Colour prediction as a weaving design selection help tool in Jacquard CAD

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ABSTRACT – REZUMAT

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The final colour prediction of a weave design made of dyed yarns is a difficult problem. This study shows how a geometric model can be developed to obtain the final colour prediction objectively. For this purpose, a woven material was divided into weft, warp and pores. Then, all parameters needed for the calculation of each colour contribution were identified. A geometrical model based on construction parameters was developed to predict the surface colour contribution of each coloured yarn in a weave surface. To validate the predicted colorimetric data, a visual assessment experiment was conducted. Then, the difference between the predicted and actual colour appearance of the weave pattern was evaluated and analysed in function of weaving structures, and weft yarns colours. For this purpose, simple woven structures (plain, twill 1/3, basket 2/2 and satin Turc) with four coloured weft yarns were used. Results show that the proposed model could correctly predict the final colour of weave designs. Therefore, the model has the potential to eliminate subjective evaluations and reduce prototype sample production by automating the process of weave/colour simulation, thereby reducing the cost and time for product development. The methods of utilization of colour in woven textiles depend upon the composition of the weave design to be woven and the structure parameters of the cloth.

Keywords: *weave design, colour prediction, Jacquard CAD, dyed yarns*

Predicția culorilor ca instrument suport pentru selecția designului legăturii în Jacquard CAD

Predicția finală a culorii unui design al legăturii realizat din fire vopsite este o problemă dificilă. Acest studiu arată cum poate fi dezvoltat un model geometric pentru a obține predicția finală a culorii în mod obiectiv. În acest scop, un material țesut a fost împărțit în bătătură, urzeală și pori. Apoi, au fost identificați toți parametrii necesari pentru calculul fiecărei contribuții de culoare. A fost dezvoltat un model geometric bazat pe parametrii de construcție pentru a preconiza contribuția culorii suprafeței fiecărui fir colorat într-o legătură. Pentru a valida datele colorimetrice preconizate, a fost efectuat un experiment de evaluare vizuală. Apoi, diferența dintre aspectul de culoare preconizat și cel real al modelului de legătură a fost evaluată și analizată în funcție de structurile de legătură și de culorile firelor de bătătură. În acest scop s-au folosit structuri simple țesute (pânză, diagonal 1/3, panama 2/2 și atlas turc) cu patru fire de bătătură colorate. Rezultatele arată că modelul propus ar putea preconiza corect culoarea finală a modelelor de legătură. Prin urmare, modelul are potențialul de a elimina evaluările subiective și reduce producția de probe prototip prin automatizarea procesului de simulare a legăturii/culorii, reducând astfel costul și timpul de dezvoltare a produsului. Metodele de utilizare a culorii în materialele țesute depind de compoziția design-ului legăturii care urmează să fie țesută și de parametrii de structură ai ţesăturii.

Cuvinte-cheie*: design de legătură, predicție de culoare, Jacquard CAD, fire vopsite*

INTRODUCTION

Visual inspection is the conventional method of assessing colour and still is practised widely, colour instrumental measurement is an important alternative because it eliminates the human factor [1].

Instrumental methods can be categorized into quality control procedures and formulation methods. Consequently, the use of digital instruments to determine or to specify colours by comparison with visual standards is becoming a necessity for many industries including computer colour-matching formulation, paints, printing and plastics colouration. The primary objective of colourimetry is the numerical description of colour using physical measurements. Each colour can be positioned in so-called a colour space. The CIELAB system, recommended by the CIE 1976 is the most adopted in the textile industry case. The principle consists of using the theories of primary colours and optical colour mixing of knitted or woven samples [2–9]. For dyed and printed textile materials, the intensity of the colour is proportional to the concentration of the adsorbed/absorbed dyes. Another proportionality must be considered with big interest. In woven designs from coloured threads, a coloured pattern is a consequence of two possible arrangements where the warp is over the weft or vice versa. Thus, the primary elements of woven fabric design are combination ways of weaves and blending of colours using such weaves. That being said, most Dobby and Jacquard fabrics producer's facilities are now equipped with Computer Aided Textile Design systems [9]. In the pre-computer era, the designing

