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Durability Assessment of Functionally Printed Knitted Fabrics for T-Shirts

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Abstract
Knitted shirts are an appropriate carrier of easily readable information, and therefore, in recent years, QR Codes have been very often printed on T-shirts. With the purpose of investigating QR Code fastness printed on textiles, in this paper a methodology is proposed for the durability assessment of functionally printed knitted fabrics that includes the implementation of long-term care and wearing simulation - which the T-shirts are exposed to over their lifetime. Dimensional changes after multiple washing and drying cycles were determined for non-printed and functionally printed white knitting, as well as the abrasion resistance and tendency to surface pilling after multiple rubbing cycles. The effect of usage simulation on the functional print's durability was defined, as well as the color fastness, readability and aesthetic properties. It was found that the structure of knitted fabrics, their dimensional stability, the number of care and wear cycles performed, the printing technique and size of black modules in the QR Code all have an influence on the results obtained.

Key words: *printed textiles, knitted fabrics, T-shirt, durability, usage simulation, QR Code.*

Introduction

The T-shirt has been adopted by all age levels and all social classes and is one of the most popular clothing items. Just as the technology of mass production has made it possible for everyone to have T-shirts, further application of manufacturing advancements and digital printing technology has made it possible and practical for everyone to have T-shirts customised to fit his/her individual needs. As knitted fabrics can be a carrier of easily readable wearable information, individuals can create their own computerised designs [1, 3]. T-shirt print designs with fashion and advertising messages are a phenomenon of the twentieth century, particularly the latter half. In recent years QR Codes have printed on the shirts, having a decorative and functional role (***Figure 1***).

Figure 1. *T-shirts with printed QR Code*

Figure 2. *Smudged or damaged QR Codes.*

The QR (Quick Response) Code is the trademark for a type of matrix barcode (or two-dimensional code) first designed for the automotive industry. More recently, the system has become popular outside of the industry due to its fast readability and large storage capacity compared to standard UPC (Universal Product Code) barcodes. The code consists of black modules arranged in a square pattern on a white background. The information encoded can be made up of four standardised kinds of data: numeric (0–9), alphanumeric (0–9, A–Z, space, $, %, *, +, -, ., /, :), byte/binary and Kanji. The amount of data that can be stored in the QR Code symbol depends on the data type, version (1 to 40 – indicating the overall dimensions of the symbol) and error correction level.

The approximate error correction capability at each of the four levels are as follows: level L (Low) - 7% of code words can be restored, level M (Medium) - 15%, level Q (Quartile) - 25%, and level H (High) - 30% of code words can be restored. The error correction functionality is implemented according to each of smudge/damage, utilising the Reed-Solomon code, which is highly resistant to burst errors. Reed-Solomon codes are arranged in the QR Code data area. By this error correction functionality, the codes can be read correctly even when they are smudged or damaged in the users' usage environment (***Figure 2***) up until the error correction level. Symbols often get distorted when attached to a curved surface (***Figure 3***) or printed on elastic materials (eg. knitted fabrics). To correct this distortion, the QR Code has alignment patterns arranged with a regular interval within the range of the symbol. The variance between the centre position of the alignment pattern estimated from the outer shape of the symbol and

Figure 3. *Distorted QR Codes.*

Table 1. *Structural and construction characteristics of knitted fabrics.*

Fabric sample	Fiber type	Weight, g/m^2	Thickness, mm	Wales/cm	Courses/cm
1	95% cotton 5% elastane	155.3	0.45	16	24
2	100% cotton	152.2	0.41	14	21

Table 2. *Characteristics of QR Codes prepared.*

QR code	Size, pixels	Printing size, mm	Resolution, dpi
QR 1a	690 x 690	25 × 25	701
QR 1b		50 × 50	351
QR 2a	1650 x 1650	25 × 25	1676
QR 2b		50 × 50	838

the actual centre position of the alignment pattern will be calculated to have the mappings corrected. This will make the distorted linear/non-linear symbols readable.

The QR Code is detected as a 2-dimensional digital image by a semiconductor image sensor and is then digitally analysed by a program. The program locates the three distinctive squares at the corners of the image, and normalises the image size, orientation, and angle of viewing. The small dots are then converted to binary numbers and the validity checked with an error-correcting code. Users with a camera phone equipped with the correct reader application can scan the image of the QR Code to display text, contact information, connect to a wireless network, or open a web page in the telephone's browser [4 - 7].

Application of the QR Code is usually commercially implemented in paper, packaging and plastic materials, as well as metal substrates, while their application to textile materials has been, until recently, poorly represented. All textile materials, knitted fabric especially, are characterised by large non-uniformity of the structural and surface properties which are susceptible to further changes in use and after care [8, 9]. In this regard, it can be assumed that both the durability and readability of QR Codes printed on knitted fabrics greatly depend on the knitting dimensional stability and wear resistance during use. Also the functionality of the damaged but still decodable QR Code will be affected by size of the missing piece of code, as well as by changes in the modules' size and their appearance, sufficient colour contrast between the background and modules in the QR Code, and the colour fastness of the print.

a. b.

Figure 4. *QR Codes applied: a. QR Code 1; b. QR Code 2*

The colour fastness of printed textiles were commonly assessed by grades of colour fastness to washing according to the EN ISO 105-C06, colour fastness to dry and to wet rubbing according to EN ISO 105-X12, and colour fastness to wet scrubbing of pigment printed textiles according to EN ISO 105-C07 [10 - 12]. The standardised procedures for determination of the print's colour fastness to washing and rubbing did not fully meet the conditions of long-term care and wearing simulation of T-shirts, as they are too gentle (single wash, 10 rubbing cycles, including straight line motion of rubbing finger) or too aggressive for thin knitted fabrics (brush scrubbing), and most commonly do not allow testing of the entire surface of the functional print. Additionally numerical ratings of the textile colour fastness are mostly visually assessed – compared with grey scale for assessing change in colour complying with EN 20105-A02 and the staining of adjacent fabrics according to EN 20105-A03 [13, 14]. As ratings depend on the experience and subjective estimation of the evaluator, it is necessary to include an objective instrumental assessment based on spectrophotometrically determined *CIEL*a*b** colourimetric values and calculation of the change in colour ΔE^* according to contemporary guidelines.

