STRUCTURAL AND AESTHETIC DESIGN OF WOVEN FABRICS

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ABSTRACT: Design of woven fabrics involves certain problems concerned with structural and technical factors. These are mainly related with the objective of securing the structural balance and stability of the fabric structure as well as possibility of obtaining the planned surface appearance with the available production means. It should also be kept in mind that, during the design process, the aimed fabric is to possess certain performance properties in use. Some guidelines are underlined, in this paper, to carry out a satisfactory and realistic design work by referring to related works in this field.

Keywords: Structural fabric parameters, yarn parameters, surface design, warp plan, production order, weavability

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ÖZ: Dokuma kumaşların tasarımı yapısal ve teknik faktörlere ilişkin bazı problemler içerir. Bunlar genellikle kumaş yapısının yapısal dengesi ve dayanıklılığını güvenceye alma hedefi yanında var olan üretim araçları ile planlanan bir yüzey görünümünü elde etme olanağına ilişkindirler. Tasarım sürecinde amaçlanan kumaşın bazı kullanım özelliklerine sahip olması gerektiğini de hatırda tutmak gerekir. Bu bildiride yeterli ve gerçekçi bir tasarım çalışması yapmak için bu alandaki ilgili çalışmalar ışığında bazı ip uçları vurgulanmaktadır.

Anahtar Sözcükler: Yapısal kumaş parametreleri, iplik parametreleri, yüzey tasarımı, çözgü plan, üretim emri, dokunabilirlik

1 INTRODUCTION

There are two aspects to consider in designing a woven fabric, the first being to define its structural properties which manifest themselves in its physical performance, the second being structural and aesthetic features which create its desired surface appearance. These properties may be listed as raw material content, the yarn properties like their type, count, twist, strength, extensibility, softness, structure and their colour, fabric constructional parameters like the weave structure and yarn densities which define on the whole its thickness and unit weight.

Woven fabric design has traditionally been an effort of weaving craftsmen and, in the case of fabrics like jacquard fabrics and carpets, partly of the artists. Engineering approaches have also been made to functional design of fabrics by Peirce (1947), Leaf and Clement (1986), Dastoor et al (1994), Leaf and Chen (2000), Seyam and El-Shiekh (1993) and Baser (1984, 2008). However, the industrial design approach has mainly been based on structural design principles laid down by authors like Ashenhurst (1884), Armitage (1907), Law (1922), Brierley (1931), Peirce (1937) and Hamilton (1964), and on industrial experience.

Fabric unit weight is, in general, a fabric property which enhances its strength and durability together with fibre strength. Thus, fabric type which defines raw material and yarn structural parameters and fabric unit weight are generally first specifications to define at the start of design work. Although surface design seems to be an aesthetic element to be imposed upon fabric structure, it is not directly applicable except in printed and jacquard fabrics - though there are technological limitations in those cases too. Thus, having decided on the fabric kind the two main design objectives for a woven fabric design are fabric unit weight and dimensions of figure (or figures) on fabric surface.

2 DESIGN APPROACHES IN INDUSTRY AND EDUCATION

There seems to be three different approaches to fabric design in industry and textile design education as: 1. Analysis approach to fabric design based on sample analysis, 2. Technical design work carried out usually on point paper with certain calculations, 3. Conversion of aesthetic design to fabric constructional design.

2.1 Analysis Approach

"This is the approach widely used in industry based on a full analysis of a fabric sample. It may be applied with a view to obtain either an exact reproduction or a modified version of the sample product" (Baser, 2008).

2.2 Technical Approach

This is generally applied in designing simple fabrics like dressings, shirtings, linens, work cloths, etc. and involves obtaining a fabric of certain unit weight with a given weave and specified raw material content. "This is an approach somewhat nearer to engineering design when certain tables, formulae and other useful information or standard construction data are used" (Baser, 2008).

In industry, the designers produce a collection of samples each belonging to a single fabric type or one consisting of a collection of various designs obtained in the same piece of fabric varying in colour, effect or even weave, each being a modification of a particular design solution. These swatches of fabrics are presented to the customers for them to select the most preferred version for their actual orders. "This part of the process is in fact a trial and error approach" (Baser, 2008).

2.3. Aesthetic Approach

This is the approach of artists and art students and is not so widely adopted in industry but in art schools. "It is, however, coming into the forefront by the introduction of computer design of fabrics and garments. Confining the discussion to fabric design, it is a process starting from surface appearance of the fabric and going through the technical work. This sort of approach is certainly very much valid for the design of printed or jacquard fabrics and in particular for designed carpets, but there will be problems with dobby designed fabrics" (Baser, 2008).

