

3.2.3 Tkanina 5 in Tkanina 6

Pri Tkanini 5 in Tkanini 6 smo položaj izhodiščne barve premaknili na os a*, tako da spremenjene barvne komponente prehajajo tudi v druge kvadrante barvnega prostora CIE L*a*b*. Izbrana izhodiščna barva je nenasičena zelena z vrednostmi (L* = 60, a* = –10, b* = 0). Poleg tega, da spremenjene barve prehajajo v druge kvadrante, smo pri obeh tkaninah barve osnove in votka spreminjali tako, da smo ustvarili 12 spremenjenih barv osnove in 12 spremenjenih barv votka.

Barve osnove in votka smo pri Tkanini 5 spreminjali po 1. načinu. Barva osnove prehaja skozi tri kvadrante barvnega prostora CIE L*a*b*, in sicer iz drugega v tretji in v četrti kvadrant, kar je razvidno tudi s slike 9. S spremembo osnova postane modrovijolične barve. Barva votka pa se spremeni v bolj nasičeno zeleno in ostaja v izhodiščnem, drugem kvadrantu barvnega prostora CIE L*a*b*. Razlika v nasičenosti barve, ki je nastala med zadnjo barvo osnove in zadnjo barvo votka, znaša ΔC^*_{12-1} = 34,73. Sprememba kota

Table 9: Values L, C*, h, of warp colours of Fabric 5 and colour differences ΔE* between individual colours.*

	Warp											
	1	2	3	4	5	6	a	8	9	10	11	12
L*	54.15	54.50	54.92	55.04	54.38	54.26	52.76	53.91	54.05	53.35	53.93	53.70
C*	21.69	19.30	16.06	13.50	10.72	8.14	11.11	6.19	6.24	8.97	11.30	12.63
h	157.09	160.42	164.92	165.20	174.79	190.30	169.95	228.86	246.84	272.12	286.88	289.38
	Difference between warp colours											
	2–1	3–2	4–3	5–4	6–5	7–6	8–7	9–8	10–9	11–10	12–11	12–1
ΔE*	2.72	3.54	2.56	3.48	3.66	4.76	9.52	1.98	4.31	3.53	1.47	31.61

Table 10: Values L, C*, h, of weft colours of Fabric 5 and colour differences ΔE* between individual colours.*

	Weft											
	a	b	c	d	e	f	g	h	i	j	k	l
L*	56.24	56.26	56.14	56.05	55.76	56.03	54.70	56.28	55.41	52.44	54.35	52.86
C*	11.86	13.95	18.95	20.56	23.43	26.08	27.09	34.38	37.28	42.50	44.34	47.36
h	172.49	161.01	157.77	152.62	151.74	149.42	149.51	147.76	147.84	148.26	146.90	147.05
	Difference between weft colours											
	b–a	c–b	d–c	e–d	f–e	g–f	h–g	i–h	j–i	k–j	l–k	l–a
ΔE*	3.48	5.08	2.38	2.91	2.85	1.68	7.52	3.03	6.02	2.83	3.37	37.30

Table 11: Values L, C*, h of colours that are on the diagonal of Fabric 5 and colour differences ΔE* between warp and weft colours and between colours on the diagonal.*

	Diagonal											
	1a	2b	3c	4d	5e	6f	7g	8h	9i	10j	11k	12l
L*	56.81	56.89	57.24	56.49	56.40	56.01	55.61	56.43	56.16	53.30	55.28	53.77
C*	11.78	12.14	11.74	11.19	12.65	11.81	12.48	11.66	12.71	15.29	14.69	18.24
h	173.24	172.10	167.77	170.74	166.51	168.52	170.01	171.61	168.72	167.34	166.75	162.85
	Difference between warp colour and weft colour											
	1–a	2–b	3–c	4–d	5–e	6–f	7–g	8–h	9–i	10–j	11–k	12–l
ΔE*	11.07	5.62	3.84	8.02	14.85	20.75	17.26	34.02	38.76	47.60	53.47	57.89
	Difference between colours on the fabric's diagonal											
	–	2b–1a	3c–1a	4d–1a	5e–1a	6f–1a	7g–1a	8h–1a	9i–1a	10j–1a	11k–1a	12l–1a
ΔE*	–	0.41	1.12	0.78	1.66	0.96	0.99	0.36	1.35	3.76	3.25	6.99

components, in between them. In most cases the colour differences between the initial colour and the other colours were small.

