EXPERT SYSTEM TO SELECT THE FABRICS FOR TRANSFORMABLE GARMENTS

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Abstract: *The aim of this study is to develop a prototype of the expert system of the fabrics selection to design transformable clothing with a required level of quality. Based on the final values of the factors the lists of fabrics' properties were formed for any given combinations of garment types. Roughness was selected as a preferable parameter to evaluate the smoothness of the fabric in comparison with the friction coefficient. The ranges of the roughness characteristics for the groups of fabrics were obtained and summarised. Multifractal analysis of the roughness characteristics was performed. Recommended ranges of fabrics properties for transformable garments are obtained as intersections of the uncountable sets, which determine the value ranges of specific parameters of the main fabric properties. As a result of research the expert system knowledge base for solving the subtasks of fabrics selection for the transformable garments in the shell 'Rapana' has been developed. The prototype provides a dialogue with the user as a series of questions and answers of system's user. Thus, the necessary conditions for the further development of artificial intelligence techniques in the design of clothing were created.*

Keywords: *fabric, roughness, multifractal analysis, expert system*

1 INTRODUCTION

Today, fashion industry is facing a huge challenge towards sustainability because fast fashion is dominating the mass market. Fast fashion and consumers' purchasing format are closely linked to each other [1]. The life cycles of fashion items are shortened and the items are being replaced within a very short period to fulfil consumers' needs. Transformable fashion is one of the appropriate alternatives to reduce consumption and reinforce consumers to engage in sustainable lifestyle [2]. The traditional wardrobe is similar in basic functionality and no longer sustained social and consumer needs. It results in the growing need for transformable fashion.

The ability to change its function makes transformable clothes very useful when life conditions are changing as fast as nowadays [3]. These clothes can be worn for longer periods of time and on various occasions, thus minimizing waste generation in two ways by reducing the consumer's need to purchase additional garments, and by decreasing materials consumption in the fashion industry.

2 ANALYSIS OF PUBLISHED DATA AND STATING THE PROBLEM

There is much different information about the appearance of the transformable clothing in literature [2-4], fashion shows, online shops, fashion magazines, online fashion reviews, patents databases, etc. Many researchers investigate the principles of transformation in the clothing design [5].

Transformable fashion or convertible fashion can be defined as a garment that can be comfortably worn in multiple ways. It can be transformed into another shape and able to transform back to the original shape by altering its components. Transformable garments belong to the chains of transformations which usually include at least two different types of garments. Each of them must be made of different fashion fabrics and, besides that, they must meet different quality requirements.

A reversible garment is a type of transformable fashion as well. A reversible garment is a garment that can be worn at least in two different ways. There is no true "inside out" to the reversible garment, since either way, it gives a fashionable appearance. Therefore, each side must have some lining properties. Lining is an inner layer of a fabric, fur, or other material that provides a neat finish; conceals seam allowances, interfacing, and construction details; and allows a garment to slip on and off easily.

High saturation of information environment and the risk of making wrong decisions increase the relevance of information technology as a means to support decision-making [6]. One way to address the informal or weakly formalized problems is the use of artificial intelligence methods and the creation of expert systems (ES).

Nowadays, scientists in the world successfully implement elements of artificial intelligence and the ES at various stages of designing clothes. Among them are expert systems for selection of clothes style according to the constitution features of consumers [7], for the choice of clothes to form a harmonious image of individual consumers [8], to assess the quality of design clothes drawings [9] and for the formation of industrial clothing range [10]. Some of them are aimed for the rapid change in design of women's outerwear [11], for the choice of clothes models based on the assessment of consumers' emotional impressions using the methodology of Kansei Engineering [6]. Development and implementation of interactive systems to select ready-made clothes via the Internet are shown in [12]. Development of ES for the design of special and corporate clothes is presented in [13].

However, none of them considers issues of designing the transformable clothing or selection of fabrics for such garments while usually the chosen fashion fabric defines the quality of clothes.