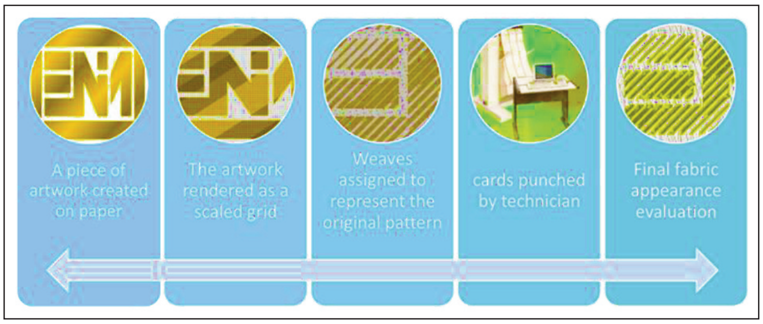


Fig. 1. Jacquard weaving design process in the pre-computer era

process was done in the following flow chart as follow (figure 1):

– A piece of artwork was created on paper.
– The artwork was then rendered as a scaled grid (known as squared paper or design paper), whose columns and rows represented warp and weft yarns, respectively.
– Weaves were then assigned to specific areas to represent the original pattern.
– A technician then punched cards, direct from this technical design layout, in which each card represents one pick of the actual fabric.
– Finally, the weaving structure aspect is evaluated on a final woven fabric.

Modern CAD systems provide a variety of design tools that are supported by standardized colour and weaving structure databases that allow the simulation of weave structures on the computer monitor that could be printed on paper. In figure 2, we illustrate the Nedgraphics® Jacquard weaving design from different technical views: design view, card view, weaves view and 3D simulation view a CAD weaving software.

As illustrated in figure 2, for each colour in the design view, a weaving structure is selected then the card view is generated. Weaving designers can use a 3D simulation to check the weaving layout.

However, deviations in the colour values of these simulations still occur. Also, the colour on fully flat fabric simulations on paper or computer screens is 2D which differs from the real three-dimensional nature of fabrics and yarns [9].

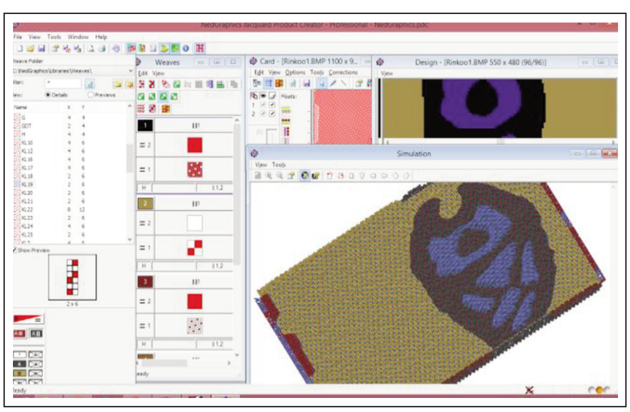


Fig. 1. Jacquard weaving design using CAD system (NedGraphics®)

The colorimetric result in the thread-based assay is also not easy to interpret with bare eyes [10]. This is because colour changes happen in small spaces, and a camera or scanner is required to quantify them. Some researchers provided a model that involves colorimetric measurements for colour prediction. However, a colorimetric tool is less used when fabrics are made from coloured yarns [11]. Among the literature review presented in this introduction, there is a lack of scientific methods to help designers choose weaving structures in Jacquard to highlight patterns.

This study aims to explore the colour difference prediction of simple weaving structures as a help tool in the Jacquard weave design selection. Coloured weft yarns used in the developed model are compared to measured results to evaluate the prediction of the final shade. Consequently, this prediction will offer more reproducibility and accuracy in the shade matching of fabrics made from coloured yarns which is hard to obtain. Colour simulation of a weaving design prediction could be used as a help tool to select a weaving structure related to a weaving design colour.