Differences were also visually assessed and it was noticed that perceivable differences between the initial colour and the last colour of a fabric simulation's diagonal occurred when those two colours were most distanced in the colour space. With the assistance of visual evaluation of fabric simulations printed on paper, the skeleton numerical value of colour difference was set, which in the case of the analysed samples defines the border value of visual difference between colours that is still not noticeable. The value is ΔE = 3. For Fabric 1 and Fabric 2, where colours are in the green area, this value was not exceeded, despite relatively big differences between the warp and the weft colours.*

It has to be stressed that the results presented in this article are gained through the analysis of fabric simulations printed on paper and not with the real fabrics, for which the results would be most probably different.

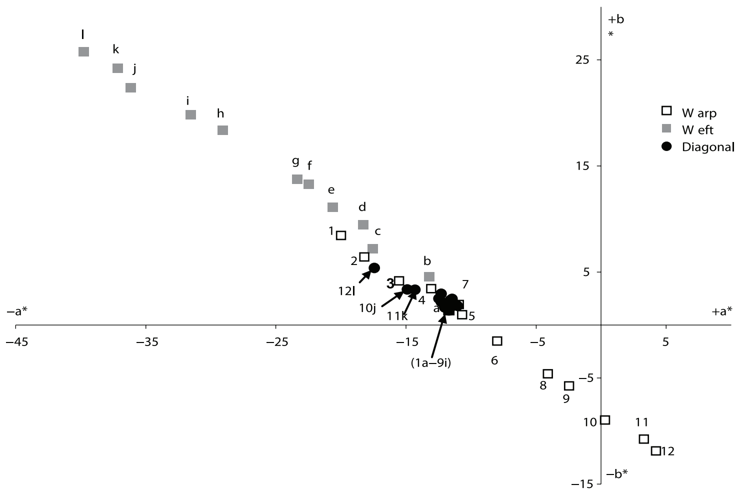

Figure 9: The review of colour values of Fabric 5.

barvnega tona med omenjenima barvama je v primerjavi s spremembo nasičenosti zelo velika, in sicer $\Delta h_{12–l}$ = 142,33.

Glede na rezultate smo ugotovili, da je največja skupna barvna razlika med izhodiščno barvo „1a“ in zadnjo barvo diagonale „12l“ ($\Delta E^*_{1a–12l}$ = 6,99). Med omenjenima barvama je tudi največja razlika v kotu barvnega tona ($\Delta h_{1a–12l}$ = 10,39), pa tudi razlika v nasičenosti barv ($\Delta C^*_{1a–12l}$ = 6,46). Barvna razlika med izhodiščno barvo in zadnjo barvo na diagonali tkanine je majhna v primerjavi z razliko med barvama „1“ in „a“ ($\Delta E^*_{1–a}$ = 11,07) ter barvama „12“ in „l“ ($\Delta E^*_{12–l}$ = 57,89). Razlika med referenčno barvo in med barvami prvih osmih barv diagonale tkanine („2b“–„9i“) je razmeroma majhna, največja je med barvama „1a“ in „5e“ ($\Delta E^*_{1a–5e}$ = 1,66). To je vidno tudi na sliki 9. Te barvne razlike tudi niso vizualno opazne. Zadnje tri barve diagonale („10j“, „11k“ in „12l“) se od referenčne barve bolj razlikujejo, kar je tudi vizualno opazno.

Pri Tkanini 6 smo barve osnove in votka spreminjali po 2. načinu. Barva osnove prehaja iz 2. v 1. kvadrant CIE L*a*b*-prostora. Barvni ton se spreminja iz zelenega v rdečkastega. Barva vot-

Table 12: Values L, C*, h, of warp colours of Fabric 6 and colour differences ΔE* between individual colours.*

	Warp											
	1	2	3	4	5	6	a	8	9	10	11	12
L*	55.37	56.27	56.22	56.00	55.43	55.44	54.54	55.41	56.03	55.35	55.97	54.83
C*	18.71	14.76	12.79	9.30	6.00	4.60	7.98	1.56	2.41	4.98	9.23	12.15
h	175.67	173.58	176.00	171.09	176.75	154.73	165.22	55.34	33.21	9.66	10.62	6.29
	Difference between warp colours											
	2–1	3–2	4–3	5–4	6–5	7–6	8–7	9–8	10–9	11–10	12–11	12–1
ΔE*	4.10	2.06	3.61	3.42	2.47	3.67	8.62	1.23	3.05	4.28	3.15	30.64