The aim of this study is to develop a prototype of the expert system for the fabrics selection to design transformable clothing with a required level of quality, which might be achieved by proper fabrics selection.

3 MATERIALS AND METHODS

Recommended ranges of fashion fabrics properties for transformable garments (or garments of the transformational chain) are to be obtained as intersections of the uncountable sets which determine the value ranges of specific parameters of the main fabric properties of the different end uses. If the garment is reversible, then one of the sets reflects the properties of the lining [3].

3.1 Input Data

The following Table 1 gives a summary of all weighting factors for the fabrics of different end uses. Types of garments, which compose typical chains of transformations, determine a number of groups of fabrics in the Table 1 (suit fabrics, raincoat fabrics, coat fabrics, and lining). The weighting factors of lining fabrics' properties were defined on the preliminary stage of the current research.

3.2 Listing the main properties of the fashion fabrics

In the cases when transformable clothing contains more than one garment type, the weighting factors of the main fabrics properties might be computed as arithmetical means of the weighting factors, which are assigned to the fabrics related to the garment types. Based on the final values of the factors the lists of properties were formed for any given combinations of garment types (Table 2).

Values of properties were selected out of the standards with general specifications for the outerwear, lining fabrics, woolen fabrics, semiwoolen fabrics, cotton and mixed fabrics, linen fabrics, waterproof and jacket fabrics, fabrics for waterproofs, and for the fabrics for dresses.

Table 1 Weighting factors of the fabrics properties

Properties	Code	Suit	Jacket	Coat	Lining
Wrinkle resistance [%]	X_1	0.20	0.16	0.05	–
Pilling [pills/cm^2]	X_2	0.15	–	–	–
The number of cycles of abrasion [cycle]	X_3	0.15	0.06	0.25	–
Dimensional stability (shrinkage) [%]	X_4	0.14	0.15	0.05	–
Air permeability [dm^3/(cm^2·s)]	X_5	0.12	–	0.10	0.19
Elasticity: residual strain [%]	X_6	0.12	–	0.12	–
Stiffness [μN·cm^2]	X_7	0.12	–	0.08	–
Water resistance [mm H_2O]	X_8	–	0.24	–	–
Water permeability [g/(m^2·s)]	X_{10}	–	0.22	0.12	–
Thermal resistance [(m^2·K)/W]	X_{11}	–	0.11	0.20	–
Colour fastness [point]	X_{12}	–	0.06	–	0.11
Bursting strength [daN]	X_{13}	–	–	0.03	–
Sewed seam slippage (yarn slippage) [daN]	X_{14}	–	–	–	0.11
Smoothness	X_{15}	–	–	–	0.36
Permeability of water vapour [g/(m^2·hr)]	X_{16}	–	–	–	0.11
Hygroscopicity [%]	X_{17}	–	–	–	0.12

