AUTEX Research Journal, Vol. 23, No 2, June 2023, DOI 10.2478/aut-2022-0006

DE GRUYTER

ASSESSMENT AND SEMANTIC CATEGORIZATION OF FABRIC VISUAL TEXTURE PREFERENCES

Duje Kodžoman[1], Aleš Hladnik[1], Alenka Pavko Čuden[1], Vanja Čok[2]

1 University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Textiles, Graphic Arts and Design, Ljubljana, Slovenia
2 University of Ljubljana, Faculty of Mechanical Engineering, Chair of Engineering Design and Transportation Systems, Ljubljana, Slovenia
*Corresponding Author. E-mail: dujekodzoman@gmail.com

Abstract:

The texture of a fabric can be perceived by the haptic and visual senses. Visual texture can be defined as a visual quality of a surface. It is an important phenomenon because it can be significant in many fields, such as textile design and e-commerce. At the same time, when we consider the semantics of the word, it is important to take into account that there are a variety of manifestations of fabrics (e.g., woven, knitted, etc.). The mechanism of visual texture perception of fabrics was investigated by measuring visual evaluation values. In our experiment, 12 textile samples with different surface textures are evaluated using thirty-four adjectives (Kansei words). For each visual texture, the adjectives with the highest mean ratings are extracted and analyzed. By using Hierarchical Cluster Analysis (HCA) and Principal Component Analysis (PCA), we aimed to discover and determine preferences for the visual texture of fabrics. The result is a semantic explanation of fabric texture with the adjectives proposed, which can help customers to evaluate the quality of the textile.

Keywords:

Fabric; hierarchical cluster analysis; principal component analysis; semantic meaning; textile; texture; visual preference

1. Introduction

Texture is one of the essential structural elements of natural images; others, such as color and shape, are also important and have been studied extensively in the field of image retrieval [1] and analyzed in many types of images. Despite its importance and ubiquity in image data, there is no formal approach or completely precise definition of texture [2].

However, a commonly accepted definition states that textures are surface qualities of textiles that are related to the material's physical structure, construction, mechanical properties, and surface characteristics of the material and are perceived as a whole through a combination of tactile and visual cognition [3]. Generally, texture is defined as a visual pattern consisting of a few basic repeating primitives called textons [4]. "Textons" are fundamental microstructures in natural images (and videos) and are considered the atoms of pre-attentive human visual perception [4]. Texture analysis is one of the most challenging problems in image processing and computer vision as well as a long-standing one. The visual aspect of surface variation is called visual texture. Visual textures are significant in images that exhibit variations in pixel intensity at the resolution limit but whose spatial covariance is relatively homogeneous [5]. Artists and designers have long used visual textures as a means to evoke emotions and set moods (see [6, 7]).

In the textile industry, the conventional approach to evaluating the surface properties of fabrics is based on manual operations using microscopes. With the development of computer vision technology, many researchers have used 3D laser and computer vision techniques to measure the geometric texture features of fabrics for a variety of applications, such as surface roughness inspection in manufacturing [8, 9, 10], texture classification [11, 12, 13], defect detection in textile quality control [14, 15], shape recognition [16], etc.

From a theoretical point of view, textures can be divided into tactile and visual textures. The former, also called actual textures or physical textures, are actual surface variations [17], including but not limited to fur, wood grain, sand, and the smooth surfaces of canvas, metal, glass, and leather [18]. Physical texture differs from visual texture in that it has a physical quality that can be felt by touch [19]. Visual texture is the illusion of a physical texture. Every material has its own

visual texture. Photographs, drawings, and paintings use visual texture to portray their participant matter both realistically and interpretively [20].

When we look at woven fabrics, knitted fabrics, and lace, we perceive fine surface structures, textures, and patterns that are different in each of them. At the same time, they evoke feelings of comfort and beauty through different types of visual information [21]. For humans, aesthetic quality is always coupled with identifying the semantic content of images referring to visual texture [22]. When people evaluate the aesthetic quality of an image, they must first understand what they are evaluating. Semantic content is predominantly objective, while aesthetic attributes are subjective. Humans are capable of both visual and haptic perception of textile surface modalities. Nevertheless, there would be a difference in judgments even if perceptions were extracted from the same textile surfaces. We can estimate tactile properties from vision alone or at least create the tactile impression of the product based on the visual assessment. In online shopping, for example, we can often evaluate the properties of clothing based on pictures and assess how the particular fabric would feel on our skin. In the context of online shopping, the visual perception of fabrics is crucial, and the success of the product and its sales depends on it.

1.1. Toward E-commerce: Visual Perception of Fabric Structure

The online shopping experience encompasses several factors, such as shortening shopping time, facilitating price comparison, access to product and technology news, and others. However, some aspects of e-commerce regarding the experience of contact with the product are a hindrance [23]. Lester at al. [24] argue that one of the major shortcomings of online shopping is that shoppers cannot touch the products. Citrin at al. [25] explain that the need to touch products is negatively related to online purchasing, especially for clothing. The shopping experience (and buying decision) can be impaired because of the desire to try on, touch, and feel the clothes [26]. Since apparel may pose certain risks when purchased online, it is important that e-companies develop strategies and solutions to reduce this risk. Therefore, understanding the differences between consumers and their knowledge and perceptions regarding the appealing product and fabrics can consequently maximize purchase intention.

The e-commerce fashion industry is on the rise and everything is sold based on visual perception. However, while the absolute numbers of clothing items are steadily increasing, one of the biggest problems of the e-commerce industry is the lack of opportunity to physically try on and touch a product. To compensate for this disadvantage, online retailers need to sell an experience, not just a product. We reviewed the literature and found that there is a lack of in-depth studies on the visual perception of fabric textures. There are studies on predicting the subjective feel of fabrics and the perception of fabric softness [27, 28], a study on the subjective feel of leather in automobiles [29], and a study on the expression and verbalization of tactile feelings [30].

Zhao et al. [31] set up an online questionnaire in which they asked participants to view a dynamic apparel picture and select their preferred words to describe the picture. Moody, Kinderman, and Sinha [32] conducted an experiment to investigate clothing preference by asking participants to view different clothing styles and then select their preferred ones. In another study, Zhao et al. [33] investigated summer shirt fabric preferences and their characteristics—the influence of gender, visual, and tactile influence on fabric preference. They found that visual details were essential factors influencing customer preferences.

When we see an object, we generally have a good idea of how it would feel [34, 35]. This visual prediction of haptic material properties has practical implications for retail businesses that rely on visual communication [36]. It is well known that an appealing visual display of products increases consumer purchase intention [37, 38]. Napompech [39] argues that online apparel sellers should post realistic images of garments from different angles on their website to help buyers imagine how the garment would fit on their own bodies. Wijntjes et al. [36] found that dynamic visual information (a movie) reveals more about how fabrics feel than static visual information (a picture). Information such as color, size, and fit were found to be particularly important factors in reducing perceived risk in clothing purchases, especially when they provided information about sensory and experiential aspects [38]. We all have a variety of memories about textiles that come from experiences of looking at, touching, and wearing them [40].

In 2015, Shanthi and Kannaiah [41] noted that online shopping is a growing reality that helps consumers reduce search time for products and services, and today online shopping is booming—a pandemic year drove many more shoppers online. According to a Statista report [42], fashion is the largest market segment in B2C eCommerce, and its global size was estimated to be $525.1 billion in 2019. The market is expected to continue growing at 11.4% per year [43]. In previous studies, researchers have used various techniques to measure visual texture preferences, and Kansei engineering has been widely used in this context. Kansei engineering is a consumer-oriented technology for new product development that aims to develop or improve products and services by transferring customers' psychological feelings and needs into the product design domain [44, 45]. Often users use Kansei words or adjectives to describe their feelings about products. Therefore, it is important how products are explained semantically. Küller [47] has developed a structured method called semantic environment description (SMB). The SMB method is easy to administer, has high reliability and validity, can be easily adapted for cross-cultural comparisons, and provides useful knowledge for design, engineering, and marketing.