MATERIALS AND METHODS

Fabrics weaving designs

Experiments were carried out employing 16 samples: 4 simple weaving designs (plain weave, 1/3 right twill, basket 2/2 and satin Turc) and for each structure, 4 coloured yarns were used (undyed, blue, green and red). Weave design and flat view of the used samples and basic metrological parameters are presented in table 1. For all samples, the warp density is 30 ends/cm. The 50% cotton/50% polyester yarns are used as warp and weft yarns and have a count number of 33.5 tex. Samples were woven using a flexible rapier weaving machine: Picanol Gam Max with an electronic dobby as a shedding mechanism a denting plan of 14×2 was used.

The final fabric colour depends on each component colour and the compacity of the structure. All samples were relaxed using a RelaxLab according to the NFG 07-102 test standard (AFNOR).

Coloured yarn colour strength

The weft threads were red, blue, green and undyed. The warp threads were only undyed. The colour resulting from these samples is not an intrinsic property of the object and its perception may vary depending on the wavelength or the colour distribution of the light source which is also depending on the textile reflectance. For each coloured yarn, colour coordinates (L, a, b) were measured with the help of a colorimetric SPECTRAFLASH FF6000 using a D65 light source at, a 10° viewing angle.

Yarns and pores contribution

Woven fabrics are formed by interlacing yarns as a binary system (warp and weft yarns). Each yarn gives it contributes to the geometrical shape and affects predicting the final colour. This contribution is not the only function of warp and weft density but also a function of the pattern.

Each component contribution calculation is based on the constructional parameters of each yarn in the fabric. By using fabric design illustration, as an example of the satin Turc (presented in figure 3), the fractions of individual colour components in a colour repeat according to the flow chart are used according to the CIELAB colour space to calculate colour difference tolerance.

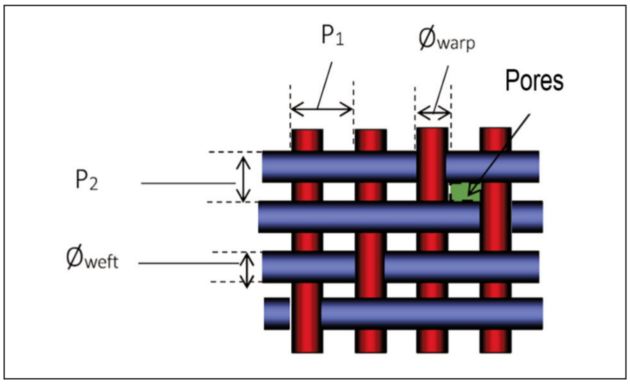


Fig. 3. Schematic presentation of a satin Turc structure and interlacing point made up of three components warp, weft and pores (P_1: distance between two warp yarns, P_2: distance between two warp yarns, $Ø_{warp}$: warp yarn diameter and $Ø_{weft}$: weft yarn diameter)

According to figure 3, the surface proportion of each component according to the fabric's total surface is calculated (all dimensions were expressed in centimetres).

The warp yarn surface contribution to the fabric is:

Warp-Contribution =

$$= 100\,\frac{4Ø_{Warp}\,Ø_{Weft}+20Ø_{Warp}(P_2-Ø_{Weft})}{16P_1P_2} \quad (1)$$

The weft yarn contribution on the fabric surface:

Weft-Contribution =

$$= 100\,\frac{4Ø_{Weft}\,Ø_{Warp}+20Ø_{Weft}(P_2-Ø_{Warp})}{16P_1P_2} \quad (2)$$

And the pore's contribution to the fabric surface:

$$\textit{Pores-Contribution} = 100\,\frac{8(P_1-Ø_{Warp})(P_2-Ø_{Weft})}{16P_1P_2} \quad (3)$$

RESULTS AND DISCUSSION

Component geometrical contribution

Based on equations 1, 2 and 3, each component's geometrical contributions to the weaving fabric are presented in figure 4.