Therefore, and due to the fact that the fastness of QR Codes printed on textiles is not fully defined in literature, in this paper a methodology was proposed for durability assessment of functionally printed knitted fabrics that includes the implementation of long-term care and wearing simulation - which the T-shirts are exposed to over their lifetime. It includes the implementation of multiple washing and drying cycles, as well as multiple rubbing and abrasion cycles performed over the entire surface of functional prints, which faithfully imitates the movements of the body in contact with other surfaces. With the aim of confirming the applicability of the methodology proposed, two QR Codes were printed on white weft-knitted fabrics with different amounts of information in two sizes using screen printing and transfer printing techniques. Dimensional changes after multiple washing and drying cycles were determined for non-printed and functionally printed knitting, as well as the abrasion resistance and tendency to surface pilling after multiple rubbing cycles using a Martindale abrasion tester. The effect of usage simulation on the functional print's durability was defined, as well as colour fastness, readability and aesthetic properties.

Experimental

Materials

The investigation was carried out on two white single jersey weft-knitted fabrics most frequently used for T-shirts: the first made of a cotton and elastane fiber mixture and the second of cotton. Properties of the knitted fabrics used are shown in ***Table 1***.

Preparation of QR codes

QR Codes with two different amounts of information (1 and 2) in two sizes (a: 25 × 25 mm and b: 50 × 50 mm) were designed. The codes selected were smaller in size with the purpose of facilitating the definition of the influence of the code size and the size of the black modules in the QR Code on the results. Facilities that are stored in the QR Codes are text information. The content of the first QR Code has the name Adi Anadolac and that of the second QR Code are data of the institution: Faculty of Textile Technology, University of Zagreb, Prilaz baruna Filipovica 28a, 10000 Zagreb, Croatia, e-mail: fakultet@ttf.hr, website: http://www.ttf.unizg.hr (***Figure 4***).

Both QR Codes were created using the applications QR Code and 2D Code Generator / Kerman Erkan on the web page [15]. The sizes of both QR Codes are shown in ***Table 2***. The error correction level for both QR Codes was set to the commonly used medium-low [6]. The QR Codes were scanned using a smart phone - Samsung Galaxy S+ and the program i-nigma (3GVision) [16]. The resolution of this smart phone camera is 5 megapixels.

The printing pattern (***Figure 5***) was prepared in the CMYK colour space and stored in the standard TIFF format, which ensured a unified appearance of the QR codes on various computers and operation systems, and in consequence on the print.

Functional printing

In order to transfer readable information, repeat patterns were printed in black colour on both knitted fabrics using two of the printing techniques most frequently used for T-shirts: direct screen printing (S) and indirect transfer printing (T).

Screen printing is a versatile applicable printing process. The basic advance of screen printing is in printing costs while printing large quantities of textiles. Generally it consists of a structured PET stencil mounted in a frame for stabilisation [17, 18]. The frame lay on the top of the printing media (knitted fabric) and the textile printing ink (here, Aqua 16709-Black, KIIAN S.p.a.Italy – water based ink with matt finish) was pressed through the stencil by a scraper onto the media. Drying was performed at room temperature for approx 2 h, and curing at 150 °C for 3 minutes.

The second set of prints was made with a Roland LEC-300 printer using piezo ink-jet technology with Roland ECO-UV ink. Non-transparent polyurethane transfer foils (Poliflex Printable 4016) printed for indirect printing, in the size of 150 × 150 mm, were transferred separately onto textile materials by means of a heat press - Senko DHP T-15, at a pressure of 32 kPa in 20 seconds at 168 °C (fabric sample 2) and 150 °C (fabric sample 1).

Methodology for durability assessment

The impact of usage simulation on the durability of printed QR Codes influenced by dimensional, structural and surface changes in knitted fabrics was determined on the basis of the methodology proposed for durability assessment that includes the implementation of multiple washing and drying cycles, as well as multiple rubbing and abrasion cycles. Therefore for non-printed and functionally printed knitted fabrics, the following were determined:

■ **Abrasion resistance -** using a Martindale abrasion tester according to EN ISO 12947-3 [19]. When using this method, for determination of the test sample's mass loss (expressed in %), the specimen tested moves according to the Lissajous curve, and the standard woven wool fabric is abraded over the entire surface. The diameter of the test specimen should be 38 mm, which allows to determine the readability of the QR Codes only in the size of 25 × 25 mm. The mass loss of test specimens under an abrasion load of 595±7 g was determined after the following number of rubs: 250, 500, 750, 1000, 2500, 5000, 10000, 15000, 20000 and 25000.

■ **Propensity to surface fuzzing and piling -** according to the modified Martindale method (EN ISO 12945-2 [20]). Piling is an effect caused by wear and tear that considerably spoils the original appearance of a fabric. It begins with the migration of fibers to the external parts of yarns, an as a result fuzz emerges on the fabric surface. Due to friction, this fuzz gets entangled, forming pills that remain suspended from the fabric by long fibers. Pills develop on a fabric surface in four stages: fuzz formation, entanglement, growth, and wear-off. The fabrics tested were rubbed with standardised wool abradant (face/face), under an abrasion load of 415 g. To predict the pilling of fabrics in a fraction of the time that would occur in normal use, the fabrics were assessed visually by comparing with photographs of samples with different degrees of piling (1-5), after 125, 500, 1000, 2000, 5000 and 7000 pilling rubs. As the diameter of test specimens for the pilling table was 140 mm, the **readability** of all printed QR Codes after 7000, 14000, 21000 and 28000 pilling rubs was further tested.

■ **Dimensional stability -** after 1, 5, 10, 15, 20 and 25 multiple washing cycles according to procedure 6N (normal agitation during heating, washing and rinsing at 60 °C) of EN ISO 6330 [21] with non-phosphate reference detergent 3 (without optical brightener). The distances between paired shrinkage dots placed on the fabric are manually measured before and after laundering and flat drying (procedure C). The percentage change in the length and width of the knitted fabrics was calculated, and the state of whether the dimension has decreased (shrinkage) was expressed by means of minus, or increased (extension) by means of plus. The influence of changes in the dimensions of printed QR Codes (caused by dimensional changes in the fabric) on their **readability** was also analyzed.

Figure 5. *Pattern prepared for printing.*

■ **Colour fastness, change in the surface appearance and readability of printed QR Codes** - after multiple washing and drying cycles, and multiple pilling rubs. The black parts of QR Codes were assessed for colour loss and the white parts for staining (based on spectrometric determined *CIE* $L^*a^*b^*$ colourimetric values including the brightness L^*, saturation C^* and hue h^*) using a remission spectrometer - X.Rite DT41 at D65/10 with ColourShop software. The *CIE*$L^*a^*b^*$ colour parameter differences Δa^*, Δb^*, ΔL^*, ΔC^* and ΔH^* were calculated between the untreated reference sample and samples after the simulated condition of use. The change in colour ΔE^*_{00}, given by mathematical ***Equation 1*** [22], was calculated from colour

$$\Delta E^*_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C' \Delta H'}{k_C S_C k_H S_H}} \qquad (1)$$

Equation 1.