Table 2 Lists of the fabrics properties of different end uses

End use of fabric	Garments types	Number	Revers	Main properties
Suit	Suit jacket	1	–	X_1, X_2, X_3, X_4, X_5, X_6, X_7
Raincoat	Jacket	1	–	X_1, X_3, X_4, X_8, X_9, X_{10}, X_{11}
Coat	Coat	1	–	X_1, X_3, X_4, X_5, X_6, X_7, X_9, X_{10}, X_{12}
Raincoat	Raincoat	1	–	X_1, X_3, X_4, X_8, X_9, X_{10}, X_{11}
Suit and raincoat	Suit jacket, jacket	2	–	X_1, X_3, X_4, X_8, X_9
Suit and raincoat	Suit jacket, raincoat	2	–	X_1, X_3, X_4, X_8, X_9
Suit and raincoat	Suit jacket, jacket, raincoat	3	–	X_1, X_3, X_4, X_8, X_9
Suit and coat	Suit jacket, coat	2	–	X_1, X_3, X_5, X_6, X_7, X_{10}
Raincoat and coat	Raincoat, coat	2	–	X_1, X_3, X_4, X_8, X_9, X_{10}
Raincoat and coat	Jacket, coat	2	–	X_1, X_3, X_4, X_8, X_9, X_{10}
Raincoat and coat	Raincoat, jacket, coat	3	–	X_1, X_3, X_4, X_8, X_9, X_{10}
Suit, raincoat and coat	Suit jacket, raincoat, coat	3	–	X_1, X_3, X_4, X_9, X_{10}
Suit, raincoat and coat	Suit jacket, jacket, coat	3	–	X_1, X_3, X_4, X_9, X_{10}
Suit, raincoat and coat	Suit jacket, jacket, raincoat, coat	4	–	X_1, X_3, X_4, X_9, X_{10}
Suit and linings	Suit jacket	1	+	X_1, X_5, X_{14}
Raincoat and linings	Raincoat	1	+	X_5, X_8, X_9, X_{11}, X_{14}
Raincoat and linings	Jacket	1	+	X_5, X_8, X_9, X_{11}, X_{14}
Raincoat and linings	Raincoat, jacket	2	+	X_5, X_8, X_9, X_{11}, X_{14}
Coat and linings	Coat	1	+	X_3, X_5, X_{10}, X_{14}
Suit, raincoat and linings	Suit jacket, jacket	2	+	X_1, X_4, X_5, X_{11}, X_{14}
Suit, raincoat and linings	Suit jacket, raincoat	2	+	X_1, X_4, X_5, X_{11}, X_{14}
Suit, raincoat and linings	Suit jacket, raincoat, jacket	3	+	X_1, X_4, X_5, X_{11}, X_{14}
Suit, coat and linings	Suit jacket, coat	2	+	X_3, X_5, X_{14}
Raincoat, coat and linings	Raincoat, coat	2	+	X_3, X_5, X_9, X_{10}, X_{11}, X_{14}
Raincoat, coat and linings	Jacket, coat	2	+	X_3, X_5, X_9, X_{10}, X_{11}, X_{14}
Raincoat, coat and linings	Raincoat, jacket, coat	3	+	X_3, X_5, X_9, X_{10}, X_{11}, X_{14}
Suit, raincoat, coat and linings	Suit jacket, raincoat, coat	3	+	X_1, X_3, X_5, X_{11}, X_{14}
Suit, raincoat, coat and linings	Suit jacket, jacket, coat	3	+	X_1, X_3, X_5, X_{11}, X_{14}
Suit, raincoat, coat and linings	Suit jacket, jacket, raincoat, coat	4	+	X_1, X_3, X_5, X_{11}, X_{14}

4 EXPERIMENTAL PART

According to the information in the Table 2, the most important property of fabric for the reversible garment is its smoothness. Such a property is usually evaluated by the friction coefficient. However, recently more and more often frictional properties of the fabrics are evaluated by roughness characteristics [14-16]. The exact values of them are constant parameters, while the friction coefficient depends on conditions of the measurement. Therefore, roughness is a preferable parameter to evaluate the smoothness of the fashion fabric in comparison with the coefficient of friction.

4.1 Fabrics Roughness

In this way, empirical measurements of the linings roughness will determine a range of fabrics, which might be used for reversible garments. Thus, according to method [16], two parameters (R_a, R_{max}) were used to reflect fabric roughness: R_a – arithmetical mean deviation of the profile [µm]; R_{max} – maximum height of the profile [µm]. The script and scanned images of tissue samples were used in 3D computer graphics software (Rhinoceros) to evaluate the fabrics' roughness [16]. The minimal numbers of measurements were calculated based on the results of the preliminary research: 58 – for the lining, 122 – for the coat fabrics, 73 – for the suit fabrics, and 50 – for the jacket fabrics. Hence, the ranges of the roughness characteristics for the abovementioned groups of fabrics were obtained and summarised in the Table 3.