According to figure 4, it is noticed that the component contribution is a function of the weft densities. The more the structure is compact, the less the pores contribution percentage. This is due to the surface partition layout of each component.

Colour prediction model

To determine the most appropriate colour model to use with different structures, several Kubelka-Munk theory-based approaches were employed [9, 12]. An assumption was made that a yarn colour on the fabric surface was independent of the other yarn colours [13, 14] and this assumption leads to the K/S model described below:

$$\log(K/S)_{mixing} = C_i \log(K/S)_i \quad (4)$$

where (C_i) is the concentration of each coloured yarn (each component contribution percentage), K – the light absorption coefficient and S – the light scattering coefficient.

The flow chart of figure 5 illustrates the steps used to calculate the final colour attributes for any given weave structure using a colour mixing model. This schema is developed to design the database tool, to make the colour information accessible and easy to use.

This theory can be also used to model the colour of various forms of textile materials. In this case, the colour contributions of dyes will be replaced by the colour contribution of each coloured yarn.

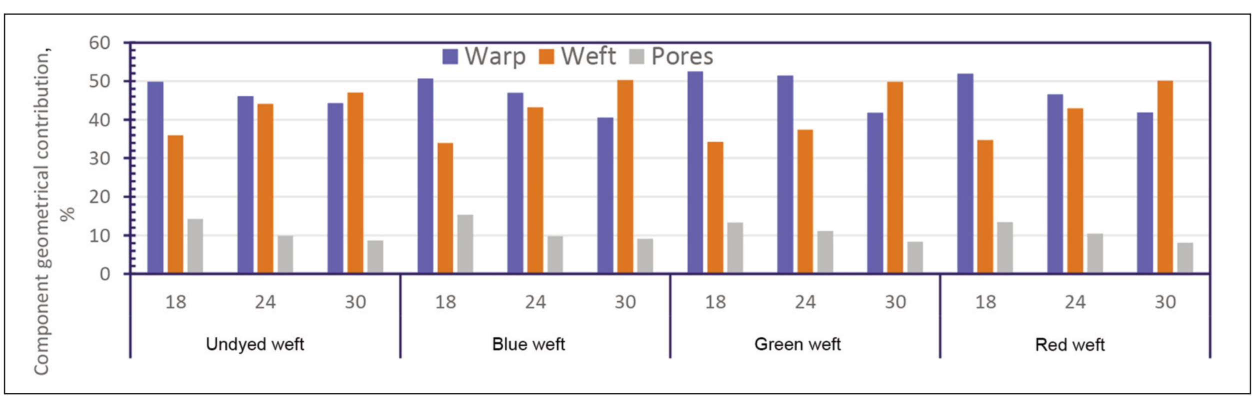


Fig. 4. Geometrical contribution of tested yarns in the case of plain weave (undyed warp, warp density = 30 ends/cm)