The semantic environment description (SMB method) is a method that can be used to evaluate and better understand the overall impression of an environment, and according to Küller [46] it can help to reveal how people assess their impression based on pleasantness and the information rate. Küller's adjectives were originally grouped into eight factors: Pleasantness, Complexity, Unity, Enclosedness, Social Status,

Potency, Affection, and Originality [47]. These factors and KWs have been used in studies related to computer-based environment [48], indoor environment with emphasis on office interior [49, 50], virtual environment [51], outdoor environment at nursing homes [52], healthcare environment [53], the automotive industry [54, 55], e-commerce [56], and many other fields. Lokman and Kamaruddin [57] proposed affinity clusters for affective product design where words are collected for each topic.

However, we believe that the visual texture of fabrics should be explained semantically, and the aim of this study is to define the consistency of kansei words or adjectives that best describe the affective characteristics of clothing products. Our interest was to find out how the texture of fabrics and their material composition is perceived and semantically described by users. This will help both industry and academia to capture users' subjective emotional experiences of fabric texture preferences.

2. Experimental

This study focuses on the subjective assessment of 12 visual texture preferences of fabrics. The semantic content was not specified, so respondents did not know which fabric texture they were evaluating.

The procedure for this study was adopted from Nagamachi [44] and Karlsson [45]. We used the steps related to the Kansei engineering: (1) collection of adjectives describing the emotional attributes of fabrics and textiles, (2) collection of fabric visual texture database of stimuli, (3) procedure-assessment of fabric visual texture preferences with the semantic scales, (4) data analysis using Hierarchical Cluster Analysis (HCA), (5) data analysis using Principal Component Analysis (PCA), and (6) interpretation of the results.

The 83 respondents were predominantly female (75.9%), and 24.1% were male. Most of the respondents were 35 years old or younger (81.9%). In addition, many had a college degree (60.2%), while 36.1% had a high school degree or a lower level of education. In all, 63.2% of student respondents were studying graphic design and 21.1% were studying fashion design. The country of residence of most respondents was Slovenia (43.4%), followed by Croatia (37.3%). All respondents participated in the study voluntarily and were asked to confirm that they had normal or corrected-to-normal vision in order to proceed with the completion of the questionnaire.

2.1. Materials—Collection of Adjectives

The first step of this study was to extract adjectives that describe the impression one has of a texture, such as attractive, luxurious, dynamic, etc. (see all adjectives in Table 1). In this study, 34 adjectives (17 pairs) were collected from WGSN, experts and pertinent literature. Based on these adjectives, a checklist was developed to assess the samples in the evaluation session. The checklist includes all adjectives arranged on a 7-point Semantic Differential scale from a negative to a positive connotation.

The search procedure for the adjectives was based on a review of the literature—scientific papers, but also fashion articles. We looked for adjectives suitable for the description of the visual texture of fabric. We paired the appropriate adjectives with their positive/negative poles. After extracting the adjectives, we checked their distribution in research from different areas (see Table 1).

2.2. Materials—Collection of Fabric Visual Texture Database of Stimuli (Samples)

The visual texture database of stimuli used in our experiment consists of 12 types of commercially available fabrics with different patterns, as shown in Figure 1, and they were used as samples. All samples were mostly beige or white, but they were converted into binary (black and white) images.

Selected samples were produced by various manufacturing technologies: weaving, knitting, knitting finished with fulling to achieve a particularly soft look and handle, and leather processing. The raw materials used to produce the selected textures were either natural, such as cotton, wool, silk, and leather/suede, or man-made such as polyamide, polyester, polyacrylonitrile and polypropylene. The influential factors that define the textures are summarized in Table 2.

The selected textures are described below.

Jersey is a soft, stretchy, knitted fabric originally made of wool, but now also made of cotton, blends, and synthetic fibers. Single jersey is a lightweight fabric made on a single knitting machine needlebed [58, 59]. Its technical face is smooth, with the side limbs of the needle loops having the appearance of columns of Vs in the wales. On the technical back, the loops form columns of interlocking semicircles [60]. Jersey stretches slightly more in the transverse direction than in the longitudinal direction. It also tends to curl at the edges and is less stable than some other types of knits [61].

Satin weave has a visible sheen and feels smooth, which is due to a tightly woven structure that allows the yarn to lay across the surface of the fabric. Fabrics in satin weave are often used as linings because they glide easily over other garments. They typically have a glossy surface and a dull back and drape well. The compactness gives the satin fabric more body and less porosity, making the fabric warmer. Long yarn floats make it susceptible to abrasion and snagging [61, 62].

Faux (fake) fur is a type of textile fabric made to simulate genuine animal fur. It is a pile fabric and is typically made from polymer fibers that are processed, dyed, and cut to match a specific fur texture and color. The primary polymer used for faux fur is acrylic and modacrylic. Today's faux furs are almost indistinguishable from the natural furs they imitate. They are more durable and resistant [63, 64].

Leather is a material made by tanning animal hides or skins. Leather stretches but does not return to its original shape. It is one of the oldest fabrics used by humans for clothing. It is not constructed but cut from the animal as a skin [58].

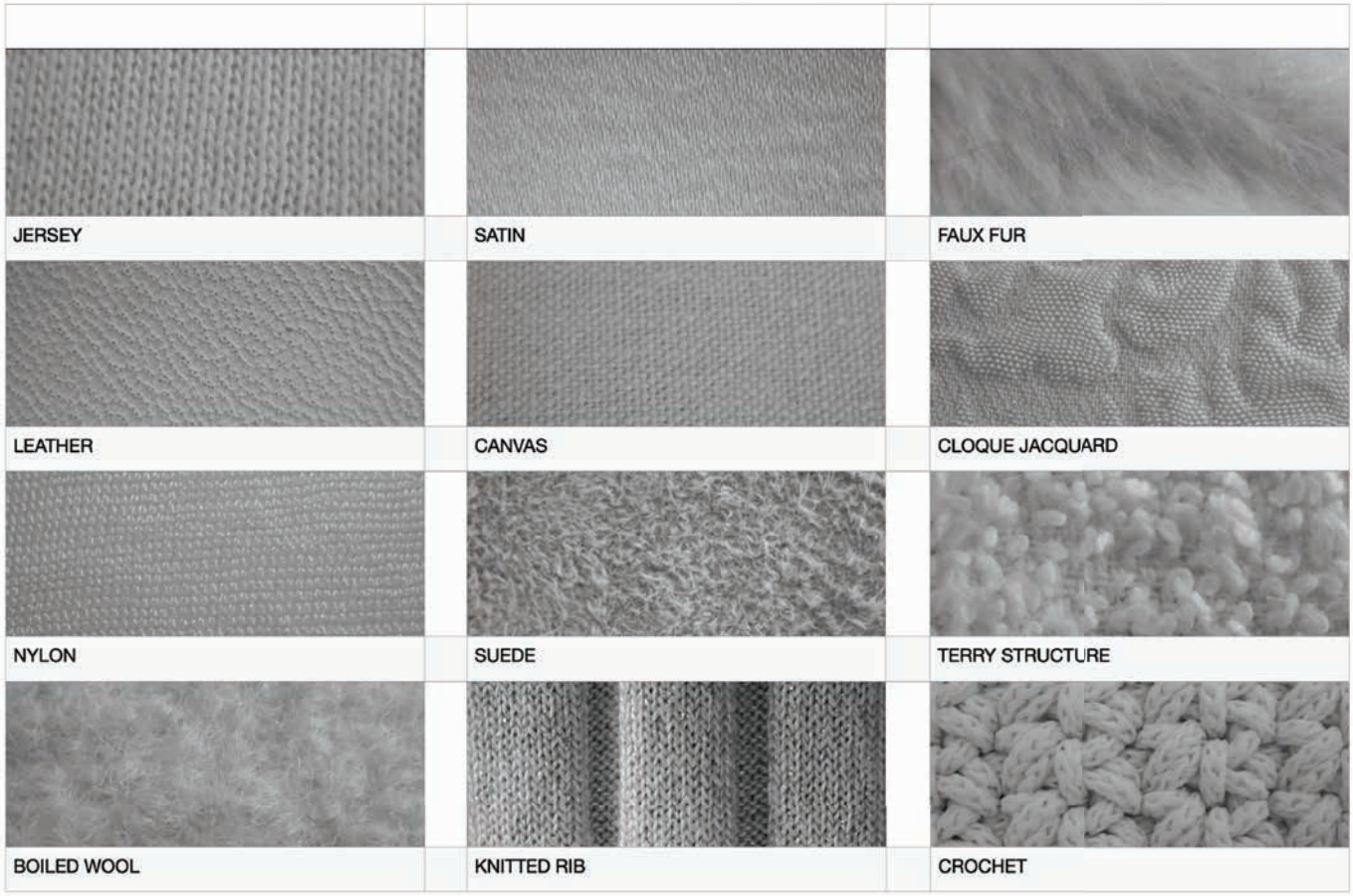


Figure 1. Fabric texture samples.