Table 13: Values L, C*, h, of weft colours of Fabric 6 and colour differences ΔE* between individual colours.*

	Weft											
	a	b	c	d	e	f	g	h	i	j	k	l
L*	56.16	56.21	56.16	56.17	56.00	55.17	54.34	55.81	55.51	55.74	55.18	55.06
C*	9.62	13.84	16.44	18.55	21.56	23.84	24.14	28.28	30.38	33.11	35.76	37.72
h	175.33	174.08	173.28	173.88	175.07	177.08	178.13	179.55	179.29	180.06	180.01	179.21
	Difference between weft colours											
	b–a	c–b	d–c	e–d	f–e	g–f	h–g	i–h	j–i	k–j	l–k	l–a
ΔE*	4.20	2.65	2.11	3.02	2.58	0.97	4.44	2.14	2.75	2.73	2.03	28.16

Table 14: Values L, C*, h of colours that are on the diagonal of Fabric 6 and colour differences ΔE* between warp and weft colours and between colours on the diagonal.*

	Diagonal											
	1a	2b	3c	4d	5e	6f	7g	8h	9i	10j	11k	12l
L*	56,66	56,12	56,13	56,49	56,15	55,67	55,72	55,84	56,00	56,12	55,51	54,06
C*	12,95	13,16	12,77	12,48	11,35	11,10	13,20	11,56	12,07	11,98	11,21	8,27
h	170,48	168,71	169,15	169,01	170,40	172,43	171,06	179,36	177,02	174,17	177,88	178,27
	Difference between warp colour and weft colour											
	1–a	2–b	3–c	4–d	5–e	6–f	7–g	8–h	9–i	10–j	11–k	12–l
ΔE*	9,14	0,95	3,73	9,28	15,58	19,72	16,51	29,18	32,35	38,00	44,86	49,70
	Difference between colours on the fabric's diagonal											
	–	2b–1a	3c–1a	4d–1a	5e–1a	6f–1a	7g–1a	8h–1a	9i–1a	10j–1a	11k–1a	12l–1a
ΔE*	–	0,72	0,64	0,59	1,68	2,15	0,98	2,49	1,77	1,38	2,71	5,53

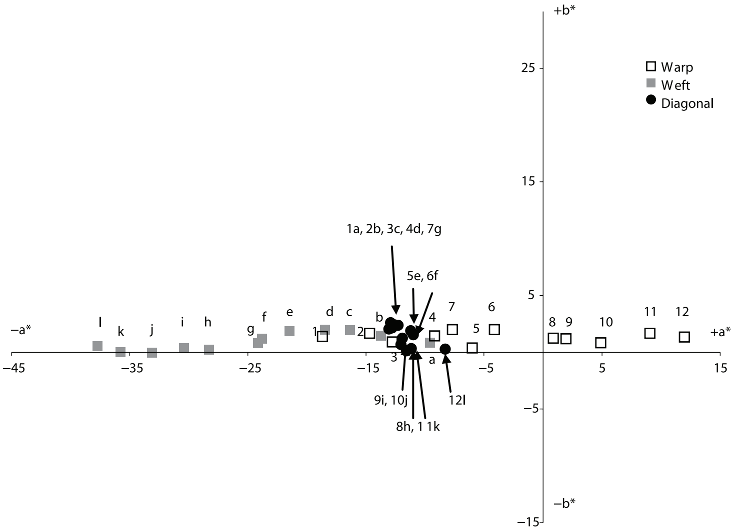

Figure 10: The review of colour values of Fabric 6.

ka prehaja iz manj nasičene zelene v bolj nasičeno zeleno barvo. Razlika v nasičenosti barve med zadnjo osnovno nitjo in zadnjo votkovno nitjo je ΔC^*_{12-l} = 25,57. Sprememba kota barvnega tona med omenjenima barvama je v primerjavi s spremembo nasičenosti zelo velika, in sicer Δh_{12-l} = 172,92. To je tudi največja sprememba kota barvnega tona med osnovo in votkom pri vseh tkaninah, ki smo jih analizirali v raziskavi.