3 MAJOR PROBLEMS IN WOVEN FABRIC DESIGN

One of the main difficulties in designing a functional woven fabric is to define a set of design and process parameters which will result, when applied, a weavable and dimensionally stable fabric with required quality and aesthetic properties. Weavability is related with yarn densities to be imposed and elastic properties of yarns and means that the weaving process is actually applicable or possible without undue yarn breaks (especially of warps) and machine faults or stoppages. Dimensional stability, on the other hand, is that the finished fabric preserves its dimensions in wet treatments like washing and in subsequent long term use without contractions. Setting theories have been proposed to fulfil these requirements by various authors starting with Ashenhurst (1884) and followed by Armitage (1907), Law (1922) and Brierley (1931). These theories define theoretical values for yarn densities in warp and weft depending on yarn type, yarn diameter (or count) and weave construction and may generally be expressed as

$$S = F_w K \sqrt{N} \ , \ d = \frac{1}{K\sqrt{N}} \tag{1}$$

where K is a constant, N is yarn count, d is the yarn diameter, F_w is a weave factor depending on the weave structure given by Ashenhurst (1884) as

$$F_w = \frac{w+i}{w} \tag{2}$$

where w is the number of yarns and i is the number of intersections per unit weave. Thus, Eq. (1) defines the yarn density in terms of yarn and weave properties. The yarn constant K and weave factor F_w are defined in different ways by various authors. However, this general setting formula (Eq. 1) may be expressed in more detail and to cover single and complex fabrics as (Baser 2020)

$$S_{F/1} = k_{F/2} F_{wF} K_{F/1} V_F \sqrt{N_{F/1}} (1 - z) \qquad (3)$$

where $k_{F/2}$ is the crimp factor for face yarns in complex fabrics, for weft in single fabrics, F_{wF} is the weave factor for face weave in complex fabrics, for warp in single fabrics , $K_{F/1}$ yarn constant for face yarns in complex fabrics, for warp in single fabrics, $N_{F/1}$ yarn count for face weave in complex fabrics, for warp in single fabrics, V_F is a firmness factor, z is a density reduction factor for various fabric types. The weave factor is defined in a different way by Brierley (1931) differentiating between weave groups as plain, matt, twill and sateen. Snowden (1965) gave rules and proposed values for the firmness factor V_F and density reduction factor z for various fabric types (single or complex).

Apart from structural problems dealt with above there may be difficulties from the aesthetic point of view in obtaining figures in desired dimensions in tappet and dobby looms. This is because, first, the dimensions of a figure to be obtained depends on yarn densities and secondly there may be limitations in the number of warp movements necessary to create the figure contour in a given loom equipped with a certain number of heald frames. Baser (1984, 2008) proposed formulae which related the figure width, as an aesthetic element, to structural parameters, namely yarn count and density and to the weave factor. This interrelation is obtained by substituting Eq. (1) into the relation

$$S = \frac{a}{A} \qquad (4)$$

where a is the figure width, A is the number of heald frames (or of warp movements) allocated for figured section and N is the warp yarn count given by

$$N = \left(\frac{A}{akKF_w} \right)^2 \qquad (5)$$

The fabric unit weight, on the other hand, is expressed as

$$W = \frac{200kS}{N} = \frac{200k^2 KF_w}{\sqrt{N}} \qquad (6)$$

By rearranging Eq. (6) one gets

$$\frac{W\sqrt{N}}{F_w} = 200k^2 K = \text{Constant} \qquad (7)$$

Baser (1984) proposed that Eq. (7) could be defined as a design function which expressed the interrelation between structural and aesthetic parameters for a figured single woven fabric and developed this approach, later, for complex structures.

4. FABRIC DESIGN AS AN OPTIMIZATION PROBLEM

Fabric design as a general product design problem may be considered an optimization problem to determine principal design parameters to lead to the production of a fabric required to satisfy an objective function. Baser (2008) noted the mathematical bases of such an approach. The objective functions may be fabric unit weight, fabric strength, fabric cost or a specific quality function such as fabric handle. Multi-objective optimization methods will not be so suitable for fabric design problems since there are so many process parameters involved some of which operate in contradictory ways such as fabric thickness enhancing non-permeability and warmth whereas deteriorating softness and fabric handle.