Canvas is an extremely durable, heavy, tightly woven, and very stiff fabric made from a uniform yarn. It was formerly used for sails and was made in a tight plain weave [58, 61, 65]. Today it is used for sports equipment and footwear, sportswear, workwear, bags, upholstery, art supplies, etc. [66].

Jacquard is a woven structure that creates patterns and textures through a complicated weave system in which warp and weft threads are raised and left. An intricate pattern is woven on a special mechanical loom rather than printed on the surface. Compared with printed designs, a jacquard pattern is much more wearable and retains its luster over a longer period of time. Cloqué is a lightweight fabric with a puckered, sculpted, or bubbled effect on the surface. It has a high/low relief pattern with shiny and matte areas. The ruffle effect is created by weaving yarns under varying tension. Cloqué jacquard is a fabric with a jacquard weave that has a ruffle or bubble effect. It is often made from silk, wool, and cotton blends [58, 65, 67, 68].

Nylon (polyamide) is a strong, lightweight synthetic fiber, but it melts easily at high temperatures. It is also a smooth fiber, which means that dirt does not easily adhere to its surface. It has very low absorbency, so it dries quickly and does not require ironing. Nylon has long been of major importance in the manufacture of women's hosiery as it can be heat set and is strong, elastic and abrasion resistant. In the filamentous form, it is characterized by moderate sheen. The main advantage of polyamide fabric is its elasticity and softness. It does not retain heat effectively or transport moisture to the same extent as other fabrics, but it can be formed into thin fabrics such as stockings [61, 67, 69].

Suede is a type of leather made from the underside of animal skin, giving it a soft surface. It has a fuzzy surface produced by brushing the flesh side of the hide with abrasive-coated rollers. It is usually made from lambskin, but can also be made from other types of animals, including goats, pigs, calves and deer. Suede is softer, thinner, and not as strong as full-grain traditional leather [58, 61].

Terry is a fabric with loops that can absorb large amounts of water. It is mostly used for towels and bathrobes. It can be made by weaving or knitting. It is usually made of 100% cotton, but can sometimes contain polyester. In the fabric, the ground is visible in the spaces between the uncut loops of the pile. Terry has a moderately soft drape. The loop pile tends to snag and pull. The fabric gives off lint easily [61, 62].

Boiled wool is made by boiling woolen fabrics to shrink and compress the fibers. It is a thick and dense knitted fabric with the stability and shape retention of a woven fabric. It is very durable, comfortable to wear and warms in inclement weather conditions. It looks the same on both sides [70].

Ribbing is the general term for any knitting pattern that results in vertical columns of knit and purl loops. Knitted rib is a knitted

Table 1. Distribution of adjectives in previous scientific articles and study areas.

Adjective pairs	Study area	Author
Bad-Good	outdoor environment, healthcare environment, product design	Bengtsson et al. [52], Sundberg et al. [53], Lokman et al. [57]
Boring-Interesting	indoor environment, virtual environment, outdoor environment, healthcare environment, product design	Fischl G. [49], Houtkamp et al. [51], Bengtsson et al. [52], Sundberg et al. [53], Habyba et al. [56], Lokman et al. [57]
Cheap-Luxurious	e-commerce, product design	Habyba et al. [56], Lokman et al. [57]
Disturbing-Calm	computer-based environment, indoor environment, e-commerce, product design	Janssens J. [48], Fischl G. [49], Evensen et al. [50], Habyba et al. [56], Lokman et al. [57]
Gentle-Powerful	automotive industry, product design	Sutono et al. [54], Lokman et al. [57]
Inexpressive-Expressive	healthcare environment, product design	Sundberg et al. [53], Lokman et al. [57]
Insensitive-Sensitive	product design	Lokman et al. [57]
Ordinary-Special	outdoor environment, healthcare environment, automotive industry, product design	Bengtsson et al. [52], Sundberg et al. [53], Sutono et al. [55], Lokman et al. [57]
Sad-Happy	product design	Lokman et al. [57]
Stative-Dynamic	product design	Lokman et al. [57]
Unappealing-Appealing	product design	Lokman et al. [57]
Unattractive-Attractive	automotive industry, product design	Santos M. Lokman et al. [54], Lokman et al. [57]
Unexciting-Exciting	product design	Lokman et al. [57]
Unharmonious-Harmonious	computer-based environment, indoor environment, product design	Janssens J. [48], Fischl G. [49], Lokman et al. [57]
Premodern-Modern	computer-based environment, outdoor environment, healthcare environment, automotive industry, e-commerce, product design	Janssens J. [48], Bengtsson et al. [52], Sundberg et al. [53], Sutono et al. [55], Habyba et al. [56], Lokman et al. [57]
Unsophisticated-Sophisticated	product design	Lokman et al. [57]
Weak-Strong	computer-based environment, indoor environment, product design	Janssens J. [48], Fischl G. [49], Lokman et al. [57]

Table 2. Factors influencing texture: production technology, raw material composition and origin.

SAMPLE NUMBER	TEXTURE	TECHNOLOGY	MATERIAL COMPOSITION	MATERIAL ORIGIN
1	jersey	Knitting	100% cotton	natural textile fibers
2	satin	Weaving	100% silk	natural textile fibers
3	faux fur	Knitting	80% acrylic / 20% polyester	synthetic textile fibers
4	leather	leather processing	natural leather	natural leather
5	canvas	Weaving	100% cotton	natural textile fibers
6	cloqué jacquard	Weaving	100% silk	natural textile fibers
7	nylon	Knitting	100% polyamide	synthetic textile fibers
8	suede	leather processing	natural suede	natural leather
9	terry	Weaving	100% cotton	natural textile fibers
10	boiled wool	knitting + fulling	100% wool	natural textile fibers
11	knitted rib	Knitting	100% cotton	natural textile fibers
12	crochet	Knitting	100% polypropylene	synthetic textile fibers

fabric with alternating raised and lowered rows. It is more elastic and durable than plain knitted fabric [58].

Crochet is a process of making textiles by intertwining loops of yarn, thread, or strands of other materials with a crochet hook. The word *crochet* comes from the French word *croc*, meaning "hook." Stitches are made with a single crochet hook to pull one or more loops through the previous loops of a chain. This construction can be built up to create a patterned fabric [58].

2.3. Procedure and Image Acquisition

Subjects were asked to complete an online questionnaire. Then, 12 samples (fabric texture stimuli) were shown one by one with 34 adjectives (17 pairs). The arrangement of the samples (see Figure 2 and Table 1) is numbered as presented in the study. The online survey system/tool did not allow us to randomly arrange the fabric texture samples. Subjects were asked to rate their feelings in the checklist according to the scale provided. The questionnaire included two sections: (1) demographic data of the respondents, including age, gender, education, and occupation; and (2) sensory experience, consisting of 204 questions. Images were presented as rectangles (2,400 × 700 pixels) on a white background. All respondents were required to adjust their screen settings to maximize the brightness of the screen, and this was a prerequisite to begin completing the questionnaire. Images were captured using a Canon IXUS 50 camera (lens model: 5.8–17.4 mm; focal length: 5.8 mm). The specimens were illuminated by a natural (sun) rather than an artificial light source. The camera was placed perpendicularly above the sample surface, the original image size was 2,592 x 1,944 pixels, and the image resolution was 180 dpi. Finally, the region of the image was set to 2,400 x 700 pixels and the image resolution to 180 dpi.