Table 3. *Abrasion resistance of non-printed knitted fabrics.*

Mass loss of non-printed fabrics, %		
Number of rubs	Fabric sample 1	Fabric sample 2
250	-0.05	-0.09
500	-0.15	-0.24
750	-0.31	-0.24
1000	-0.37	-0.49
2500	-1.22	-0.89
5000	-3.03	-2.49
10000	-3.98	-3.24
15000	-5.37	-5.25
20000	-6.17	-6.40
25000	-7.78	-7.50

Table 4. *Abrasion resistance of printed knitted fabrics.*

Mass loss of printed fabrics (%)				
Number of rubs	Screen printed fabrics		Transfer printed fabrics	
	Sample 1	Sample 2	Sample 1	Sample 2
250	-0.05	-0.04	0	0
500	-0.20	-0.23	0	0
750	-0.43	-0.23	0.02	0.05
1000	-0.45	-0.28	0.05	0.10
2500	-1.20	-1.28	0	0.13
5000	-2.20	-2.19	0	0.15
10000	-3.81	-3.57	-0.13	0.15
15000	-5.02	-5.29	-0.16	0.10
20000	-6.42	-6.92	-0.24	0
25000	-7.89	-7.77	-0.27	-0.02

preferences for hue, lightness and saturation in a uniform *CIE L*a*b** colour space and converted to the gray scale rating (*GS*) according to EN ISO 105-A05, and to the staining scale rating (*SSR*) according to EN ISO 105-A04 (numerical ratings 1-5) [23, 24].

The single factor analysis of variance (ANOVA) was used to verify the influence of the usage simulation on the properties tested, as well as the significance of changes determined on the readability of QR Codes printed by two different techniques on knitted fabrics. In this analysis, the *factor* is a categorical predictor variable, composed of *groups*, and *treatment* is a factor with various types of treatments (two different printing techniques) comprising the groups. It would mean that a *subject* is given only one (one fabric sample) of the two possible treatments.

One-way ANOVA consists of separable parts; partitioning sources of variance and hypothesis testing can be used individually. It estimates three sample variances: *variance* based on the observation deviations from their appropriate treatment mean, *treatment variance* (*variance between groups*) based on the deviations of treatment means from the grand mean, and *total variance* (*variance within groups*) based on all observation deviations from the grand mean. The statistical significance of the experiment and the effect of any treatment are estimated by taking the difference between the mean of observations which receive the treatment and the grand mean (*F*).

ANOVA is used to test the null hypothesis that *various printing treatments have exactly the same effect.* There are two methods of concluding the ANOVA hypothesis test, both of which produce the same result:

- The textbook method is to compare the value of *F* observed with the critical value of *F* determined from the tables. The critical value of *F* is a function of the degrees of freedom (*DF*) of the numerator and the denominator and the significance level (α). If $F \geq F_{crit}$ the null hypothesis is rejected.
- The computer method calculates the probability (*p*-value) of a value of *F* greater than or equal to the value observed. The null hypothesis is rejected if this probability is less than or equal to the significance level (α). *P*-values lower than 0.05 mean the treatments had a statistically significant effect on the properties tested at the 95.0% confidence level.

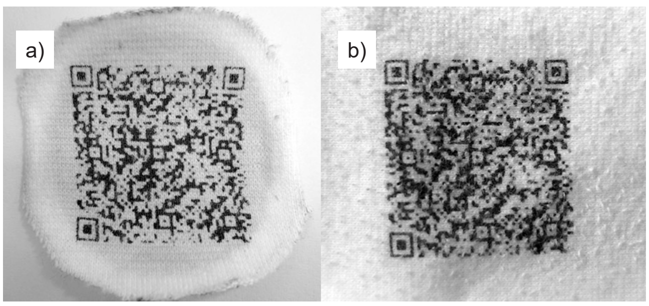

Figure 6. *Non-decodable screen printed QR 2a Codes on cotton/elastane knitted fabric (sample 1): a) after 25000 abrasion rubs, b) after 21000 pilling rubs.*

Table 5. *Evaluation of knitted fabric propensity to surface piling*

Pilling assessment				
Number of piling rubs	Non-printed fabrics		Screen printed fabrics	
	Sample 1	Sample 2	Sample 1	Sample 2
0	5	5	5	5
125	4-5	4-5	4-5	4-5
500	4	4	4	4
1000	4	4	3-4	3-4
2000	4	3-4	3-4	3
5000	3-4	3	3-4	3
7000	3	2-3	3	2-3
21000	2	2	2	2

Results and discussion

The results obtained from the investigation are presented in ***Tables 3 - 16***. The impact of abrasion on the knitted fabrics mass loss expressed in percentage with regard to the initial sample mass, calculated as an average of 4 measurements, is shown in ***Table 3*** for non-printed samples and for printed samples (QR 1a and QR 2a) by the screen printing technique and transfer printing in ***Table 4***.

For the initial non-printed knitted fabric samples, as well as those screen printed, considerable weight loss was found, along with significant thinning. An increase in the number of abrasion rubs on the screen printed samples also leads to intensified wear of the functional prints in both knitted fabrics, which after 20000 abrasion cycles caused the non-readability of QR Code 2a with smaller black modules (***Figure 6.a***). The abrasion of prints is more pronounced on the surface of single jersey cotton fabric mixed with elastane (sample 1), where the additional breakdown of yarns occurred during the last 5000 cycles of wear.

At the beginning of the abrasion resistance test, transfer printed fabrics coated with polyurethane film of significantly larger thickness in comparison to the initial samples (thickness of the first sample was 0.50 mm and the second sample 0.47 mm) were abraded with standard wool abradant. Finally at the test's end, as light reduction in the weight of the samples tested occurs, which is more pronounced in the first knitting. With good readability, this is referred to as the high abrasion resistance of the transfer printed QR Codes.