There are works that applied optimization approach to fabric design such as that of Leaf and Clement (1986) which developed a method of mathematical analysis to design a plain woven fabric with certain mechanical properties and unit weight. They pointed out that the behaviour of a fabric could be expressed directly by the reactions it gave to stresses which could be expressed approximately by linear relations as

$$F = E\varepsilon \, , M = B/l \, , \, S = G\alpha \qquad (8)$$

where F, M, S are tensile force, bending moment and shear force and ε, l, α are strain, bending length and shear angle respectively. Thus the fabric behaviour depended on E_1, E_2 the Young moduli in two directions, B_1, B_2 the bending rigidities in two principal planes and G the shear modulus. Leaf and Clement added to these constants two more, namely the fabric unit weight W and the fabric cover K, related to fabric structure, determining the fabric behaviour. They expressed these constants as functions of stresses (or tensions, T_1, T_2), deformations and of fabric structural constants as

$$E_1 = E_1(T_1, T_2, \beta_1, \beta_2, p_1, p_2, l_1, l_2)$$

$$E_2 = E_2(T_1, T_2, \beta_1, \beta_2, p_1, p_2, l_1, l_2)$$

$$B_1 = B_1(T_1, T_2, \beta_1, \beta_2, p_1, p_2, l_1, l_2) \qquad (9)$$

$$B_2 = B_2(T_1,T_2,\beta_1,\beta_2,p_1,p_2,l_1,l_2)$$

$$G = G(T_1,T_2,\beta_1,\beta_2,p_1,p_2,l_1,l_2)$$

$$W = W(T_1,T_2,\beta_1,\beta_2,p_1,p_2,l_1,l_2)$$

$$K = K(T_1,T_2,\beta_1,\beta_2,p_1,p_2,l_1,l_2)$$

There are seven equations which can be expressed by defining the required values which denote the fabric properties. An eighth equation is given by Peirce to represent the state of the fabric before stress as

$$\beta_1 = \sin\theta_1 / p_2^2 = \beta_2 \sin\theta_2 / p_1^2 \tag{10}$$

where θ_1, θ_2 are weave angles and p_1, p_2 fabric lengths in weave unit.

Thus it is necessary to find the forms of the functions defining these constants. The easiest of them are fabric unit weight and fabric cover which are given by the equations

$$W = (T_1 l_1 + T_2 l_2) / p_1 p_2 \tag{11}$$

$$K = \frac{d_1}{p_1} + \frac{d_2}{p_2} - \frac{d_1 d_2}{p_1 p_2} \tag{12}$$

Leaf and Clement defined the remaining five elastic constants by equations given by authors namely Leaf and Kandil (1980), Leaf and Aida and Sheta (1984), Clement (1985) and Livesey and Owen (1964). They applied an iterative method to obtain a design solution which follows:

If the equations (9) are represented as $Y_{is} = Y_i(x_1, x_2, \ldots, x_n)$ and it is assumed that $x_i = x_{j0}(1,2,\ldots,n)$ is an expected temporary value of the solution, then $Y_{i0} = Y_i(x_{10}, x_{20}, \ldots, x_{n0})$ can be calculated. When the calculation of s as

$$s = \sum_{i=1}^{n} \left(\frac{Y_{is} - Y_{i0}}{Y_{is}} \right)^2 = s(x_{10}, x_{20}, \ldots, x_{n0}) \tag{13}$$

is minimized as $Y_{i0} = Y_{is}$ for all i, then a solution is found. Thus, Leaf and Clement (1986) determined the elastic and structural constants for five sample fabrics and found agreement between theoretical and experimental values which meant that a design solution was found.

The subsequent work by Chen and Leaf (2000) "deals with the engineering design of woven fabrics for both domestic and industrial applications" in which a software program, MECHFAB, was developed to optimize fabric structural parameters.

In another work by Baser (2012), on the other hand, a mathematical function was defined for the aesthetic value to be calculated on a number of single figured worsted and cotton fabrics designed and produced by Sokmen (2004). A statistical method of assessment was applied to compare results obtained between those by expert judges and those determined by the application of the theory developed. The theoretical values calculated for each fabric sample were used to select the best one according to the design objective. The sample fabrics and the figure developed with twill weaves in single worsted fabrics are shown in Figure 1 with average, lowest and highest scores given by judges who were required to evaluate aesthetic appeal or aesthetic quality. The figure shape was chosen as one which contained contours with diagonal and curved lines and different weaves and yarn densities were applied in weaving samples as discriminatory features.