Table 3 Fabric roughness characteristics

Roughness parameter	R_a [µm]	R_{max} [µm]
Suit and lining	3.2-191.9	10-645
Coat and lining	25-191.9	91-645
Raincoat and lining	1.9-133.5	6-396
Suit, raincoat and lining	3.2-133.5	10-396
Suit, coat and lining	25-191.9	91-645
Raincoat, coat and lining	25-133.5	91-396
Suit, raincoat, coat and lining	25-133.5	91-396

4.2 Multifractal Analysis

Nowadays, scientists of the world successfully implement fractal analysis in clothing design [17]. We suppose that fabrics roughness might be investigated by using multifractal analysis as well.

If we consider a fabric fragment to be a self-similar object and a section profile – a multifractal and regard the series of values of coordinates on the profile as a multifractal set, MFFA can be applied. Recently, we developed a method of MFFA, giving a description of the time series within the framework of a simple numerical procedure [18]. Subsequent optimization of method of MFFA allowed one to carry out the multidimensional analysis of multifractal multiplicities [19-25]. Following [22], we represent a self-athena surface by two-dimensional array X (i,j) where the discrete arguments i, j run the values i=1, 2, …, M and j=1, 2, …, N. Then the investigated surface is divided into Ms×Ns nonoverlapping square segments of s×s sizes, where the numbers Ms=[M/s] and Ns=[N/s] represent an integer part obtained after dividing of interval of changing arguments *i*, *j* into the segments. Noting the importance of the investigated function in each of its by indices *v*, *w*, we present it by the sequence $Xvw(i;j)=X(l_1+i;l_2+j)$, where the arguments $1\leq i$, $j\leq s$ are changed in the segment, which is defined by numbers $l_1 = (v-1)s$ and $l_2 = (w-1)s$. Then for each segment, we calculate the cumulative sum:

$$u_{vw}(i;j)=\sum_{k_1=1}^{i}\sum_{k_2=1}^{j}X_{vw}(k_1;k_2) \tag{1}$$

where $1\leq I$ and $j\leq s$.

From the geometric point of view the dependence $u_{vw}(i;j)$ determines the fractal surface. Like the one-dimensional time series, irregular dependence $u_{vw}(i;j)$ should be measured from the smooth surface $\tilde{u}_{vw}(i;j)$, which takes into account the trend in the changing of original function $u_{vw}(i;j)$ and is called a trend.

$$\tilde{u}_{vw}(i;j)=ai+bj+c \tag{2}$$

where the parameters *a*, *b*, *c* are determined by the method of least squares.

In the trend interpolation one can use more advanced functions $\tilde{u}_{vw}(i;j)$, however it only slightly improves the accuracy due to the significant spending of computer time. Accounting the trend leads to residual matrix:

$$\tilde{u}_{vw}(i;j)=u_{vw}(i;j)-\tilde{u}_{vw}(i;j) \tag{3}$$

~ the use of which provides a specific dispersion of segment:

$$F^2(v;w;s)=\frac{1}{s^2}\sum_{i=1}^{s}\sum_{j=1}^{s}\varepsilon_{vw}^2(i;j) \tag{4}$$

Averaging over all segments leads to total dispersion:

$$F_q(s)=\left\{\frac{1}{M_sN_s}\sum_{v=1}^{M_s}\sum_{w=1}^{N_s}\left[F(v;w;s)\right]^q\right\}^{1/q} \tag{5}$$

which is deformed by parameter *q* the change of which is limited by the real values. According to (5), the negative values *q* amplify the contribution of segments corresponding to small fluctuations and positive ones give out large values $F(v; w; s)$. If $q=0$ the definition (5) should be replaced by:

$$F_0(s)=exp\left\{\frac{1}{M_sN_s}\sum_{v=1}^{M_s}\sum_{w=1}^{N_s}ln\left[F(v;w;s)\right]\right\} \tag{6}$$

To obtain statistically reliable data, one should change the value s from $s_{min}\approx 6$ to $s_{max}\approx min(M,N)/4$. For self-similar sets, it leads to the scaling ratio:

$$F_q(s)\sim s^{h(q)} \tag{7}$$

where $h(q)$ is a generic index of Hearst.