2.4 Data Analysis

HCA is a cluster analysis method that aims to form a hierarchy of clusters. Using this method, we were able to identify an average linkage between the groups consistent with the textile samples. For the clustering method, we used Ward's method to measure the squared Euclidean distance. HCA was performed with the aim of determining the number of clusters and their consistency. We then performed *k*-means clustering with the selection of three main semantic categories. The aim was to find out which pairs of adjectives are grouped together and how they are related to the textile samples.

As an alternative approach to the same goal—grouping adjective pairs—we adopted another multivariate method, PCA. PCA creates new variables, known as principal components (PCs), which are orthogonal linear combinations of the original variables. The number of extracted PCs is equal to the number of variables, but often the first few PCs already account for most of the variability in the data, so the higher ones mainly represent data noise and can be neglected. A thorough mathematical description of the procedure can be found in Jolliffe [71].

3. Results and discussion

For the HCA, we used Ward's linkage method. From the results of the HCA dendrogram, we can see that there are three main semantic categories (Figure 2).

As mentioned earlier, Küller's factors are Pleasantness, Complexity, Unity, "Enclosedness," Social status, Potency, Affection, Originality, and these factors have been used in many studies (see Table 1). In our study, the semantic categories Potency and Originality were kept unchanged in their names, while the Social status category was renamed Elegance. The Kansei affinity cluster Elegant was proposed in the study by Lokman and Kamaruddin [57] and has been used in studies related to the automotive industry [54, 55] and e-commerce [56].

The adjectives in the first cluster are: Cheap-Luxurious, Unmodern-Modern, Unsophisticated-Sophisticated, Gentle-Powerful, and Weak-Strong. Cheap-Luxurious is the most characteristic pair of the first cluster. We call this semantic category "Potency," and its description implies the expression of intensity and strength. Only two visual textures of fabrics are most prominent in this cluster (see bold values in Table 5), and they are satin and leather. This means that in terms of e-commerce and online shopping, satin and leather could be semantically described as strong, solid and sturdy fabrics whose structure appears coherent. In relation to the most characteristic pair of this cluster, both fabric textures are perceived as Luxurious—satin (M = 4.02, SD = 1.57) and leather (M = 4.58, SD = 1.59).

The adjectives in the second cluster are: Inexpressive-Expressive, Ordinary-Special, Unexciting-Exciting, Static-Dynamic, Boring-Interesting. The most characteristic pair for this cluster is Inexpressive-Expressive. The name of this semantic category is "Originality," and its description implies the quality of being different and interesting. The most prominent fabric textures in this cluster are faux fur, cloqué

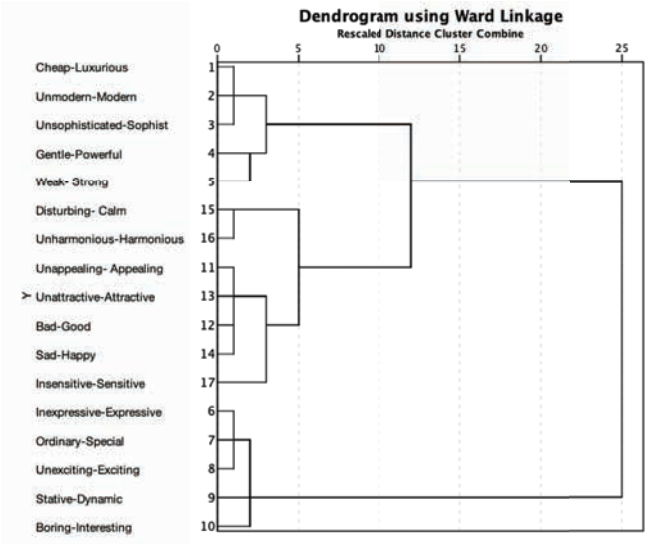


Figure 2. Dendrogram using Ward's method.

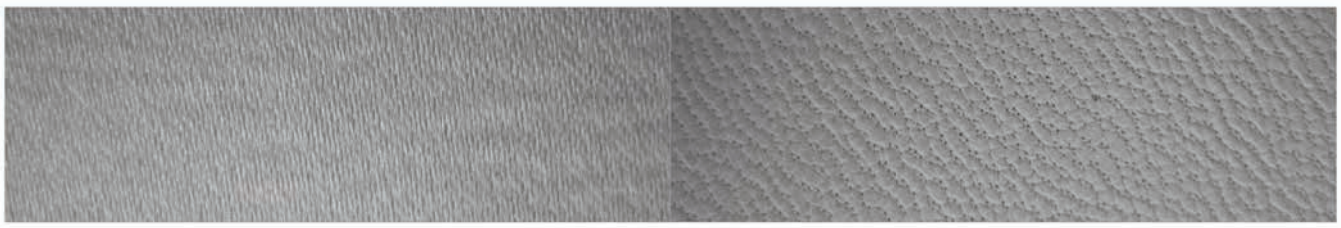


Figure 3. Selected textures: satin and leather.

Table 3. Semantic categorization and description of clusters.

SEMANTIC CATEGORY	DESCRIPTION	ADJECTIVES
POTENCY	The expression of intensity and strength.	Cheap-Luxurious, Unmodern-Modern, Unsophisticated-Sophisticated, Gentle-Powerful, Weak-Strong
ORIGINALITY	The quality of being different and interesting.	Inexpressive-Expressive, Ordinary-Special, Unexciting-Exciting, Static-Dynamic, Boring-Interesting
ELEGANCE	The measurement of a socio- economic value.	Unappealing-Appealing, Bad-Good, Unattractive-Attractive, Sad-Happy, Disturbing-Calm, Unharmonious-Harmonious, Insensitive-Sensitive

jacquard, suede, terry structure, boiled wool, and crochet. All of the above-mentioned fabrics have a haptic texture, and therefore their semantic value is associated with the adjectives Expressive, Dynamic, and Interesting. Although the textures of suede (8) and boiled wool (10) are completely different in terms of material composition and production technology; both fabrics look fluffy in terms of visual texture and scored the highest mean value for the adjectives Dynamic and Interesting (Table 6). Faux fur (3) and terry (9) textures both have a hairy surface and were characterized as Dynamic but are otherwise made from completely different materials (synthetic and natural) and with different technologies (knitting and weaving). Faux fur and boiled wool scored a high mean value for the adjective Interesting; while cloqué jacquard and terry also scored a high mean value for the adjective Calm. As mentioned earlier, the most characteristic adjective for this cluster is Expressive, and all 6 fabric textures scored high for this adjective: cloqué

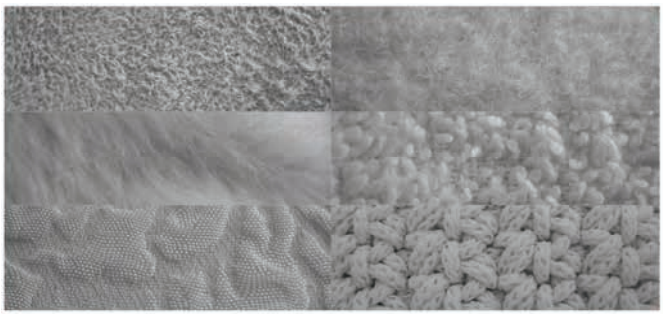


Figure 4. Selected textures: suede and boiled wool (top row); faux fur and terry (middle row); cloqué jacquard and crochet (bottom row).

Table 4. Cluster membership.