The theoretical approach to aesthetic evaluation based on certain assumptions, as agreed by experts generally, were such as: Larger figures are more appealing, long yarn floats spoil the contours, higher yarn density enhances the aesthetic feeling. An aesthetic value function was built, given as

$$E = W_1 Z_1 + W_2 Z_2 + W_3 Z_3 + W_4 Z_4 + W_5 Z_5 \tag{14}$$

Class 3-C: 97.4
HV: 122.7, LV: 87.0

Class 4-C: 107.4
HV: 110.4, LV: 88.6

Figure 1. Sample fabrics (HV: Highest value or score, LV: Lowest value or score)

where Z_1, Z_2, Z_3, Z_4 and Z_5 are components for figure size, sharpness of figure contour, surface smoothness, thread setting and bright appearance respectively and the coefficients W represent factor weights determined by expert judges. The variables Z are functions expressed in terms of the above assumptions and calculated on the bases of structural parameters of the woven sample fabrics given as

$$Z_1 = f\left(A, \frac{1}{S}\right), \ Z_2 = f\left(S, A, \frac{1}{F}\right), \ Z_3 = f\left(\frac{1}{d}, F\right), \ Z_4 = f(S), \ Z_5 = f\left(\frac{1}{d}, F, S\right) \tag{15}$$

Here, F is the average yarn float lengths in the weaves employed, A is the number of warp movements or heald frames used for figuring, d is the yarn diameter. The interrelations between the structural parameters were included in the formulation of the standardized Z functions, namely

$$Z_1 = Z_{01} / \overline{Z}_{01}, \ \ Z_2 = Z_{02} / \overline{Z}_{02}, \ \ Z_3 = Z_{03} / \overline{Z}_{03}, \ \ Z_4 = Z_{04} / \overline{Z}_{04}, \ \ Z_5 = Z_{05} / \overline{Z}_{05}$$

$$Z_{01} = \frac{A(F+1)}{kFK\sqrt{N}}, \ Z_{02} = \frac{kKA.\sqrt{N}}{F+1}, \ Z_{03} = \frac{kFK\sqrt{N}}{F+1}, \ Z_{04} = \frac{kFK\sqrt{N}}{F+1}, \ Z_{05} = \frac{kF^2K^2N}{F+1} \tag{16}$$

Statistical analyses were carried out on jury assessments of aesthetic value of the fabrics produced to search consistency of jury judgements. Both expert and non-expert juries were found consistent in their judgements. Multiple regression equations were obtained along with theoretical evaluation, for the aesthetic value in terms of the design variables from the scores obtained for each class of fabrics, as

$$y = \beta_0 + \beta_1 F + \beta_2 A + \beta_3 N \tag{17}$$

and multiple correlation coefficients were calculated. A correlation analysis was also applied to investigate agreement between jury evaluations of the aesthetic value and its theoretical determination as explained above.

5. COMPUTER-AIDED WOVEN FABRIC DESIGN

The methods adopted in computer aided woven fabric software are similar to those of conventional design techniques starting developing structural design on a point paper arrangement created on computer screen. In CAD software an interface is usually developed consisting of a set of menus and lists. Menus are activated to start certain functions of design work. These functions are generally those run to prepare colour palette, to prepare veave designs on the screen ruled in point paper fashion, to create picking and drafting plans. There may be a data base to select standard weaves and yarn types to be used in creating screen image of the designed fabric. The screen images are created in pixel or raster (vector) based subroutines. Woven fabric CAD software are marketted for dobby designs as well as for jacquard designs.

5.1 CAD Software for Dobby Looms

The computer aided (CAD) software for both dobby and jacquard looms are generally designed with means of transferring the design information to the relevant loom. As a result of examination of the CAD systems Textile CAD, Dolphin 2 (In),

Ocean 2 (In), Penelope Dobby (Informatica Textil), Easy Weave (Fashion Studio), Igos-Dobby (Nedgraphics), Pixel Dobby (Pixelart), Pointcarré Dobby Weaving Software (Pointcarré) it may be stated that the following functions are realized in (Baser, 2005):

1. Development of weave an surface design
2. Creating colours
3. Application of colour plans
4. Preparation of drafting, picking and denting plans
5. Applications of different settings (yarn densities)
6. Checking the weavability of the fabrics designed
7. Generating different weaves and different colour possibilities
8. Simulation of fancy yarns
9. Fabric simulation
10. Three dimensional yarn and fabric simulations
11. Design of sample swatches
12. Cost calculation

Although not all these functions are not provided in all of the software, the principal functions such as weave and figure development, the application of colour plans, the preparation of drafting, picking and denting plans and different setting alternatives exist almost in all.