As the transfer printed fabrics show no tendency of surface peeling (grade 5), in ***Table 5*** peeling ratings are shown (1- the worst, 5 – the best) only for non-printed and screen printed knitted fabrics. The results presented show a reduction in piling grades after an increased number of rubbing cycles. A minimal difference between the grades of non-printed and screen printed fabrics was found after 1000 and 2000 control cycles, which can be explained by the better visibility of black coloured pills on the white background caused by the black print's abrasion. After 21000 piling rubs, along with pilling grade 2, QR code 2a printed in the size 25 × 25 mm were found unreadable in both knitted fabrics (***Figure 6.b***). Single factor ANOVA shown in ***Tables 6*** and ***7*** shows considerably higher values of *treatment variance* (mean square values between groups) compared to the *total variance* (mean square values within the groups) and the rejection of the null hypothesis. This confirms that *various printing treatments have a different effect* on mass loss and piling assessment after wearing simulation for both knitted fabrics tested (S1 and S2) or that the at least one of the means is different. The influence of wearing simulation is more pronounced in screen printed fabrics (SP), which is confirmed by higher dispersion of the results within group 1 – ie. variance based on observation deviations from their appropriate treatment mean. It amounts to the mass loss of screen printed samples S1-SP 8.1480 and S2-SP 8.7027 (***Table 6***), and for piling grades of screen printed samples S1-SP 0.8393 and S2-SP 1.0313 (***Table 7***), while the values of transfer printed (TP) samples are below or equal to zero. The significant difference in material mass loss identified and induced piling on the surface of screen printed knitted fabrics also affects the poorer readability of screen printed QR Codes, which is primarily evident for the smaller QR Codes, with more encoded data.

The results presented in ***Table 8*** (see page 134) indicate different dimensional changes in the knitted fabrics investigated diring washing. Deformation was recorded for both single jersey knitting - shrinkage in length and extension in the width direction. However, better dimensional stability is detected in the second sample made of cotton. With an increased number of domestic washing and drying cycles (5 - 20), the dimensional changes are mostly higher, and after 20 cycles a slight

Table 6. *Single factor analysis of variance – influence of abrasion rubing on mass loss of screen printed (SP) and transfer printed (TP) fabrics: a. for first knitted fabric (sample 1, S1), b. for second knitted fabric (sample 2, S2).*

a. SUMMARY						
Groups	**Count**	**Sum**	**Average**	**Variance**		
Mass loss S1-SP	10	-27.67	-2.7670	8.1480		
Mass loss S1-TP	10	-0.73	-0.0730	0.0136		
ANOVA: single factor						
Source of variation	**Sum of squares**	***DF***	**Mean square**	***F***	***p*-value**	F_{crit}
Between groups	36.2882	1	36.2882	8.8924	0.0080	4.4139
Within groups	73.4546	18	4.0808			
Total	109.7428	19				
Hypothesis testing						
$F \geq F_{crit}$	$p \leq 0.05$	Hypothesis				
yes	yes	reject (various printing treatments do not have the same effect – there are significant differences between them)				
b. SUMMARY						
Groups	**Count**	**Sum**	**Average**	**Variance**		
Mass loss S2-SP	10	-27.8	-2.7800	8.7027		
Mass loss S2-TP	10	0.66	0.0660	0.0046		
ANOVA: single factor						
Source of variation	**Sum of squares**	***DF***	**Mean square**	***F***	***p*-value**	F_{crit}
Between groups	40.4986	1	40.4986	9.3022	0.0069	4.4139
Within groups	78.3658	18	4.3537			
Total	118.8644	19				
Hypothesis testing						
$F \geq F_{crit}$	$p \leq 0.05$	Hypothesis				
yes	yes	reject (various printing treatments do not have the same effect – there are significant differences between them)				

Table 7. *Single factor analysis of variance – influence of pilling rubs on pilling assessment of screen printed (SP) and transfer printed (TP) fabrics: a. for first knitted fabric (sample 1, S1), b. for second knitted fabric (sample 2, S2).*

a. SUMMARY						
Groups	**Count**	**Sum**	**Average**	**Variance**		
Piling S1-SP	8	29	3.6250	0.8393		
Piling S1-TP	8	40	5.0000	0.0000		
ANOVA: single factor						
Source of variation	**Sum of squares**	***DF***	**Mean square**	***F***	***p*-value**	F_{crit}
Between groups	7.5625	1	7.5625	18.0213	0.0008	4.6001
Within groups	5.8750	14	0.4196			
Total	13.4375	15				
Hypothesis testing						
$F \geq F_{crit}$	$p \leq 0.05$	Hypothesis				
yes	yes	reject (various printing treatments do not have the same effect – there are significant differences between them)				
b. SUMMARY						
Groups	**Count**	**Sum**	**Average**	**Variance**		
Piling S2-SP	8	27.5	3.4375	1.0313		
Piling S2-TP	8	40	5.0000	0.0000		
ANOVA: single factor						
Source of variation	**Sum of squares**	***DF***	**Mean square**	***F***	***p*-value**	F_{crit}
Between groups	9.7656	1	9.7656	18.9394	0.0007	4.6001
Within groups	7.2188	14	0.5156			
Total	16.9844	15				
Hypothesis testing						
$F \geq F_{crit}$	$p \leq 0.05$	Hypothesis				
yes	yes	reject (various printing treatments do not have the same effect – there are significant differences between them)				

Table 8. Percentage change in length and width of non-printed fabrics after multiple washing and flat drying cycles (W&D).

Number of W&D cycles	Dimensional stability, %			
	Sample 1		Sample 2	
	Length	Width	Length	Width
1	-7.2	+0.2	-3.3	+0.1
5	-11.5	+1.7	-4.1	+0.9
10	-13.3	+2.1	-6.0	+1.3
15	-14.1	+2.2	-6.6	+1.5
20	-15.4	+2.6	-7.3	+1.6
25	-14.3	+0.6	-5.3	+0.4

Table 9. Percentage change in length and width of printed knitted fabrics after multiple washing and flat drying cycles (W&D).

Number of W&D cycles	Dimensional stability, %							
	Screen printed fabrics				Transfer printed fabrics			
	Sample 1		Sample 2		Sample 1		Sample 2	
	Length	Width	Length	Width	Length	Width	Length	Width
1	-8.3	+0.1	-5.6	+0.5	0	0	0	0
5	-11.8	+0.8	-5.9	+0.7	-1.7	-1.7	-1.6	-1.6
10	-13.2	+1.3	-6.6	+1.1	-2.5	-3.1	-2.3	-2.1
15	-13.3	+2.0	-7.3	+1.4	-3.4	-4.3	-3.6	-3.6
20	-14.1	+0.8	-8.2	+0.8	-3.9	-5.6	-4.1	-3.7
25	-14.0	+0.2	-8.0	+0.7	-5.6	-6.5	-5.2	-4.1