In the double logarithmic coordinates the dependence (7) is represented by a straight line whose slope gives the rate $h(q)$ for diverse values of parameter *q*. The mass index can be found from the dependency $h(q)$:

$$\tau(q)=qh(q)-D \tag{8}$$

where *D* is the topological dimension of the space containing the investigation object (for the surface D=2).

Multifractal spectrum *f(α)* is determined by the Legendre transform:

$$f(\alpha)=q\alpha-\tau(q),\ \alpha=d\tau/dq \tag{9}$$

Equations (8) and (9) provide a complete set of multifractal characteristics that describe the self-similar objects [19, 20].

The method of MFFA was applied to two types of fabrics: 1 – the lining and 2 – the coat fabric. The images of fabrics were taken with the digital microscope Sigeta Forward LCD (10-500x). The obtained digital image was cut with the tools for viewing and processing images to the size of 1 mm (using the scale). Then the bitmap image of the fabric profile was scaled to real size and construction lines were applied (Figure 1). In Figure 2 the dependence of variance on the scale *s* in double logarithmic coordinates for the abovementioned fabrics is demonstrated.

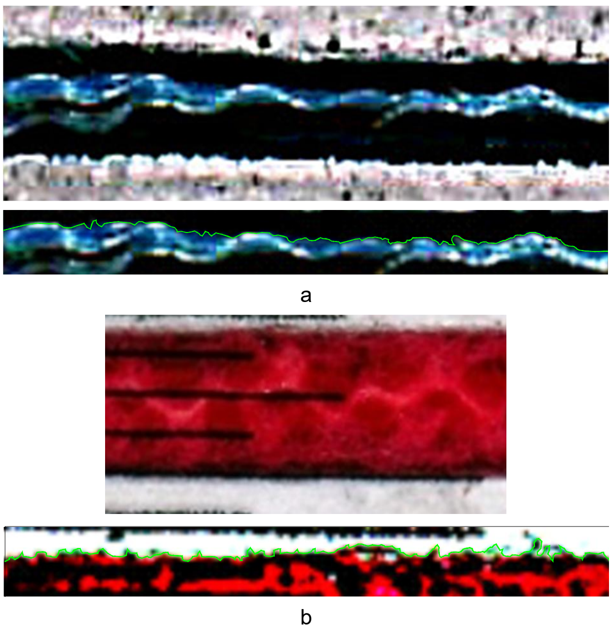


Figure 1 Arbitrary images of normal fabric sample profiles: lining (a) and coat fabric (b)

The given figures show that a linear type of dependence is evident, and it does not practically change for different values of *q*. If we pay attention to Figure 2, we can observe significant variance distinctions with the same value q=1 that vividly indicates the differences in fabric roughness.

The negative values of *q* were disregarded because the method of multifractal analysis is inapplicable when *q*<0. Further application of the method MFFA gave mass indices of the samples under investigation.