5.2 CAD Software for Jacquard Looms

CAD systems developed for jacquard fabrics provide great advantages as flexibility and time saving. Almost all the work that a designer do on paper which require great care can be done on computer screen. Besides, various pictures, photographs, drawings, traditional figures and scanned images of fabric samples can be used in developing the surface design. On examining systems developed for jacquard designing such as Pixel Studio (Pixelart), VDMS (Viable Systems), Actrom Master (PMB), Hi-Tex (Colarado International), PC Edit/PC Weave (Bonas), Jac-Design (Grosse), Penelope Jacquard (Informatica

Textil), Tex-Design (Softec Bongioanni), Texcelle (Nedgraphics), Easy Jacquard (Fashion Studio), Pointcarré Jacquard Weaving Software (Pointcarré) it was seen that such software could fulfill the following functions listed in three groups (Baser, 2005):

A- Preparation of Surface Plans

1. Free drawing

2. Extraction of figures from the main drawing and transferring them to another design

3. Resizing of the selected figures, their rotation or repeating

4. Transfer of pictures or drawing to computer by scanning or electronic pencil

5. Correction or change of drawings

6. Building a colour palette

7. Colouring the drawings

8. Change of colours in designs prepared or scanned, reduction of the number of colours

9. Determination of repeats of drawings or of scanned designs

10. Creation of point paper arrangements of various dimensions

11. Creation of point paper arrangements in dimensions proportional to warp and weft setts

B- Weave Development

1. Development of weaves on computer screen in point paper representation

2. Archieving weaves developed and calling back a selected one

3. Display of weaves, resizing them in proportion to warp and weft densities

4. Application of colour plans to selected weaves and display of fabric appearances on face and back

5. Creation of final point paper design by combining surface design with weave structure (or structures).

6. Application of extra yarn or double weaves to design

7. Preparation of drafting, picking and denting plans

8. Changing yarn float lengths (for extra yarns) when desired

C- Yarn Simulations

1. Simulation of yarns in required colour

2. Simulation of fancy yarns

3. Three dimensional yarn simulation

D- Fabric Simulation

1. Simulation of fabric face and back appearances by applying colour plans

2. Simulation of fabric appearances according to required yarn densities

3. Three dimensional fabric simulations

E- Other functions such as the transfer of picking (pegging) plan directly to card puncher or electronic jacquard

In a series of studies Baser and his co-workers have developed design approaches and computer programs based on the mathematical approach to woven fabric design explained above resumed as follow:

A program was developed for fabric design (Baser and Ozden, 1990) as part of Ozden (1988)'s M.Sc. thesis work which stored data of design parameters belonging to selected commercial fabrics listed according to main structural parameters such as fabric type, yarn type, fabric unit weight, yarn count, yarn densities etc. in a hierarchical order. The relevant design parameters of commercial fabrics could be called up in the process of designing at the time of a decision to be made, to assign a value to a certain design parameter, thus giving guidance to the designer to make appropriate decisions to run the design program. The design parameters obtained by the analyses of a number of commercial worsted, woollen, cotton and filament fabric samples were listed in hierarchical order in a table incorporated in the program as a stored data base. Another work was to develop a program to simulate fabric surface appearances of stripe and check fabrics of various weaves used on the computer screen (Baser and Ozden, 1990). The weave structures could be generated automatically by the program which applied methods of developing derivative weaves from simple weaves namely plain, matt, twill and sateen. Fabric surface simulations of coloured check designs based on 2/2 twill and bird's eye weaves obtained by a program prepared by Baser in Gwbasic programming codes are shown in Figure 2 and 3.

Another program using Visual Basic 6.0 language which provided possibilities to design figured single fabrics as well as coloured stripe and check fabrics was developed by Yıldırım and Baser (Baser, 2005). The interface of the program and the figured fabric image obtained by using 2/1 and 1/2 twill weaves in figure and ground respectively are shown in Figure 4.

As a follow up Baser (2020) developed a comprehensive computer program in Visual Basic Studio 10 to realise the structural and aesthetic design of woven fabrics which also provided production parameters to prepare production orders and estimated fabric cost. Thus, it was shown that the whole scope of fabric design, weaving production planning and process control could be managed using computer aid. The final interface showing the structural design of a coloured check fabric outcome is given in Figure 5.