Case Number	Adjectives	Cluster	Distance
1	Cheap-Luxurious	1	0.629
2	Unmodern-Modern	1	0.737
3	Unsophisticated-Sophisticated	1	0.860
4	Gentle-Powerful	1	1.020
5	Weak-Strong	1	1.325
6	Inexpressive-Expressive	2	0.420
7	Ordinary-Special	2	0.739
8	Unexciting-Exciting	2	0.984
9	Static-Dynamic	2	1.175
10	Boring-Interesting	2	1.188
11	Unappealing-Appealing	3	0.651
12	Bad-Good	3	0.790
13	Unattractive-Attractive	3	0.955
14	Sad-Happy	3	1.006
15	Disturbing-Calm	3	1.241
16	Unharmonious-Harmonious	3	1.353
17	Insensitive-Sensitive	3	1.622

Table 5. Final cluster centers

	1	2	3
Jersey	3,58	3,03	4,65
Satin	**4,12**	3,40	3,92
faux fur	4,12	**4,91**	4,24
Leather	**4,69**	4,63	3,97
Canvas	3,64	3,17	**4,01**
cloqué jacquard	4,79	**5,63**	4,48
Nylon	4,09	3,43	**4,51**
suede	3,80	**4,61**	3,60
terry structure	3,66	**4,71**	4,59
boiled wool	3,59	**4,31**	3,54
knitted rib	4,17	4,23	**4,77**
crochet	4,59	**5,18**	5,06

jacquard (M = 5.65, SD = 1.34), crochet (M = 5.19, SD = 1.25), faux fur (M = 5.05, SD = 1.50), terry (M = 4.75, SD = 1.47), suede (M = 4.55, SD = 1.75), boiled wool (M = 4.43, SD = 1.67).

The adjectives in the third cluster are Unappealing-Appealing, Bad-Good, Unattractive-Attractive, Sad-Happy, Disturbing-Calm, Unharmonious-Harmonious, Insensitive-Sensitive. The most characteristic pair for this cluster is Unappealing-Appealing. We call this semantic category “Elegance,” and its description implies the importance of a socio-economic value. The fabric textures in this cluster are jersey, canvas, nylon, and knitted rib. A high similarity was found between the textures of jersey (1) and nylon (7). Their similarity cannot be explained by material composition, since jersey is a natural fabric and nylon is a synthetic fabric. Instead, similarities can be found in the production technology (both are produced by the knitting technology) and in the visual resemblance of the fabric texture. All fabric textures from this cluster scored the highest mean value for the adjectives Calm and Harmonious but also the lowest mean value for the adjectives Ordinary and Static (Table 6). This means that jersey, canvas, nylon, and knitted rib could be semantically described as Calm and Harmonious textures with an emphasis on homogenized structure in terms of e-commerce and online shopping, which ultimately appear as Ordinary and Static. As for the most characteristic pair of this cluster, jersey, nylon, and knitted rib scored high mean values for the adjective Appealing—knitted rib (M = 4.92, SD = 1.65), nylon (M = 4.72, SD =1.56), and jersey (M=4.52, SD =1.61).

In addition, in order to confirm (or perhaps reject) the above grouping of 17 adjective pairs into three semantic categories, PCA was performed. The first three extracted PCs together account for over 95% of the data variance (see Figure 6; of the 17, only the data for the first 10 PCs are shown, as their cumulative variance percentage already sums up to 100). The PCA loadings, which are the coefficients of the linear combinations of the original variables, are displayed in Table 7. The corresponding PC1/PC2 and PC1/PC3 plots are shown in Figure 7a and Figure 7b, respectively. Here, the adjective pairs with high PC1, PC2, and PC3 loadings are shown contained within full-, dashed-, and dotted-line rectangles, respectively.

The adjectives with high PC1 loadings—see Table 7 numbers in bold—are Interesting, Exciting, Special, Expressive, and Dynamic. When we compare these with the HCA results (Table 4), we can find the perfect (5 out of 5) match with the members of the second cluster. Similarly, the PC2 adjectives Appealing, Happy, Good, Calm, Attractive, Harmonious, and Sophisticated correspond almost exactly to the HCA pairs of the third cluster, and the PC3 adjectives: Modern, Luxurious, Strong, Insensitive, and Powerful correspond to the HCA pairs of the first cluster. The only two pairs that differ between the HCA and PCA groupings are Unsophisticated-Sophisticated (slightly higher loading on PC2 than on PC3, where it “should” belong) and Insensitive-Sensitive (should exhibit high loading on PC2 rather than on PC3). Taking into account the different theoretical backgrounds of the two methods used, we can conclude that the correspondence of the grouping/clustering results between the two approaches is very high.

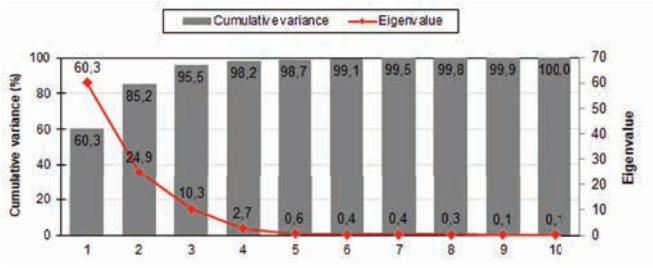


Figure 6. Eigenvalues and cumulative variance for PC1 to PC10.

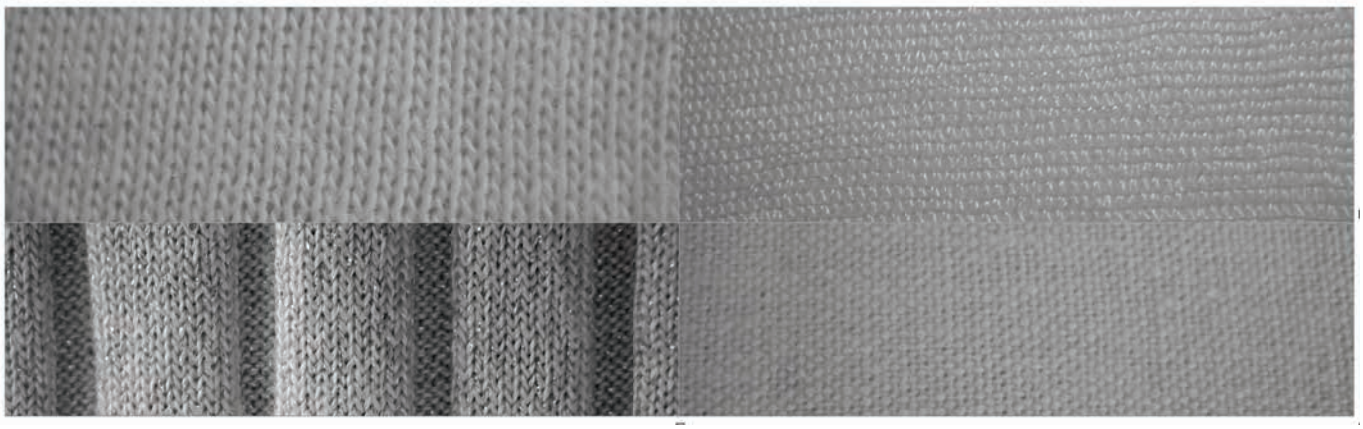


Figure 5. Selected textures: jersey and nylon (top row); knitted rib and canvas (bottom row).