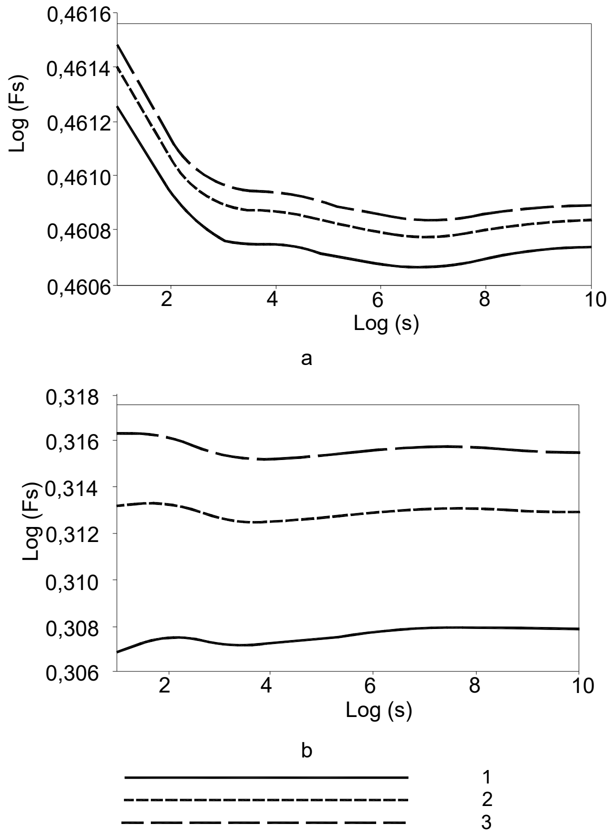


Figure 2 Dependence of dispersion on the scale *s*; Line 1 corresponds to *q*=1, Line 2 – *q*=10, Line 3 – *q*=15 for the lining (a) and for the coat fabric (b)

The linear dependence in Figures 2 and 3 demonstrates that the error of the method is minimal, i.e. the change of zoom has a little influence on the value of mass index. This proves the existence of a similar-like structure of the fabrics.

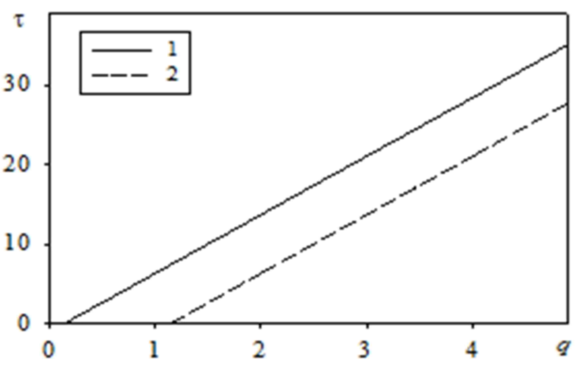


Figure 3 Dependence of mass index:

Line 1 – for the lining, Line 2 – for the coat fabric

5 EXPERT SYSTEM FOR THE FABRICS SELECTION

In order to develop a prototype of ES for subtasks of fabrics selection, we selected 'empty' shell of ES called 'Rapana' [26], which is distributed free of charge via the web-site (http://esrapana.narod.ru/) and is able to solve the problem of different industries. Complex 'Rapana' includes two components: 'Cognitograph' (software for the developers of knowledge base) and 'Expert' (application for users). Using 'Expert' does not require special training, because dialogue is conducted by natural language.

An ES, which is under development, is based on the rules called productions. A production system provides the mechanism necessary to execute productions in order to achieve some goal for the system. In the given situation, the goal is the confirmation of advisability to use the chosen fashion fabric to design the specific garment. Otherwise, the system is supposed to advise which ones of the fabrics properties are to be defined in order to make a well-founded decision. Productions consist of two parts: a sensory precondition ("IF" statements that are represented in the headers rows and columns) and an action ("THEN" statements that are represented in related cells).

The cells, which correspond to the preconditions that are advisable for the given situation, are highlighted in green (Figure 4). The cells highlighted in red represent the properties of fabric that must not be used for the specific garment. White color means that fabric with given properties might be used, but not highly recommended.

Suit and raincoat fabrics		X_1=1				X_1=0			
		X_3=1		X_3=0		X_3=1		X_3=0	
		X_4=1	X_4=0	X_4=1	X_4=0	X_4=1	X_4=0	X_4=1	X_4=0
X_8=1	X_9=1	1.000	0.781	0.841	0.622	0.727	0.508	0.568	0.349
	X_9=0	0.833	0.614	0.674	0.455	0.560	0.341	0.401	0.182
X_8=0	X_9=1	0.818	0.599	0.659	0.440	0.545	0.326	0.386	0.167
	X_9=0	0.651	0.432	0.492	0.273	0.378	0.159	0.219	0