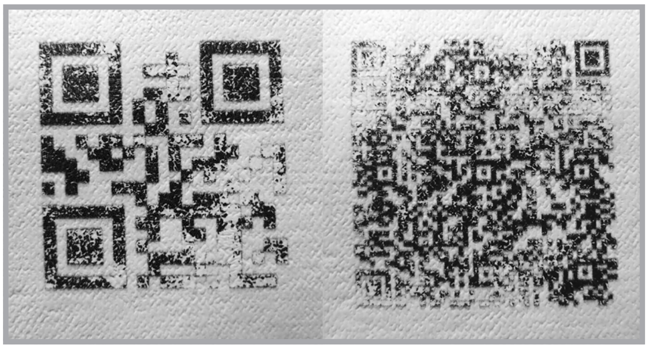

***Figure 7.** Non-decodable transfer printed QR Codes on cotton knitted fabric (sample 2) after multiple washing and drying cycles.*

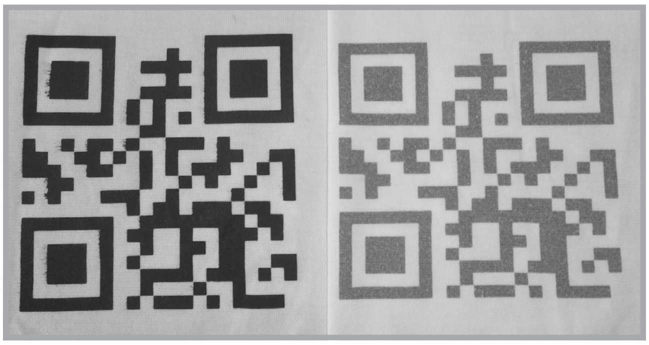

***Figure 8.** Appearance of QR 1b Code screen printed on cotton knitted fabric (sample 1) before and after 25 washing and drying cycles: influence of shrinkage and change in colour.*

relaxation of knitting structure was determined. Although white cotton T-shirts are washable at a temperature of 95 °C, after subsequent washing at a temperature of 60 °C, shrinkage in the length of approximately 7.5% was found in knitted fabric made of cotton, while in that made of a blend of cotton and elastane fibers, shrinkage was considerably higher (up to approx. 15.5%).

Similar dimensional changes were found for screen printed samples (***Table 9***) that significantly affected the uneven deformation of QR Codes after repeated washing and drying cycles. However, due to dimensional changes, only the QR 2a Codes in the size of 25 × 25 mm on knitted sample 1 after two repeated cycles of domestic washing and drying were found to be unreadable, and for knitting sample 2 after 5 multiple care cycles.

For transfer printed samples, regardless of the knitted fabric's dimensional changes, the shrinkage of transfer foil was found in both directions - length and width, which can be explained by the fact that the washing temperature applied was higher than 40 °C (recommended by the manufacturer of the transfer foil). Increased shrinkage and reduction of QR Code dimensions did not affect their readability. But after 9 washing cycles, change in the surface appearance of QR Codes on fabric samples 1 and 2 was observed, as well as cracking of the film in fabric sample 1 (due to increased fabric elasticity). Loss of colour and disappearance of certain black modules significantly influenced the readability (***Figure 7***). The following have been identified as non-decodable QR Codes:

- for knitted fabric sample 1 - QR 2a after 9 washing and drying cycles, QR 1a after 18 cycles, and QR 2b after 23 cycles.
- for knitted fabric sample 2 - QR 2a after 6 cycles, QRs 1a and 2b after 9 cycles, and QR 1b after 15 washing and drying cycles.

The single factor ANOVA presented in ***Table 10*** also results in considerably higher values of *treatment variance* compared to the *total variance* and and rejection of the null hypothesis. This confirms that *various printing treatments have a different effect* on the percentage change in length and width after long-term care simulation for both knitted fab-

***Table 11.** Colour loss of black parts (B) of screen printed QR Codes (SP) evaluated for first knitted fabric (sample 1, S1) after multiple washing and drying cycles (1 – 25 W&D) and multiple pilling rubs (7000 – 28000 PR). CIE L*a*b* colourimetric values: a*- red-green coordinate, b*- yellow-blue coordinate, L*-brightness, C*- saturation and h*-hue; ΔE*00 -change in colour, GS- gray scale rating.*

Reference	L*	a*	b*	C*	h*, °		
S1-SP-B	20.46	0.46	0.65	0.8	54.32		
Sample	**L***	**a***	**b***	**C***	**h*, °**	**ΔE^*_{00}**	**GS**
S1-SP-1W&D-B	47.76	1.06	-3.48	3.64	286.86	27.62	1
S1-SP-5W&D-B	51.85	1.26	-4.20	4.38	286.65	31.77	1
S1-SP-10W&D-B	56.84	0.72	-4.62	4.67	278.87	36.76	1
S1-SP-15W&D-B	56.91	1.56	-5.16	5.40	286.85	36.93	1
S1-SP-20W&D-B	54.47	1.49	-5.04	5.26	286.49	34.50	1
S1-SP-25W&D-B	56.51	1.92	-5.85	6.16	288.13	36.66	1
S1-SP-7000PR-B	28.13	0.01	-0.08	0.08	279.08	7.72	2
S1-SP-14000PR-B	28.77	0.48	-0.58	0.76	309.83	8.40	1-2
S1-SP-21000PR-B	29.41	0.45	-0.70	0.83	302.73	9.05	1-2
S1-SP-28000PR-B	29.70	0.48	-0.56	0.74	310.29	9.32	1-2

rics tested (S1 and S2), ie. there are significant differences determined between them. The influence of multiple washing and drying cycles is more pronounced for screen printed fabrics (S1-SP and S2-SP) in the length direction, as confirmed by the higher average values of shrinkage within group 1. In the width direction for screen printed fabrics (S1 and S2) is the established extension; but the influence of long-term care is more pronounced in transfer printed fabrics (S1-TP and S2-TP), as confirmed by the higher average values of shrinkage and variance determined within sample group 2.

Significant changes in knitting dimensions and uneven deformation (in the length and width directions) affect the readability only of smaller QR Codes, with a larger amount of encoded data printed in the screen printing technique due to the reduction in dimensions of black modules (square area smaller than 1 mm^2) immediately after 2 - 5 washing and drying cycles. In transfer printed QR Codes changes in readability happen later - after 6 - 9 washing and drying cycles, with lower dimensional changes and more uniform deformation (shrinkage in both directions). Worse readability is associated with dimensional changes in size and the level of damage of black modules (both depended on the error correction level). Uneven changes in black modules related to the cracking of the film and colour loss significantly affect the readability, as confirmed by the results shown in ***Table 13*** (see page 136).