A method of structural design of double woven fabrics was developed which employed computer drawing and animation to search the best geometrical model of fabric cross sectional geometry that gave minimum space between yarns (Baser, 2015). The geometrical model was later applied in a M.Sc. research work by Soyheptemiz (2007) to determine the best assumptions to lead to best section geometries of self-stitched double fabrics. The output of a trial computer run is given in Figure 6.
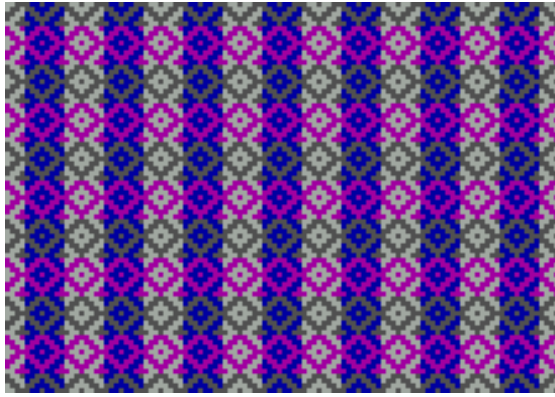
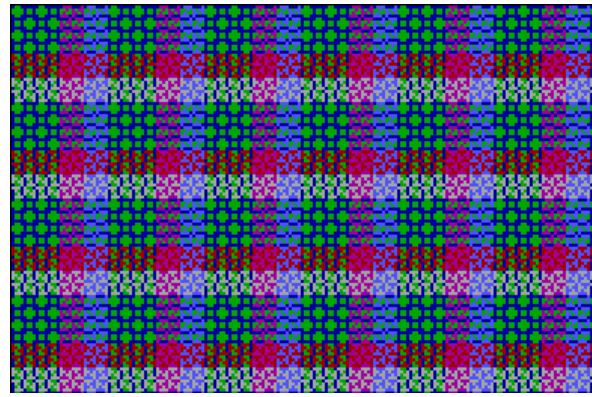**Figure 2.** A coloured check design using 2/2 twill

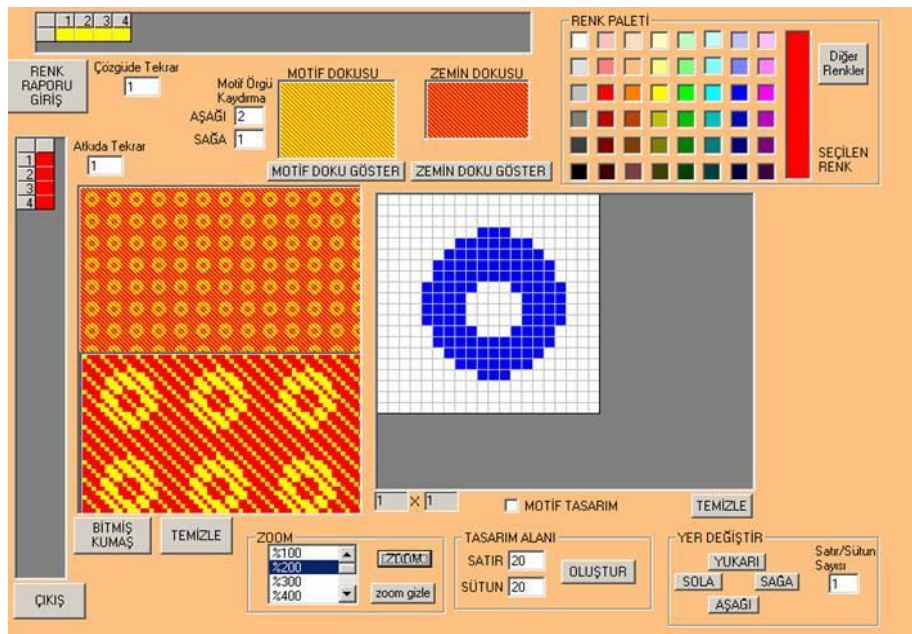**Figure 3.** A coloured check design using bird'eye weave

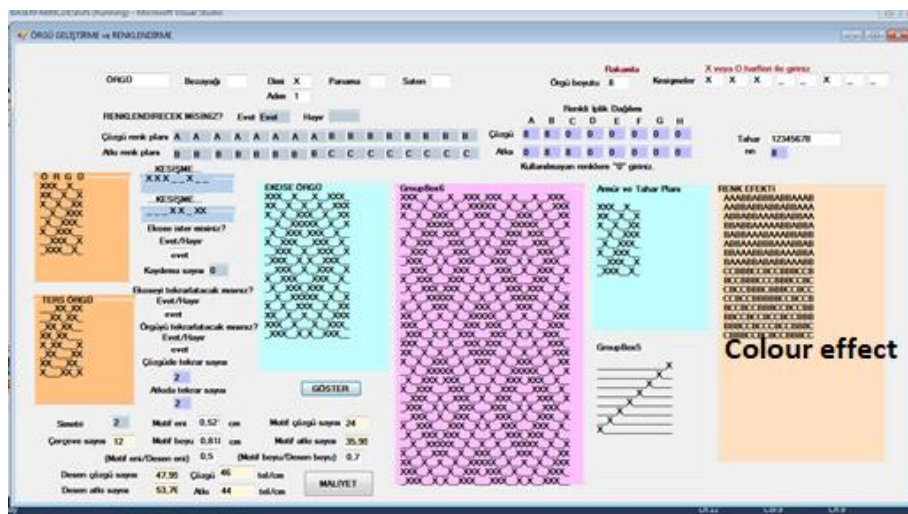**Figure 4.** Interface of fabric surface design program (Baser, Yıldırım, 2003)