Table 6. Mean value score for visual texture perception

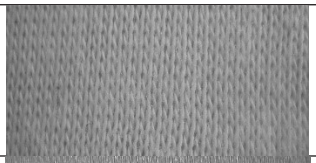
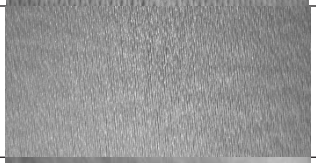
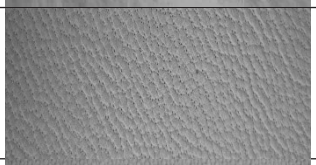
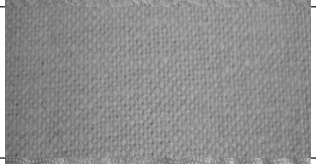
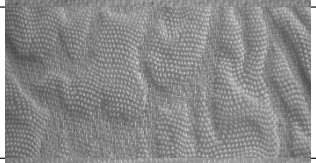
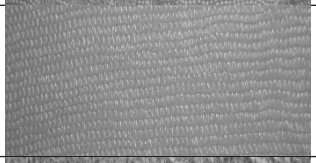
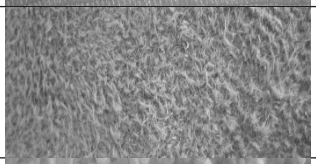
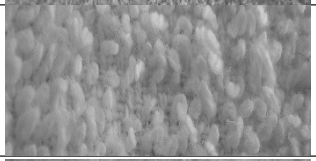
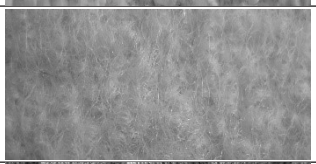
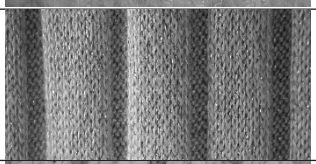
SAMPLE NUMBER	TEXTURE	SAMPLE	VISUAL TEXTURE PERCEPTION
1	jersey		Calm (M = 5.33, SD = 1.20), Harmonious (M = 4.89, SD = 1.33), Sensitive (M = 4.88, SD = 1.24) Ordinary (M = 2.59, SD = 1.41), Static (M = 2.99, SD = 1.56), Inexpressive (M = 2.99, SD = 1.35)
2	satin		Strong (M = 4.48, SD = 1.39), Modern (M = 4.16, SD = 1.56), Calm (M = 4.14, SD = 1.45) Unexciting (M = 3.23, SD = 1.41), Static (M = 3.37, SD = 1.61), Ordinary (M = 3.41, SD = 1.50)
3	faux fur		Dynamic (M = 5.36, SD = 1.37), Expressive (M = 5.05, SD = 1.50), Special (M = 4.88, SD = 1.36) Unharmonious (M = 3.72, SD = 1.74)
4	leather		Strong (M = 5.05, SD = 1.35), Interesting (M = 4.94, SD = 1.76), Powerful (M = 4.92, SD = 1.40) Insensitive (M = 3.58, SD = 1.57), Disturbing (M = 3.66, SD = 1.76), Sad (M = 3.88, SD = 1.47)
5	canvas		Harmonious (M = 4.57, SD = 1.56), Calm (M = 4.54, SD = 1.66), Strong (M = 4.42, SD = 1.68) Static (M = 2.90, SD = 1.41), Ordinary (M = 3.06, SD = 1.51), Unmodern (M = 3.13, SD = 1.43)
6	cloqué jacquard		Dynamic (M = 5.90, SD = 1.27), Special (M = 5.66, SD = 1.36), Expressive (M = 5.65, SD = 1.34) Disturbing (M = 3.88, SD = 1.58), Unharmonious (M = 3.95, SD = 1.75)
7	nylon		Harmonious (M = 5.02, SD = 1.38), Calm (M = 4.87, SD = 1.65), Appealing (M = 4.72, SD = 1.56) Static (M = 2.82, SD = 1.56), Ordinary (M = 3.31, SD = 1.45), Inexpressive (M = 3.39, SD = 1.45)
8	suede		Dynamic (M = 4.98, SD = 1.75), Interesting (M = 4.65, SD = 1.76), Special (M = 4.60, SD = 1.65) Unharmonious (M = 3.22, SD = 1.62), Disturbing (M = 3.35, SD = 1.66), Unsophisticated (M = 3.40, SD = 1.71)
9	terry		Dynamic (M = 5.19, SD = 1.51), Sensitive (M = 4.95, SD = 1.64), Interesting (M = 4.94, SD = 1.73) Gentle (M = 3.12, SD = 1.68), Unsophisticated (M = 3.72, SD = 1.60), Unmodern (M = 3.73, SD = 1.63)
10	boiled wool		Dynamic (M = 4.70, SD = 1.63), Interesting (M = 4.47, SD = 1.63), Expressive (M = 4.43, SD = 1.67) Unattractive (M = 3.11, SD = 1.50), Unharmonious (M = 3.22, SD = 1.51), Unsophisticated (M = 3.35, SD = 1.43)
11	knitted rib		Calm (M = 5.04, SD = 1.20), Appealing (M = 4.92, SD = 1.70), Harmonious (M = 4.89, SD = 1.37) Ordinary (M = 3.95, SD = 1.62), Cheap (M = 3.96, SD = 1.28), Inexpressive (M = 3.96, SD = 1.39)
12	crochet		Interesting (M = 5.54, SD = 1.44), Good (M = 5.46, SD = 1.24), Happy (M = 5.36, SD = 1.38)

Table 7. PC1, PC2 and PC3 loadings

ADJECTIVE PAIRS	PC1	PC2	PC3
Unappealing-Appealing	0.113	**0.378**	-0.038
Sad-Happy	0.173	**0.278**	-0.215
Bad-Good	0.079	**0.327**	-0.101
Disturbing-Calm	-0.099	**0.455**	-0.177
Boring-Interesting	**0.341**	0.050	-0.037
Unattractive-Attractive	0.146	**0.333**	0.033
Unexciting-Exciting	**0.336**	0.045	-0.022
Unharmonious-Harmonious	-0.092	**0.441**	0.096
Unmodern-Modern	0.189	0.084	**0.242**
Unsophisticated-Sophisticated	0.119	**0.189**	0.154
Cheap-Luxurious	0.202	0.086	**0.217**
Weak-Strong	0.073	0.174	**0.398**
Insensitive-Sensitive	0.045	0.110	**-0.476**
Gentle-Powerful	0.141	-0.021	**0.506**
Ordinary-Special	**0.429**	-0.104	0.100
Inexpressive-Expressive	**0.404**	-0.108	-0.038
Static-Dynamic	**0.465**	-0.202	-0.341

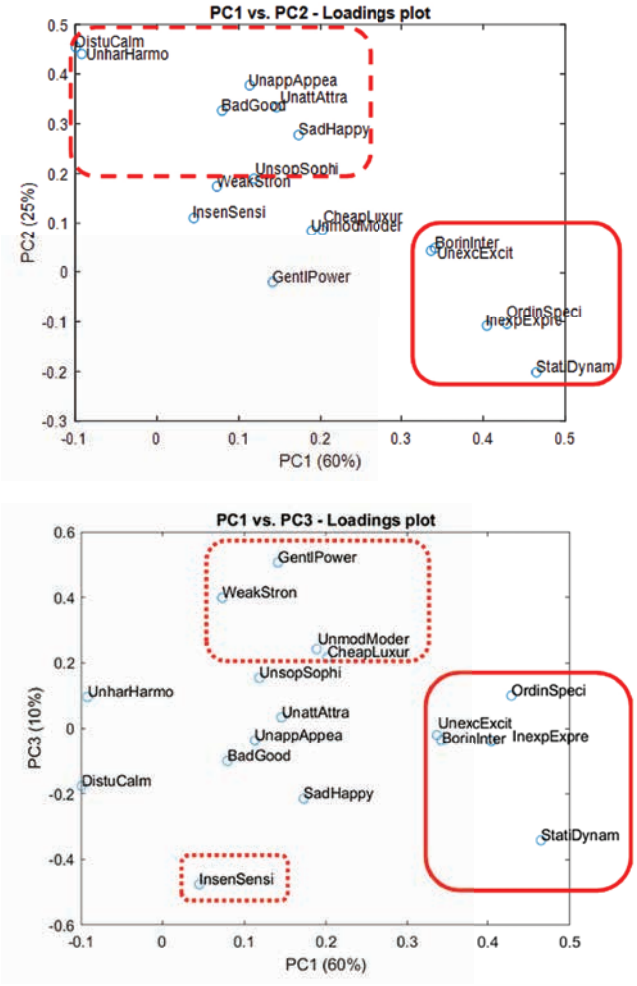


Figure 7a. PC1 vs. PC2 (left) and, 7b. PC1 vs. PC3 (right) loading plots.