Colour fastness and change in the surface appearance of both printed fabrics within the same group are very similar, and these were explained using the results obtained for the first knitted fabric (measured on larger modules of QR 1b Codes). For screen printed fabric samples the most intensive change in the appearance of QRs was noticed immediately after the first washing and drying cycle performed (***Figure 8***). The black printing ink applied for direct printing was not bound firmly enough onto the substrates, which is also indicated by high values of ΔE^*_{00} (the most influenced by change in hue and increase in the brightness of black prints) and the corresponding grades of gray scale (1- the worst, 5 – the best), presented in ***Table 11***. The low black print's colour fastness to washing, and the reduced contrast between the white background and black modules did not affect the readability of QR Codes printed in the larger size (even after an increased number of washing and drying cycles).

Table 10. *Single factor analysis of variance – influence of washing and drying on percentage change in length and width of screen printed (SP) and transfer printed (TP) fabrics: a. for first knitted fabric (sample 1, S1), b. for second knitted fabric (sample 2, S2).*

a. SUMMARY						
Groups	**Count**	**Sum**	**Average**	**Variance**		
Lenght S1-SP	6	-74.7	-12.45	4.811		
Lenght S1-TP	6	-17.1	-2.85	3.707		
ANOVA: single factor						
Source of variation	**Sum of squares**	***DF***	**Mean square**	***F***	***p*-value**	F_{crit}
Between groups	276.48	1	276.480	64.9166	0.00001	4.9646
Within groups	42.59	10	4.259			
Total	319.07	11				
Hypothesis testing						
$F \geq F_{crit}$	$p \leq 0.05$	Hypothesis				
yes	yes	reject (various printing treatments do not have the same effect – there are significant differencse between them)				
SUMMARY						
Groups	**Count**	**Sum**	**Average**	**Variance**		
Width S1-SP	6	5.2	0.8667	0.5027		
Width S1-TP	6	-21.2	-3.5333	5.9387		
ANOVA: single factor						
Source of variation	**Sum of squares**	***DF***	**Mean square**	***F***	***p*-value**	F_{crit}
Between groups	58.0800	1	58.0800	18.0335	0.0017	4.9646
Within groups	32.2067	10	3.2207			
Total	90.2867	11				
Hypothesis testing						
$F \geq F_{crit}$	$p \leq 0.05$	Hypothesis				
yes	yes	reject (various printing treatments do not have the same effect – there are significant differences between them)				
b. SUMMARY						
Groups	**Count**	**Sum**	**Average**	**Variance**		
Length S2-SP	6	-41.6	-6.9333	1.1667		
Length S2-TP	6	-16.8	-2.8000	3.5240		
ANOVA: single factor						
Source of variation	**Sum of squares**	***DF***	**Mean square**	***F***	***p*-value**	F_{crit}
Between groups	51.2533	1	51.2533	21.8533	0.0009	4.9646
Within groups	23.4533	10	2.3453			
Total	74.7067	11				
Hypothesis testing						
$F \geq F_{crit}$	$p \leq 0.05$	Hypothesis				
yes	yes	reject (various printing treatments do not have the same effect – there are significant differences between them)				
SUMMARY						
Groups	**Count**	**Sum**	**Average**	**Variance**		
Width S2-SP	6	5.2	0.8667	0.1067		
Width S2-TP	6	-15.1	-2.5167	2.4857		
ANOVA: single factor						
Source of variation	**Sum of squares**	***DF***	**Mean square**	***F***	***p*-value**	F_{crit}
Between groups	34.3408	1	34.3408	26.4941	0.0004	4.9646
Within groups	12.9617	10	1.2962			
Total	47.3025	11				
Hypothesis testing						
$F \geq F_{crit}$	$p \leq 0.05$	Hypothesis				
yes	yes	reject (various printing treatments do not have the same effect – there are significant differences between them)				

On the white background of screen printed patterns, after the first and multiple washing and drying cycles, no significant changes were observed, which can

Table 12. *Colour staining for white parts (WH) of screen printed QR Codes (SP) evaluated for first knitted fabric (sample 1, S1) after multiple washing and drying cycles (1 – 25 W&D) and multiple pilling rubs (7000 – 28000 PR). CIE L*a*b* colourimetric values: a*- red-green coordinate, b*- yellow-blue coordinate, L*-brightness, C*- saturation and h*-hue; ΔE*$_{00}$ -change in colour, SSR- staining scale rating.*

Reference	*L**	*a**	*b**	*C**	*h**, °		
S1-SP-WH	92.44	2.55	-5.12	5.72	296.40		
Sample	***L****	***a****	***b****	***C****	***h**, °**	**Δ*E**$_{00}$**	***SSR***
S1-SP-1W&D-WH	92.48	2.62	-5.24	5.86	296.57	0.14	5
S1-SP-5W&D-WH	92.65	2.73	-5.90	6.50	294.84	0.83	5
S1-SP-10W&D-WH	95.91	1.64	-5.33	5.58	287.11	3.59	4-5
S1-SP-15W&D-WH	93.17	3.33	-7.94	8.61	292.74	3.02	4-5
S1-SP-20W&D-WH	91.87	2.68	-6.39	6.93	292.74	1.40	5
S1-SP-25W&D-WH	92.85	2.92	-6.72	7.33	293.49	1.69	5
S1-SP-7000PR-WH	91.84	1.51	-3.69	3.98	292.21	1.87	4-5
S1-SP-14000PR-WH	86.43	2.99	-4.93	5.77	301.2	6.03	3-4
S1-SP-21000PR-WH	85.80	2.67	-3.85	4.69	304.74	6.76	3-4
S1-SP-28000PR-WH	84.90	2.58	-3.07	4.01	310.08	7.81	3-4

Table 13*. Colour loss of black parts (B) of transfer printed QR Codes (TP) evaluated for first knitted fabric (sample 1, S1) after multiple washing and drying cycles (1 – 25 W&D) and multiple pilling rubs (7000 – 28000 PR). CIE L*a*b* colourimetric values: a*- red-green coordinate, b*- yellow-blue coordinate, L*-brightness, C*- saturation and h*-hue; ΔE*$_{00}$ -change in colour, GS- gray scale rating.*