Figure 5. Structural design of a coloured check fabric (Baser, 2020)

```
p1= 0.050, cap= 0.010, a1= 0.012, b1= 0.010, a11= 0.010
  h=0.054, ara=0.0, z= 0.012,  mag=  2000
  e= 1.85, f1=0.040, f2=0.020, f3=%-1.850, f4=-.160
```
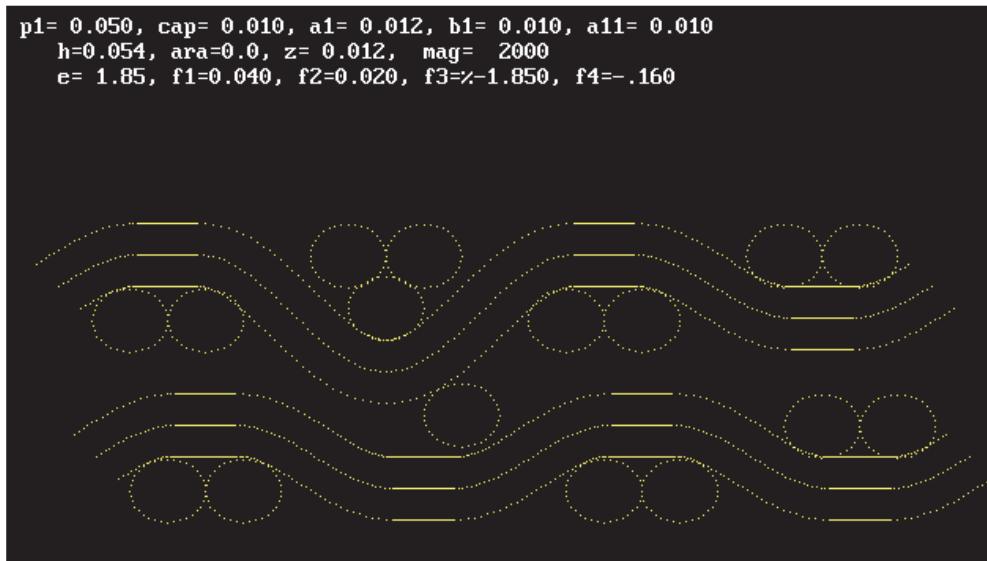
Figure 6. Geometric simulation run for a self-stitched double fabric with 2/2 twill face and back weave (Baser, 2015)

In work done by Baser, Kirtay and Onder (1986) a method of analysis of machine carpets and computer evaluations of analysis data to redesign similar structures were explained. An algorithm was also developed to calculate theoretically pile density and unit yarn lengths based on geometrical models of Wilton and Axminster carpets (Baser, 2008, 2013). The geometrical model developed by Baser for Axminster Kardax carpet structure is shown in Figure 7.

6. A GENERAL STRUCTURAL FUNCTION OF WOVEN FABRICS

Baser (2020) defined 21 types of woven fabrics of different structure by a single mathematical function in terms of weights of constituent yarns used in unit fabric area, expressed by the equation

The definitions of symbols used in Equations (18-21) are given in Table 1. It is hoped that these formulae may help to achieve the structural and aesthetic design of various single and complex woven fabrics such as figured, backed, extra yarn, double and

treble fabrics. Here the index i denotes the number of layers, the variables u and v will take values 1 or 0, zero meaning that those terms will vanish in Eq. (18) for single fabrics.
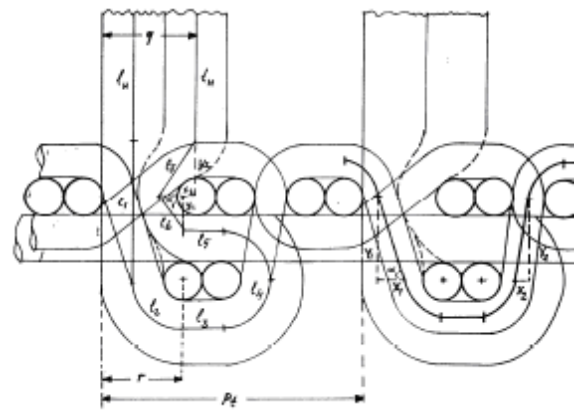

Figure 7. Axminster Kardax machine carpet geometrical model (Baser, 2013)

$$w = \frac{100ik_{F/1}S_{F/1}}{N_{F/1}} + \frac{100ik_{B/2}S_{B/2}}{N_{B/2}} + \frac{100k_{F/1}S_{F/1}}{N_{F/1}} \cdot \frac{au}{e_1 pR} + \frac{100k_{B/2}S_{B/2}}{N_{B/2}} \cdot \frac{bv}{e_2 qQ} \qquad (18)$$