Suit, coat and linings	X_3=1		X_3=0	
	X_5=1	X_5=0	X_5=1	X_5=0
X_{14}=1	1.000	0.651	0.768	0.419
X_{14}=0	0.581	0.232	0.349	0

Suit and linings	X_1=1		X_1=0	
	X_5=1	X_5=0	X_5=1	X_5=0
X_{14}=1	1.000	0.644	0.770	0.414
X_{14}=0	0.586	0.230	0.356	0

Figure 4 A fragment of the production system of the expert system that is developed

Examples of dialogues of the developed expert system, which represent consumer's answers to the system's questions and dialogue results, are shown in Figure 5. The way of decision-making for the given circumstances is presented in the Figure 6. Thus, the necessary conditions for the further development of artificial intelligence techniques in the design of clothing were created.

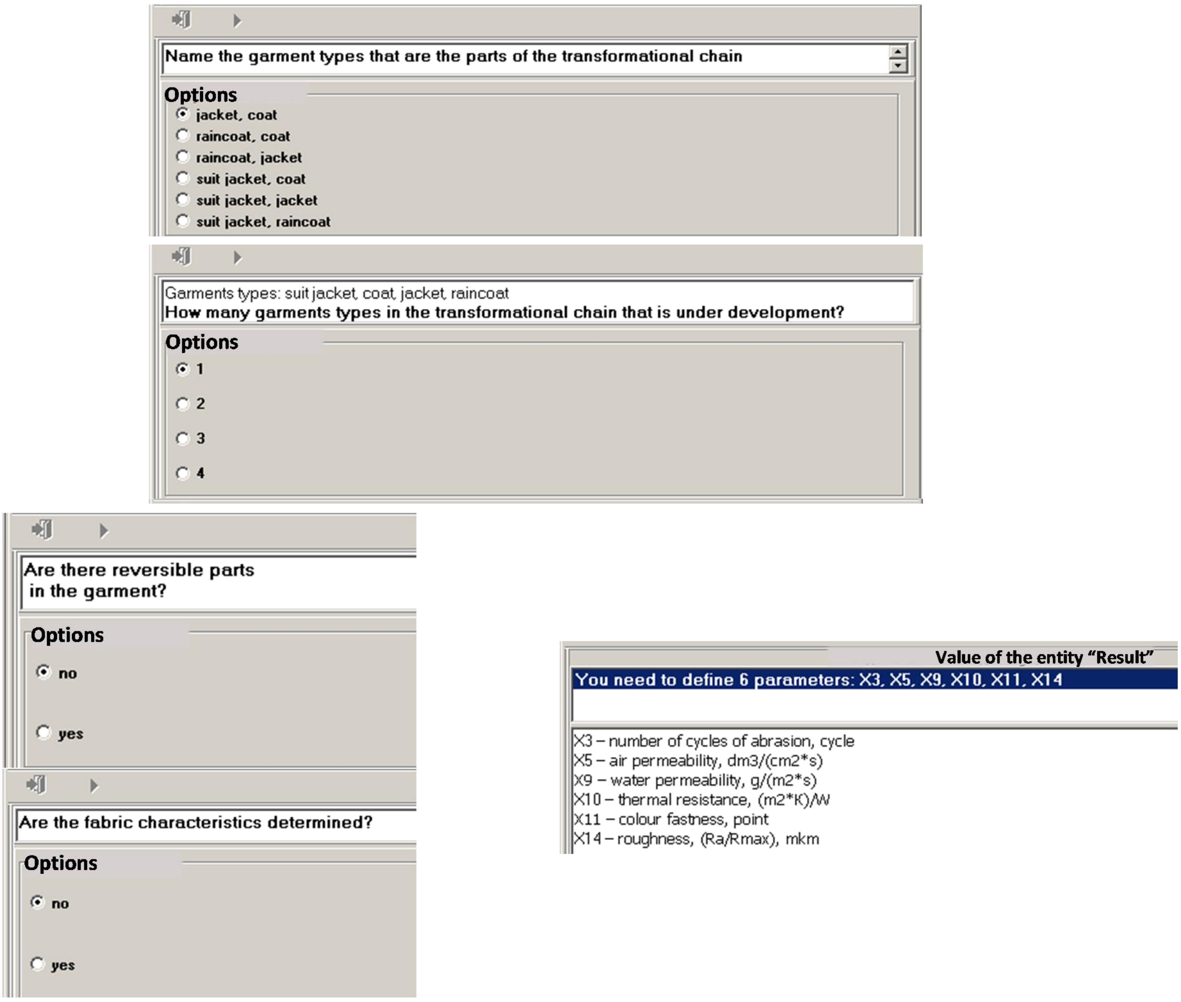
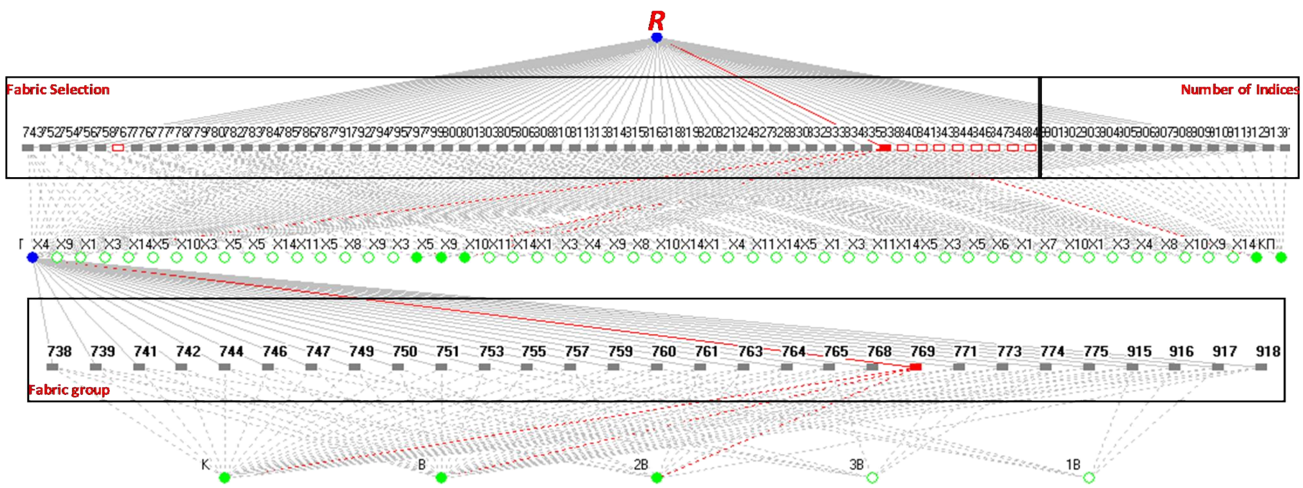


Figure 5 The expert system 'Fabric selection'



entity that has got the value as a result of the rule applied
entity that has not got a value and depends on the rule applied
entity that has not got a value and does not depend on the rule applied
K number of garments in the transformational chain
3B length of the transformational chain is 3
2B length of the transformational chain is 2
1B length of the transformational chain is 1
B type of the garment

entity that has got a value
applied rule
non applied rule
КП number of indices
R result
Г fabric group
X1-X14 indices of fabrics properties

Figure 6 The way of decision-making of the expert system 'Fabric selection'

The required level of quality of the transformable clothing under development is to be achieved through unmistakable choice of the fashion fabric that is well known as the core of any garment.

6 CONCLUSIONS

As a result of research the ES knowledge base for solving the subtasks of fabrics selection for the transformable garments in the shell 'Rapana' has been developed. The system can be used for the selection of the fabrics for the typical garments that will be designed separately, but successively one after another. Although it is no transformable garment, such chain of designing might be considered as a transformational chain. Therefore, the developed expert system might be considered as a part of the bigger one, which is aimed for the rapid change in apparel design at the specific enterprise.

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