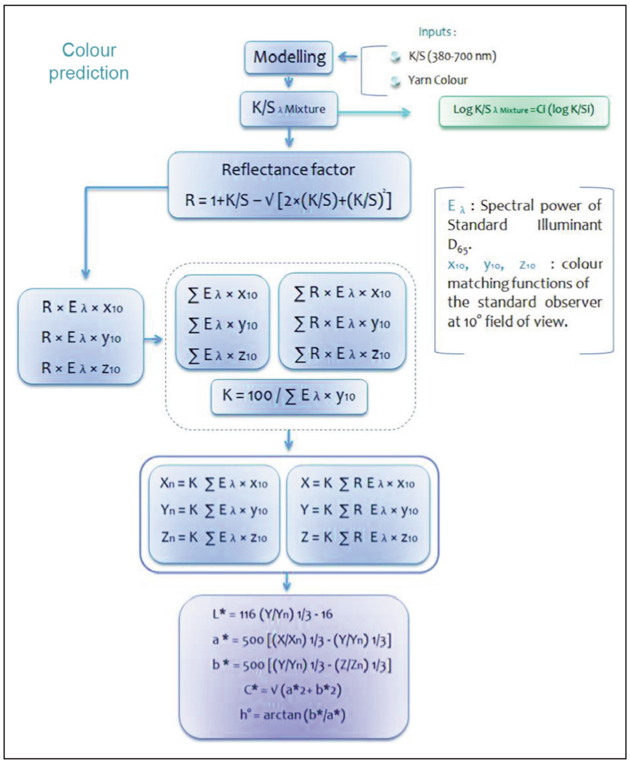


Fig. 5. Colorimetric calculation flow chart

The colour proportions for the mixing model have a near relationship with the component contribution fraction. We calculate this parameter for each tested weave design.

Model validation

The results of all 16 samples were used in the prediction of the final colour values and then compared with the measured colour values of the actual fabric samples. As described in table 1, four different colours of weft threads were used, red, blue, green and undyed. These colours were chosen because they are located in different parts of the CIE L*a*b* colour system. Red has a very high positive value of colour parameter a* whereas green is located at the opposite end of the colour system; blue is also located at the end of the system but with a very negative value.

The distance in colour space was calculated using the law of Pythagoras. It can be calculated by the following equation:

$$\Delta E_{CMC} = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (5)$$

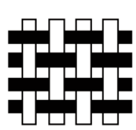
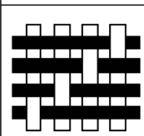
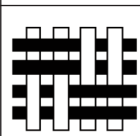
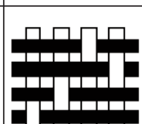
The predicted and measured colorimetric values of all 16 samples are shown in table 1.

In table 1, it can be deduced that the fraction of single-colour components (warp and weft) changes with the change in the contexture of woven material. It is also dependent on constructional parameters such as thread fineness, and density.

The colour difference ΔE_{CMC} described in equation 5 is the distance between the points for reference and standard respective coordinates in the CIELAB colour space. Such a measurement of colour difference is very useful for establishing whether a coloured sample (reference) is an acceptable match to the target (when compared with a standard). It is the only scientific evaluation of the similarity of two dyed samples and the best until now. In our case, the purpose is to evaluate how much two woven fabrics are similar. By comparing the colour difference values calculated between measured and predicted colour values, it was seen that, although each set

Table 1

COMPARISON BETWEEN PREDICTED AND MEASURED COLORIMETRIC DATA USING LOG K/S COLOR MIXING MODEL (WARP DENSITY = 30 ENDS/CM AND WEFT DENSITY = 30 PICKS/CM)

Structure	Flat View	Weft colour	Measured values			Predicted values			ΔE*
			L*	a*	b*	L*	a*	b*	
Plain weave		Undyed	87.73	1.49	12.62	86.46	–0.28	22.52	10.14
		Blue	65.04	–13.98	–16.73	74.58	–11.28	–13.72	10.36
		Green	86.88	–6.12	22.90	85.23	–5.13	41.80	19.00
		Red	55.26	16.28	3.94	68.40	11.76	24.11	24.49
Twill1/3 right		Undyed	88.73	1.33	13.50	86.38	–0.25	22.69	9.62
		Blue	56.84	–20.10	–25.17	74.80	–11.49	–14.45	22.62
		Green	86.66	–7.63	27.62	86.18	–4.61	38.02	10.84
		Red	39.93	27.45	6.95	70.46	10.39	24.21	39.00
Basket 2/2		Undyed	88.57	1.26	12.30	86.43	–0.27	22.57	10.60
		Blue	64.39	–14.08	–16.97	74.70	–11.40	–14.11	11.03
		Green	86.83	–6.01	23.04	85.84	–4.66	38.93	15.98
		Red	51.27	18.77	5.07	69.17	11.18	24.17	27.25
Satin Turc		Undyed	89.01	1.31	13.43	87.00	–0.36	21.81	8.78
		Blue	56.73	–20.60	–25.65	72.84	–12.90	–18.60	19.20
		Green	86.75	–7.47	27.76	85.37	–5.27	42.16	14.63
		Red	39.93	28.04	7.08	69.92	10.62	24.23	38.69