Rezultati so pokazali, da je največja skupna barvna razlika med izhodiščno barvo in zadnjo barvo diagonale (ΔE^*_{1a-12l} = 5,53). Ta razlika je relativno majhna v primerjavi z razliko med barvama osnove in votka „1“ in „a“ (ΔE^*_{1-a} = 9,14) ter med barvama osnove in votka „12“ in „l“ (ΔE^*_{a-l} = 49,70). Tudi vizualno se zadnja barvo opazno razlikuje od izhodiščne barve. V primeru te tkanine se prvih deset barv diagonale („2b“–„11k“) od izhodiščne barve ne razlikuje zelo. To je vidno tudi na sliki 10. Med omenjenimi barvami nastane največja skupna barvna razlika med referenčno barvo „1a“ in barvo „11k“, in sicer ΔE^*_{1a-11k} = 2,71. Največja razlika v kotu barvnega tona je med barvama „1a“ in „8h“ (Δh_{1a-8h} = 8,88), največja razlika v nasičenosti barv pa je med barvama „1a“ in „12l“ (ΔC^*_{1a-12l} = 4,68).

4 Sklepi

Z raziskavo smo ugotovili, da lahko z ustrezno barvo osnove in drugo ustrezno barvo votka dobimo simulacijo vizualno enobarvne tkanine enake oziroma zelo podobne barve, kot jo ima simulacija enobarvne tkanine, izdelane iz osnove in votka enake barve. Pri tem je lahko razlika med barvama osnove in votka precejšnja.

Ugotovili smo tudi, da sprememba barve simulacije tkanine ni velika ne glede na to, ali spreminjamo razliko med barvama osnove

in votka v nasičenosti ali v barvnem tonu. Do teh ugotovitev smo prišli tudi v primerih, ko so spremenjene barve prehajale v druge kvadrante CIE L*a*b*-prostora in je bila razlika v barvnem tonu med osnovo in votkom precejšnja.
Ugotavljali smo skupno barvno razliko med izhodiščno barvo simulacije tkanine in barvo tiste simulacije tkanine, ki je narejena iz osnove in votka, katerih barvi sta v CIE L*a*b*-prostoru približno enako oddaljeni od izhodiščne barve, v vseh primerih pa barva tkanine na navidezni premici, ki poteka skozi barvni komponenti, leži med komponentama. V večini primerov so barvne razlike med izhodiščno barvo in nastalimi barvami tkanine majhne.
Razlike smo tudi vizualno ocenjevali in opazili, da so nekoliko bolj opazne razlike nastale med izhodiščno barvo in zadnjo barvo diagonale simulacije tkanine, pri kateri sta bili barva votka in barva osnove v barvnem prostoru najbolj oddaljeni druga od druge. S pomočjo vizualnega ocenjevanja na papir natisnjenih simulacij tkanin smo določili okvirno numerično vrednost, ki v primeru naših vzorcev določa mejo, do katere je sprememba barve vizualno sprejemljiva, in sicer $\Delta E^* = 3$. Pri Tkanini 1 in pri Tkanini 2, torej tkaninah, katerih barve so v zelenem barvnem območju, ta vrednost ni bila presežena kljub razmeroma velikim razlikam med barvami osnove in votka.
Poudariti je treba, da so to rezultati, ki smo jih dobili s pomočjo analize na papir natisnjenih simulacij tkanin in ne s pomočjo dejanskih tkanin. Če bi analizirali dejanske tkanine, bi bili rezultati verjetno drugačni.

5 Viri

1. DIMITROVSKI, K. Barvno oblikovanje pestrih tkanin. V: *Interdisciplinarnost barve – V aplikacji*. Ed. Jeler, S., Kumar, M., Maribor: Društvo koloristov Slovenije, 2003.
2. KLANJŠEK GUNDE, M. Svetloba in barve – fizikalni vidik. V: *Interdisciplinarnost barve – V znanosti*. Ed. Jeler, S., Kumar, M., Maribor, Društvo koloristov Slovenije, 2001.
3. GOLOB, V., GOLOB, D. Teorija barvne metrike. *Interdisciplinarnot barve, 1. del – V znanosti*. Ed. Jeler, S., Kumar, M., Maribor, Društvo koloristov Slovenije, 2001.
4. KOČEVAR, T. N. *Vpliv parametrov konstrukcije in kompozicije tkanin na optično mešanje barv na njeni površini: doktorska disertacija*. Ljubljana: Univerza v Ljubljani, Naravoslovnotehniška fakulteta, 2000.
5. DIMITROVSKI, K., GABRIJELČIČ, H. Izračunavanje i merjenje boja tkanina iz različito obojenih niti. *Tekstil*, 1999, vol. 50 (11), p. 558–567.