4. CONCLUSIONS

The e-commerce fashion industry is on the rise, many decisions regarding textiles are made based on visual perception, and sales are also based solely on visual assessment. We believe that the visual texture of fabrics should be explained semantically, and in this study, we have proposed and defined suitable adjectives that can help to describe fabrics and clothing products accurately and more precisely. We used 12 types of commercially available fabrics with different patterns (jersey, satin, faux fur, leather, canvas, clique jacquard, nylon, suede, terry, boiled wool, knitted rib, and crochet) and outlined a list of 34 adjectives and their affinity clusters adapted from Küller. The three most attractive/appealing visual textures of fabrics in our study are crochet, knitted rib, and cloqué jacquard, while the least attractive/appealing textures of fabrics are boiled wool, suede, and canvas. In terms of e-commerce and online shopping, jersey was semantically described as a calm, harmonious, and sensitive texture. All the most characteristic adjectives belong to the Elegance cluster. The same is true for nylon and knitted rib which were described as appealing, calm, and harmonious textures, with slight differences in the arrangement of the most characteristic words. All the characteristic adjectives for faux fur, cloqué jacquard, boiled wool, and suede belong to the Originality cluster, which means that these visual fabric textures are both different and interesting. Faux fur and cloqué jacquard were described as dynamic, special, and expressive textures, while boiled wool was described as dynamic, interesting, and expressive, and suede as dynamic, interesting, and special. Canvas and satin belong to both the Elegance and Potency clusters, implying that these two fabrics appear strong and durable apart from their high measurement of the socio-economic value. Canvas was semantically described as harmonious, calm, and strong, while satin was described as strong, modern, and calm. Terry and crochet belong to the Elegance and Originality cluster, and terry was described as dynamic, sensitive and interesting, while crochet is interesting, good and happy. Finally, leather belongs to the cluster Potency and Originality and was described as strong, interesting, and powerful visual fabric texture. PCA confirmed to a large extent the HCA clustering of adjectives into three distinct semantic categories—the only two pairs that differ between the HCA and PCA groupings are Unsophisticated-Sophisticated and insensitive-sensitive.

The presented results will be beneficial to studies dealing with fabric texture preferences but primarily to fashion industry and the fabric description section of online stores. A semantic explanation of fabric texture using the suggested adjectives can help customers to assess the quality of the textile. Besides fabric composition, this supplement can be used for more accurate and successful online shopping. The limitation of our study is that it was conducted with a limited number of specimens and a relatively small number of participants, which we believe is sufficient to explore the potential of designing the anticipated system.

ACKNOWLEDGMENTS

This work was supported by the Slovenian Research Agency (Program P2-0213, Textiles and ecology).

References

[1] Wang, X. Y., Zhang, B. B., Yang, H. Y. (2014). Content-based image retrieval by integrating color and texture features. Multimedia Tools Appl, 68(3), 545–569.

[2] Haralick, R. M. (1979). Statistical and structural approaches to texture. In Proceedings of the IEEE, 67(5), 786-804.

[3] Rakhin, K. V., Onkar, P. (2018). Predicting haptic perception of textile texture and analysis between smooth-rough preferences through images. In: I. Horvath, J. P. Suárez Rivero, P. M. Hernández Castellano (Eds.), Tools and Methods of Competitive Engineering (TMCE), Las Palmas de Gran Canaria, (Gran Canaria).

[4] Julesz, B. (1981). Textons, the elements of texture perception, and their interactions. Nature, 290(5,802), 91–97.

[5] Stephens, K. D., Hoffman, D. D. (2016). On visual texture preference: Can an ecological model explain why people like some textures more than others? Perception, 45(5), 527-551.

[6] Brodatz, P. (1966). Textures: A photographic album for artists and designers. Dover (New York).

[7] Gatto, J. A., Porter, W. A., Selleck, J. (2010). Exploring visual design: The elements and principles (4th ed.). Davis Publications (Worcester, MA).

[8] Zhang, K., Butler, C., Yang, Q., Lu, Y. (1997). A fiber optic sensor for the measurement of surface roughness and displacement using artificial neural networks. IEEE Trans. Instrum. Meas., 46(4), 899–902.

[9] Moslehpour, S., Campana, C., Shetty, D., Deryniosky, B. (2009). Stand-alone surface roughness analyzer. IEEE Trans. Instrum. Meas., 58(3), 698–706.

[10] Hladnik, A., Lazar, M. (2011). Paper and board surface characterization using laser profilometry and gray level cooccurrence matrix. Nordic Pulp and Paper Research Journal, 26(1), 99-105.

[11] Scharcanski, J. (2006). Stochastic texture analysis for measuring sheet formation variability in the industry. IEEE Trans. Instrum. Meas., 55(5), 1,778–1,785.

[12] Wang, X., Georganas, N. D., Petriu, E. M. (2009). Fiber-level structure recognition of woven textile. In Proc. IEEE Int. Workshop HAVE, Lecco, Italy, (pp. 117–122).

[13] Wang, X., Georganas, N. D., Petriu, E. M. (2011). Fabric texture analysis using computer vision techniques. IEEE Trans. Instrum. Meas., 60(1), 44–56.

[14] Kumar, A. (2008). Computer-vision-based fabric defect detection: A survey. IEEE Trans. Ind. Electron., 55(1), 348–363.

[15] Abouelela, A., Abbas, H. M., Eldeeb, H., Wahdan, A. A., Nassar, S. M. (2005). Automatic vision system for localizing structural defects in textile fabrics. Pattern Recognit. Lett., 26(10), 1,435–1,443.

[16] Pan, R., Gao, W., Liu, J., Wang, H. (2011). Automatic recognition of woven fabric pattern based on image processing and BP neural network. J. Textile Inst., 102(1), 19–30.

[17] Elkharraz, G., Thumfart, S., Akay, D., Eitzinger, C., Henson, B. (2014). Making tactile textures with predefined affective properties. IEEE Trans. Affect. Comput., 5, 57–70.

[18] Skedung, L., Arvidsson, M., Chung, J. Y., Stafford, C. M., Berglund, B., Rutland, M. W. (2013). Feeling small: Exploring the tactile perception limits. Sci. Rep., 3, 1–6.

[19] Manfredi, L. R., Saal, H. P., Brown, K. J., Zielinski, M. C., Dammann, J. F., Polashock, V. S. et al. (2014). Natural scenes in tactile texture. J. Neurophysiol., 111, 1,792–1,802.

[20] Guo, X., Asano, C., Asano, A., Kurita, T., Li, L. (2012). Analysis of texture characteristics associated with visual complexity perception. Opt. Rev., 19, 306–314.

[21] Mori, T., Endou, Y. (1999). Evaluation of the visual texture and aesthetic appearance of lace patterns. The Journal of The Textile Institute, 90(1), 100-112.

[22] Mullin, C., Hayn-Leichsenring, G., Wagemans, J. (2015). There is beauty in gist: An investigation of aesthetic perception in rapidly presented scenes. J. Vis., 15(12), 123-132.

[23] Locher, P. J. (2015). The aesthetic experience with visual art at first glance. In Investigations Into the Phenomenology and the Ontology of the Work of Art. Springer International Publishing, 81, 75–88.

[24] Lester, D. H., Forman, A. M., Loyd, D. (2005). Internet shopping and buying behavior of college students. Services Marketing Quarterly, 27(2), 123-138.

[25] Citrin, A. V., Stem, D. E., Spangenberg, E. R., Clark, M. J. (2003). Consumer need for tactile input: an internet retailing challenge. Journal of Business Research, 56, 915-922.

[26] Katawetawaraks, C., Wang, C. L. (2011). Online Shopper Behavior: Influences of Online Shopping Decision. Asian Journal of Business Research, 1(2), 66-74.

[27] Kim, D. O., Yoo, S., Kim, E. A. (2005). Objective measures for perceived touch of worsted fabrics. International Journal of Industrial Ergonomics, 35(12), 1,159–1,169.

[28] Jimba, N., Ishikawa, T., Yanagida, Y., Mori, H., Sasaki, K., Ayama, M. (2019). Visual ratings of "softness/hardness" of rotating fabrics. International Journal of Clothing Science and Technology, 32(1), 48-62.

[29] Kim, W. (2021). A study on the subjective feeling affecting tactile satisfaction of leather in automobile: A structural equation modeling approach. International Journal of Industrial Ergonomics, 84(1), 1-9.