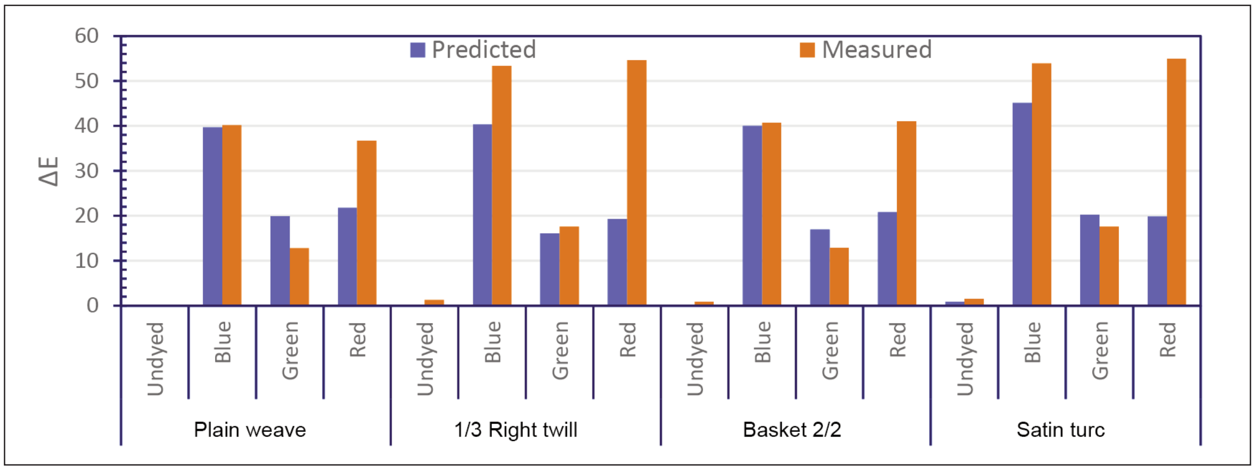


Fig. 6. Distance in colour space: plain weave structure with undyed warp and weft as reference (warp density = 30 ends/cm and weft density = 30 picks/cm)

contains the same weave structures, the log *K/S* prediction varied for each filling yarn colour. The results from the colour measurements show that there is a significant difference in colorimetric data obtained by the two different methods (colorimetric and geometrical predictions). This is due to the choice of the geometrical model and especially for the pores estimation distribution.

Table 1 suggests also that a solid colour could be produced by employing the same colour in warp and weft. However, different colours may be combined to produce either a mixed or intermingled colour effect in which the composite hue appears as a solid colour. According to table 1, the colorimetric coordinates depend considerably on the weave structure. The overall error, represented by ΔE_{CMC}, between the actual fabric measurements and the predicted, was significantly high. This is due to the close weft pick (30 picks/cm), which leads to a false estimation of the geometrical models. Alternatively, colorimetric tools cannot give good sensitivity to the overall error because they do not consider all the cited parameters. Geometry modelling could be reliable for loose density [15]. But, to estimate pores proportion for close density it is advised to use air permeability to evaluate porosity, pores size and proportion [16].

For the used patterns with multi-Color, the final colour is strategically placed in the pattern by merely using the binary system of warp and weft interlacing. The desired colour of a weave appears when the yarn is over the crossing yarns for the desired length and a small or large area if several yarns are used. Moreover, numerous mixtures of colours (such as our case) to produce other colours can be obtained from a few colours of the warp and weft yarns through proper weave interlacing. For dark shades, colour space is more sensible to metrological parameters. Table 1 suggests that the color difference is higher for dark shades (Blue & Red) compared to lighter shades (undyed & green). This makes it harder the colour simulation by the described geometrical method. Figure 6 presents the distance in colour space ΔE where plain weave with undyed warp and weft is considered as a reference.