It is also proposed that Eq. (19) is to be used with the following equations representing the relations and conditions expressed by a setting theory applied to complex structures:

$$S_{F/1} = k_{F/2}F_{wF}K_{F/1}V_F\sqrt{N_{F/1}}(1-z) \qquad (19)$$

$$S_{B/2} = k_{B/1}F_{wB}K_{B/1}V_B\sqrt{N_{B/2}}(1-z) \qquad (20)$$

$$t = \frac{S_{F/1}}{S_{B/2}} \qquad (21)$$

6. DISCUSSION AND CONCLUSIONS

Textile fabrics are planer structures with a certain thickness having strength and flexibility that enable them to cover surfaces but possess also certain rigidity to resist deformation and fibre packing density with adequate resistance to air and water flow. Since these structures need to have sufficient durability and stability of structure in subsequent use, this requirement should be secured in raw material selection and design of their weave structure. This can be achieved in the light of available knowledge and extensive research findings. However, certain practical rules have also been set out to be applied for aesthetic and structural design of woven fabrics as the outcome of long industrial practice and scientific research. An equally important requirement is that the designed structure should be producible in actual production processes which may be termed as weavability. The application of an appropriate setting theory as formulated for complex structures by equations (19) and (20) with a suitably selected ratio of yarn densities, t, will serve this purpose along with correct selections of aesthetic and technical parameters related to surface design in accord with the design capacity and weft colour possibilities of the weaving loom to be employed. Another task is to fulfil aesthetic requirements that will make them attractive for the user, which manifest themselves in fabric surface appearance. The complex relationships between structural and aesthetic parameters and the possibilities and limitations presented by the available technology and production machinery make it quite difficult to produce a satisfactory design. Although some basic knowledge about textile materials and technology are given to textile designers, it will help greatly to equip them with means to allow them to work more freely and creatively. Therefore, besides, practical formulae and production data computer aided design tools, doing most of the technical work and solve such problems behind the computer screen, will certainly be of great benefit. However, it may be useful to state, here, that the commercial CAD design software available should be furnished with more technical information and control means which secure weavability and compatibility of designed fabric with selected design variables. It will be beneficial to include in the software a large database covering design variables belonging to standard fabric types to guide and inspire the fabric designer.

It is worth mentioning that various visual materials included in CAD software about yarn and weave types, especially in those offered for Jacquard fabric designing are of great help and motivation to the designer. It may also be noted that mathematical optimization approach should be applied with care because of non linear relationships between various design variables.

It is the aim of this paper to point to the state of the art of woven fabric design and make some contribution towards this goal by drawing attention to right approaches and by giving a brief coverage of relevant research work and computer applications.

Table 1. Definitions of the symbols used in Equation (18-21)

Symbol	Definition
i	Layer definition: $i = 1$: Single layer or backed fabric, $i = 2$: Double layer fabric, $i = 3$: Treble fabric
u	Figure or wadding indicator (warp): $u = 1$: Figure or wadding exists. $u = 0$: No figure or wadding
v	Figure or wadding indicator (weft): $v = 1$: Figure or wadding exists. $v = 0$: No figure or wadding
$k_{F/1}$	k_1: Warp crimp factor for single fabrics, k_F: Face yarn crimp factor for double fabrics
$k_{F/2}$	k_2: Weft crimp factor for single fabrics, k_B: Face yarn crimp factor for double fabrics
$S_{F/1}:S_1$	Warp density for single fabrics, S_F: Face yarn density for double fabrics
$S_{B/2}:S_2$	Weft density for single fabrics, S_B: Back yarn density for double fabrics
$N_{F/1}:N_1$	Warp yarn metric count for single fabrics, N_F: Face yarn metric count for single fabrics
$N_{B/2}:N_2$	Weft yarn metric count for single fabrics, N_B: Back yarn metric count for double fabrics
a	Figure width in single fabrics or figure width in double fabrics with extra warp figuring yarns
e_1	Extra warp yarn metric count / ground yarn metric count in single or double fabrics with figuring
p	Ground warp yarn density / extra warp yarn density in single or double fabrics with figuring
R	Figure width in cm. in single or double fabrics
b	Figure height in cm. in single or extra weft single or extra weft double fabrics
e_2	Extra weft yarn metric count / ground yarn metric count in single or double fabrics with figuring
q	Ground warp yarn density / extra warp yarn density in single or double fabrics with figuring
Q	Height of the design unit in cm.
t	Yarn density of the weft or of face yarns to that of the warp or of the back yarns
z	Yarn density reduction (%)/100

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