Reference	*L**	*a**	*b**	*C**	*h**, °		
S1-TP-B	27.93	1.02	2.9	3.07	70.58		
Sample	***L****	***a****	***b****	***C****	***h**, °**	**Δ*E**$_{00}$**	***GS***
S1-TP-1W&D-B	29.51	0.37	1.18	1.24	72.52	2.42	3-4
S1-TP-5W&D-B	25.97	0.40	1.65	1.70	76.47	2.41	3-4
S1-TP-10W&D-B	31.80	-0.46	0.83	0.95	118.76	4.63	2-3
S1-TP-15W&D-B	41.38	-0.17	0.25	0.31	124.51	13.76	1
S1-TP-20W&D-B	66.64	-0.61	0.84	1.04	126.04	38.80	1
S1-TP-25W&D-B	74.62	-0.54	1.26	1.37	113.22	46.74	1
S1-TP-7000PR-B	25.91	0.54	2.08	2.14	75.54	2.23	3-4
S1-TP-14000PR-B	23.37	0.98	2.62	2.80	69.39	4.57	2-3
S1-TP-21000PR-B	21.86	1.10	1.39	1.77	51.72	6.26	2
S1-TP-28000PR-B	21.07	1.07	0.74	1.30	34.64	7.19	2

Table 14. *Colour staining for white non-transparent parts (WH) of transfer printed QR Codes (TP) evaluated for first knitted fabric (sample 1) after multiple washing and drying cycles (1 – 25 W&D) and multiple pilling rubs (7000 – 28000 PR). CIE L*a*b* colourimetric values: a*- red-green coordinate, b*- yellow-blue coordinate, L*-brightness, C*- saturation and h*-hue; ΔE*$_{00}$ -change in colour, SSR- staining scale rating.*

Reference	*L**	*a**	*b**	*C**	*h**, °		
S1-TP-WH	95.75	-0.59	1.83	1.93	107.81		
Sample	***L****	***a****	***b****	***C****	***h**, °**	**Δ*E**$_{00}$**	***SSR***
S1-TP-1W&D-WH	95.50	-0.55	1.88	1.96	106.25	0.26	5
S1-TP-5W&D-WH	96.13	-0.55	1.83	1.91	106.72	0.38	5
S1-TP-10W&D-WH	99.10	-2.00	2.81	3.45	125.45	3.76	4-5
S1-TP-15W&D-WH	95.77	-0.58	1.97	2.06	106.51	0.14	5
S1-TP-20W&D-WH	95.52	-0.71	2.41	2.51	106.4	0.64	5
S1-TP-25W&D-WH	95.76	-0.53	2.14	2.2	104.04	0.32	5
S1-TP-7000PR-WH	97.46	-1.93	3.53	4.02	118.65	2.76	4-5
S1-TP-14000PR-WH	93.85	-0.45	2.75	2.78	99.36	2.12	4-5
S1-TP-21000PR-WH	93.31	-0.49	2.90	2.95	99.65	2.67	4-5
S1-TP-28000PR-WH	93.13	-0.46	3.11	3.15	98.49	2.95	4-5

be seen also from corresponding staining grades (***Table 12***). The poor fastness of black ink in screen printed samples and a large amount of unbound dye also affects a significant change in the appearance of printed black modules after repeated pilling rubs (***Table 11***). The transfer of black dye onto the white background occurs here (***Table 12***), which is indicated by the increasing change in colour Δ$E*_{00}$ (the most influenced with a change in hue and brightness reduction).

Changes that occurred in black fields of QR Codes of transfer printed samples after 10 multiple washing and drying cycles were determined through their reduced readability and confirmed by the results shown in ***Table 13***. A significant increase in brightness and change in the hue of black modules were recorded, which caused a change in the colour and thus the *GS* grades. Although not observed by visual examination, a change in the hue of black coloured modules of transfer printed QRs also occurred after multiple pilling rubs.

No significant changes were observed on the white background of transfer printed patterns after multiple washing and drying cycles and multiple piling rubs, which can be seen also from corresponding Δ$E*_{00}$ values and staining grades (***Table 14***).

With the purpose of implementing single factor ANOVA, in ***Table 15*** are shown spectrometric values of change in the colour (Δ$E*_{00}$) of black parts of screen and transfer printed QR Codes evaluated for the second knitted fabrics after multiple washing and drying cycles (measured on larger modules of QR 1b Codes). The single factor ANOVA presented in ***Table 16*** results in accepting the null hypothesis, which confirms that the *various printing treatments have the same effect* on the colour loss of black parts of screen and transfer printed CR Codes (expressed by Δ$E*_{00}$) after long-term care for both knitted fabrics tested (S1 and S2) – ie. there is no significant difference between them. Significant change in colour (Δ$E*_{00}$) and reduction in corresponding values of gray scale ratings (*GS*) occurred on black modules of QR Codes printed using both printing techniques. That is supported by the values of the *F*-ratio calculated, which are lower than the critical values of F (F_{crit}) and p-values are higher by 0.05.

Despite the high values of change in colour (ΔE^*_{00}) determined in screen printed fabrics, no significant effect on the readability of QR Codes was established because the uniform change (ie. graying) of entire modules (***Table 11***). In transfer printed QR Codes the significance of colour loss (ΔE^*_{00}) on readability is higher, because of the uneven change in the black modules, especially after 10 washing and drying cycles, which is indicated by increased variability within group 2, the significantly greater variance of ΔE^*_{00} and corresponding values of gray scale ratings (GS) for the S1- and S2-TP-W&D-B sample groups.

Conclusions

A T-shirt with a printed QR code is a functional medium that allows the transfer of information and modern communication, and is usually applied for personal "hidden messages" for marketing purposes as a carrier of advertisements or for the purpose of promoting a company, product or service. In order to ensure the functionality of a product, it is necessary to define its durability.

The results of the analysis performed confirmed justification of the implementation of the methodology proposed for durability assessment of functionally printed knitting.

It was found that:
- The structure of knitted fabrics, their dimensional stability, the number of care and wear cycles performed, the printing technique and the size of black modules in the QR Code have an influence on the results obtained.
- For screen printed fabrics, wearing simulation significantly impairs the usage quality. Material mass loss, thinning and induced pilling on the surface of knitted fabrics significantly affects the readability of printed QR Codes. Dimensional changes in knitting (in this regard and printed QR Codes) during the simulation of care, as well as significant changes in the hue of screen printed QR Codes do not have a significant impact on their readability.
- Samples printed by the transfer printing technique are very resistant to wear. For the readability of transfer printed QR Codes, the cracking of the film and changes in their surface appearance are of crucial importance - loss of colour and disappearance of black modules that commonly occur after multiple washing and drying cycles.
- The size of printed QR Codes and black modules in the QR Code are of crucial importance for their readability on knitting. Larger codes with a smaller amount of encoded data have a more consistent functionality.

For practical application, it is therefore recommended that:
- T-shirts printed by the transfer technique, as well as those made of a blend of cotton end elastane should be washed at a lower temperature (of 40 °C).
- In screen printing the quality of dyestuff bounded onto the printed substrate is taken into account.
- QR Codes in the screen printing technique should not be printed on parts of T-shirts exposed to pronounced wear.
- For prints in knitting larger QRs with less encoded data should be chosen (of a minimal size of 50 × 50 mm).
- In the designing of QR Codes, higher error corection levels should be applied.