Undyed yarns could not highlight the colour of the weaving fabric using a small weave ratio, whereas for coloured weft yarns is indeed a difference in colours and subsequently a good appearance of the patterns on the Jacquard fabrics. Also, the differences in the distance in colour space between measured and predicted are essentially caused by the 3D shape of the fabric.

As known, all weave structures are created from a binary system. The warp yarn can be either over or under a weft yarn at the crossover areas. In this study, we used basic weaves. We also varied the colour and density of weft yarns. An infinite number of weaves have been formed and explored. Colorimetric coordinates were compared with those obtained by the proposed geometric model. For all experiments, we obtained almost the same decisions. The geometrical model gives samples that are slightly darker, yellowish and greenest. For lighter samples with lower weft density, the prediction was found to be better.

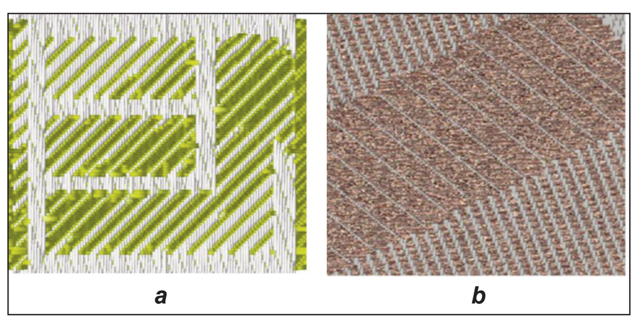


Fig. 7. Weaving design in Jacquard: *a* – without the decision tool, floats default in warp and weft direction; *b* – using colorimetric prediction for weaving structures

As a result of this study, this method could be useful as a help tool to automatically select weaving structures in a Jacquard pattern. As seen in figure 7, *a*, the Jacquard fabric design without a decision tool we can see floats and the pattern colour transition is not clear. This leads to a Jacquard fabric default in design. But in figure 7, *b*, for each pattern colour, we selected different weaving structures having an important difference in colour space, with the same yarn colours. It is seen the Jacquard fabric visual aspect is more reliable and the pattern transition is more visible.

CONCLUSIONS

The resulting colour of woven structures made of different coloured threads in the warp and weft system depends on the colour values of the threads and the constructional parameters. This research aimed to explore the possibility of predicting colour even though constructional parameters were varied.

Based on the obtained results the following conclusions can be drawn:

The final colour is a function of the constructional parameters that manifest changes in the area of each yarn on the surface.

The colorimetric data of the weave structures can be calculated by using the combined effect of the two aspects of fabric covering power, the optical (reflectance) and the geometric aspect.

Theoretically predicted ΔE colour differences can be compared with those which have been determined by a colorimetric tool. It depends on the thread's colour. The plain weave and the basket 2/2 have almost the same colour difference (between predicted and measured values). For example, in the case of the undyed weft yarn, the colour difference is 10.14 for the plain weave and 10.60 for the basket weave.

Changes to constructional parameters in one thread system can be substituted with changes to density or fineness in another system to achieve a similar colour effect on the woven surface. This study is not fully reliable in predicting the weave's final colour with accuracy. However, it could be used as a basic decision tool to help Jacquard's CAD designer select the weave design for each colour in the outline and background design.

The automation weaving structure selection in the Jacquard pattern is a very complex problem. It depends not only on the design's weaving structure choice for each pattern colour but also on weaving structure compatibility, yarn type and shade.

Nevertheless, this research attempts to gain insight into this area and construct a framework for further study. Weave design's final colour prediction in structures that are more complicated and using different types of Fancy yarn will form the subject of subsequent research.

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