[30] Chen, Y. T., Chuang, M. C. (2014). The study of tactile feeling and its expressing vocabulary. International Journal of Industrial Ergonomics, 44(5), 675-684.

[31] Zhao, Y., Sun, J., Gupta, M. M., et al. (2017). Developing a mapping from affective words to design parameters for affective design of apparel products. Text. Res. J., 87(18), 2,224–2,232.

[32] Moody, W., Kinderman, P., Sinha, P. (2010). An exploratory study: Relationships between trying on clothing, mood, emotion, personality and clothing preference. J. Fash. Mark. Manag., 14(1), 161–179.

[33] Zhao, Y., Yin, L., Ikiz, Y., Sato, T., Yu, Q., Zhang, Z., Zhu, K., Li, Q. (2020). A study on customer's preference toward summer-shirt fabric. Journal of Engineered Fibers and Fabrics, 15, 1-7.

[34] Baumgartner, E., Wiebel, C. B., Gegenfurtner, K. R. (2013). Visual and haptic representations of material properties. Multisensory Research, 26(5), 429–455.

[35] Xiao, B., Bi, W., Jia, X., Wei, H., Adelson, E. H. (2016). Can you see what you feel? Color and folding properties affect visual–tactile material discrimination of fabrics. Journal of Vision, 16(34), 1–15.

[36] Wijntjes, M. W. A., Xiao, B., Volcic, R. (2019) Visual communication of how fabrics feel. Journal of Vision, 2(4), 1–11.

[37] Swinyard, W. R. (1993). The effects of mood, involvement and quality of store experience on shopping intentions. Journal of Consumers Research, 20, 271-280.

[38] Park, J., Lennon, S. J, Stoel, L. (2005). On-line Product Presentation: Effects on Mood, Perceived Risk, and Purchase Intention. Psychology & Marketing, 22(9), 695-719.

[39] Napompech, K. (2014). Factors driving consumers to purchase clothes through e-commerce in social networks. Journal of Applied Sciences, 14(17), 1,936-1,943.

[40] Lee, W., Sato, M. (2001). Visual perception of texture of textiles. Color Research and Application, 26(6), 469-477.

[41] Shanthi, R., Kannaiah, D. (2015). Consumer's perception on online shopping. Journal of Marketing and Consumer Research, 13, 14-21.

[42] Statista. (2020). Fashion e-commerce report 2020 (online). Retrieved April 14, 2021. Web site: https://www.statista.com/study/38340/ecommerce-report-fashion/.

[43] das Neves, E. P., Brigatto, A., Samaan, C. L., Rodrigues, S. T., Paschoarelli, L. C. (2020). Perception and fabrics: A preliminary investigation about the responses patterns by the stimulation of vision and touch. Revista Design & Tecnologia, 10(20), 96-105.

[44] Nagamachi M. (1996). Kansei engineering and its applications. The Japanese Journal of Ergonomics, 32(6), 286-289.

[45] Karlsson, B., Aronsson, N., Svensson, K. (2003). Using semantic environment description as a tool to evaluate car interiors. Ergonomics, 46(13-14), 1,408-1,422.

[46] Küller, R. (1977). Psycho-physiological conditions in theatre construction. In: Arnott J. F., Chariau, J., Huesmann, H., Lawrensen, T. Theobald, R. (Eds.)., Theatre Space. Prestel Verlag (Munich).

[47] Küller, R. (1975). Semantisk miljöbeskrivning (SMB). Psykologiförlaget (Stockholm).

[48] Janssens, J. (1998). Computerised environmental simulation and perceptual evaluation—on the perception of pictures of built environments presented on computer screens. In: van der Does, J., Breen, J., Stellingwerff, M. (Eds.). Delft University Press (Delft, Netherlands).

[49] Fischl, G. (2006). Psychosocially supportive design in the indoor environment Unpublished doctoral dissertation, Luléa University of Technology: Division of Engineering Psychology, Department of Human Work Sciences, Luléa, Sweden.

[50] Evensen, K. H., Raanaas, R. K., Hägerhäll, C. M., Johansson, M., Patil, G. G. (2017). Nature in the office: An environmental assessment study. Journal of Architectural and Planning Research, 34(2), 133-146.

[51] Houtkamp, J. M., van der Spek, E. D., Toet, A. (2007). The influence of lighting on the affective qualities of a virtual theater. Predicting the Future, 25th eCAADe Conference Proceedings. Frankfurt am Main, Germany.

[52] Bengtsson, A., Hägerhäll, C., Englund, J. E., Grahn, P. (2015). Outdoor environments at three nursing homes: Semantic environmental descriptions. Journal of Housing for the Elderly, 29, 53–76.

[53] Sundberg, F., Fridh, I., Lindahl, B., Kåreholt, I. (2020). Visitor's experiences of an evidence-based designed healthcare environment in an intensive care unit. Health Environments Research & Design Journal, 1(14), 1-13.

[54] Santos, M. (2004). Study of a car seat concept design proposal using Kansei ergonomics. Retrieved April 20, 2021 from https://www.repository.utl.pt/bitstream/10400.5/5485/54/2.Study%20of%20a%20car%20seat%20concept%20design%20proposal.pdf

[55] Sutono, S. B., Abdul-Rashid, S. H., Aoyama, H., Taha, Z. (2016). Fuzzy-based Taguchi method for multi-response optimization of product form design in Kansei engineering: A case study on car form design. Journal of Advanced Mechanical Design, Systems, and Manufacturing, 10(9), 1-16.

[56] Habyba, A. N., Djatna, T., Anggraeni, E. (2017). An affective e-commerce design for SMEs product marketing based on kansei engineering. International Conference on Industrial and System Engineering (IConISE) Proceeding, IOP Conference Series: Materials Science and Engineering (pp. 337-345). Denpasar, Bali, Indonesia: IOP publishing, Surabaya.

[57] Lokman, A. M., Kamaruddin, K. A. (2010). Kansei affinity cluster for affective product design. International Conference on User Science and Engineering (pp. 38-43). Shah Alam, Malaysia.

[58] Udale, J. (2008). Basics fashion design 02: Textiles and fashion. Fairchild Books AVA (Lausanne).

[59] Parker, J. (1992). All about silk: A fabric dictionary and swatchbook. Rain City Publishing (Seattle).

[60] Spencer, D. (2001). Knitting technology: A comprehensive handbook and practical guide (3rd ed.). Woodhead Publishing (Cambridge, UK).

[61] Tortora, P. G., Collier, B. J. (1997). Understanding textiles (5th ed.). Prentice Hall Inc. (Upper Saddle River)

[62] Fritz, A., Cant, J. (1994). Consumer textiles. Oxford University Press Australia (South Melbourne).

[63] How products are made: Fake fur. Retrieved May 26, 2021. Web site: http://www.madehow.com/Volume-3/Fake-Fur.html.

[64] Tissura. (n.d). What does faux fur actually mean? Retrieved May 26, 2021. Web site: https://tissura.com/articles/faux-fur.

[65] Parker, J. (1993). All about cotton: A fabric dictionary and swatchbook. Rain City Publishing (Seattle).

[66] Hodakel, B. (2020). What is canvas fabric: Properties, how its made and where. Sewport. Retrieved Web site: https://sewport.com/fabrics-directory/canvas-fabric.

[67] Corbman, B. P. (1983). Textiles: Fiber to fabric (6th ed.). McGraw-Hill (Singapore).

[68] issura. (n.d.). Jacquard fabrics review. Retrieved May 26, 2021, Web site: https://tissura.com/articles/jacquard-fabrics.

[69] Hodakel, B. (2020). What is polyamide fabric: Properties, how it's made and where. Sewport. Retrieved May 26, 2021. Web site: https://sewport.com/fabrics-directory/polyamide-fabric.

[70] Parker, J. (1996). All about wool: A fabric dictionary and swatchbook. Rain City Publishing (Seattle).

[71] Jolliffe, I. (2002). Principal component analysis. (2nd ed.), Springer (New York).