Table 15. *Change in colour (ΔE^*_{00}) of black parts (B) of screen printed (SP) and transfer printed (TP) QR Codes evaluated for second knitted fabrics (sample 2, S2) after multiple washing and drying cycles (1 – 25 W&D).*

Screen printed fabric, S2		Transfer printed fabric, S2	
S2-SP-1W&D-B	25.54	S2-TP-1W&D-B	3.45
S2-SP-5W&D-B	30.09	S2-TP-5W&D-B	4.79
S2-SP-10W&D-B	34.81	S2-TP-10W&D-B	6.76
S2-SP-15W&D-B	34.06	S2-TP-15W&D-B	14.60
S2-SP-20W&D-B	33.05	S2-TP-20W&D-B	47.41
S2-SP-25W&D-B	33.33	S2-TP-25W&D-B	62.25

Table 16. *Single factor analysis of variance – influence of washing and drying (W&D) on colour loss of black parts (B) of screen printed (SP) and transfer printed (TP)QR Codes: a. for first knitted fabric (sample 1, S1), b. for second knitted fabric (sample 2, S2).*

a. SUMMARY						
Groups	**Count**	**Sum**	**Average**	**Variance**		
ΔE^*_{00} S1-SP-W&D- B	6	204.24	34.0400	13.8392		
ΔE^*_{00} S1-TP-W&D-B	6	108.76	18.1267	388.2101		
ANOVA: single factor						
Source of variation	**Sum of squares**	***DF***	**Mean square**	***F***	***p*** **-value**	F_{crit}
Between groups	759.7025	1	759.7025	3.7792	0.0805	4.9646
Within groups	2010.2461	10	201.0246			
Total	2769.9487	11				
Hypothesis testing						
$F \geq F_{crit}$	$p \leq 0.05$	Hypothesis				
no	no	accept (various printing treatments have exactly the same effect – there are no significant differences between them)				

b. SUMMARY						
Groups	**Count**	**Sum**	**Average**	**Variance**		
ΔE^*_{00} S2-SP-W&D-B	6	190.88	31.8133	12.0363		
ΔE^*_{00} S2-TP-W&D- B	6	129.26	21.5433	497.3567		
ANOVA: single factor						
Source of variation	**Sum of squares**	***DF***	**Mean square**	***F***	***p*** **-value**	F_{crit}
Between groups	316.4187	1	316.4187	1.2423	0.2911	4.9646
Within groups	2546.9653	10	254.6965			
Total	2863.3840	11				
Hypothesis testing						
$F \geq F_{crit}$	$p \leq 0.05$	Hypothesis				
no	no	accept (various printing treatments have exactly the same effect – there are no significant differences between them)				

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References

1. Pibernik J, Dolić J and Dilberiović I. T-shirt design by direct printing technique. *Tekstil* 2011; 60 (10): 504-511.
2. Presley A and Jenkins M. The T-Shirt: canvas for the signs of the times. *International Journal of Fashion Design, Technology and Education*, 2011; 4 (2): 141-150.
3. Shin D.-H, Jung J and Chang B.-H. The psychology behind QR codes: User experience perspective. *Computers in Human Behavior*, 2012; 28: 1417-1426.
4. Soon T J. QR Code. *Synthesis journal, Section three* 2008; pp.59-78
5. Soon, T.J. QR Code: The 2D Code of the 21st Century and Its Applications, *Synthesis Journal, Section one* 2002; pp. 6-14
6. Fuhrt B. Handbook of Augmented Reality, Springer, New York, Dordrecht, Heidelberg, London 2011, pp. 339 – 352.
7. Kato H and Tan K T. Pervasive 2D Barcodes for Camera Phone Applications. *IEEE Pervasive Computing*, 2007; 6 (4): 76-85.
8. Saville B P. Phisical testing of textiles, The Textile Institute, Woodhead Publishing, Cambridge England 1999, pp. 168-183.
9. Tomljenović A, Šikić M and Glogar M I. Functionality Evaluation of Children Summer Knitwear. *Book of Proceedings of the 5th International Textile, Clothing & Design Conference*, University of Zagreb, Faculty of Textile Technology, Dubrovnik, Croatia, 3rd-6th October 2010, pp. 741-746.
10. EN ISO 105-C06:2010 Textiles - Tests for colour fastness - Part C06: Colour fastness to domestic and commercial laundering.
11. EN ISO 105-X12: 2002 Textiles - Tests for colour fastness - Part X12: Colour fastness to rubbing. 12. EN ISO 105-C07: 2001 Textiles - Tests for colour fastness - Part C07: Colour fastness to wet scrubbing of pigment printed textiles.
13. EN 20105-A02: 1994 Textiles - Tests for colour fastness - Part A02: Grey scale for assessing in colour.
14. EN 20105-A03:1994 Textiles - Tests for colour fastness - Part A03: Grey scale for assessing staining.
15. QR Code and 2D Code Generetar / Kerem Erkan, *Available from*: http://keremerkan.net/qr-code- and-2d-code-generator/ , *Accessed:* 01.12.2012.
16. 3GVision, *Available from*: http://i-nigma.com/i-nigmahp.html, *Accessed:* 10.01.2013.
17. Kipphan H. Handbook of Print Media, Springer, Berlin, 2001, pp 55-58.
18. Zjakić I, Parac-Osterman Đ and Glogar MI. Influence of a textile surface structure on raster value increase in screen printing. *Tekstil*, 2011; 60 (1): 1-8.
19. EN ISO 12947-3:1998+AC: 2006 Textiles - Determination of the abrasion resistance of fabrics by the Martindale method - Part 3: Determination of mass loss.
20. EN ISO 12945-2: 2000 Textiles - Determination of fabric propensity to surface fuzzing and to pilling - Part 2: Modified Martindale method.
21. EN ISO 6330: 2012 Textiles - Domestic washing and drying procedures for textile testing.
22. Sharma G, Wu W, Dalal E N. The CIEDE2000 color-difference formula: Implementation notes, supplementary test data, and mathematical observations. *Color Research & Application* 2004; 30 (1): 21–30.
23. EN ISO 105-A05: 1997 Textiles - Tests for colour fastness - Part A05: Instrumental assessment of changes in colour for determination of grey scale rating.
24. EN ISO 105-A04: 1999 Textiles - Tests for colour fastness - Part A04: Method for instrumental assessment of the degree of staining of adjacent fabrics.

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