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Image based colorimetric characterization of scrub induced color changes in UV printed and water transfer printed MDF boards

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Abstract:
Conventional colorimetric evaluation methods remain inadequate for accurately characterizing scrub-induced color changes on UV-printed and water transfer-printed decorative coatings applied to MDF after chemical resistance testing; therefore, this study proposes an image-based colorimetric characterization approach using an Image Processing-Based Scrub Tester to quantitatively assess such changes under simulated domestic chemical exposure. For this study, 8 mm thick Medium-Density Fiberboard sheets with a bright white, polyvinyl chloride-coated Medium-Density Fiberboard, high-gloss acrylic coating Medium-Density Fiberboard, Medium-Density Fiberboard lam, and Medium-Density Fiberboard sheets treated with polyurethane, cellulose-based, water-based and acrylic paints were utilized. A carbon fiber-patterned organic finish was applied to the surfaces of the pre-treated Medium-Density Fiberboard sample using ultraviolet printing and water transfer printing (WTP) techniques, followed by scrubbing testing with various domestic cleaning agents in compliance with Turkish Standards. As part of the picture evaluation process in this study, digital picture of the samples was captured after and before the scrubbing process. Color measurements were then analyzed based on L^*, a^*, and b^* coordinates, conforming to the Commission Internationale de l'Éclairage (*CIE* $L^*a^*b^*$) color system, utilizing a newly developed evaluation technique. From the outcomes of the study, it was observed that the overall color shift of the water transfer printing samples was 124,63% more than the ultraviolet printed samples. To assess the precision of the Image Processing-Based Scrub Tester's color measurement system developed in this research, its results were benchmarked against those from a different color tester. As a result, the findings strongly suggest that the color test analysis performed with Image Processing-Based Scrub Tester, together with the developed software, has the potential to serve as an alternative to industrial testing equipment.

Keywords: Image-Based Color Measurement; Medium-Density Fiberboard; UV Printing; Water Transfer Printing; Chemical Scrub Resistance.

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Introduction

For an extended period, finishes or decorative treatments such as paints, varnishes, and coatings have been applied to enhance the visual appeal of wood-based composite sheets and to improve their durability against environmental influences.

Today, innovative decorative coatings such as Ultraviolet (UV) printing and water transfer printing (WTP) techniques offer superior advantages in terms of visual aesthetics and durability. In recent years, the WTP technique has been increasingly adopted for the concealment of exterior surfaces on weapons and defense-related equipment. It is also applied to ornamental components like rims, car pendulums, coverings, storage units and armbands within the automotive industry. Moreover, it is utilized to elevate the aesthetic quality of numerous plastic, metal, and composite materials determined in interior design elements (Du *et al.* 2013, Li *et al.* 2024, Panozzo *et al.* 2015, Zhang *et al.* 2015).

In the UV printing technique, UV light (radiation) cured inks, UV cationic inks and lacquers have been developed (Macherey *et al.* 2021, Neral *et al.* 2006). UV printing technique is a coating technique performed using ultraviolet rays. This process is used to protect the product, increase its resistance to abrasion, scratching, chemicals and improve its visual effect. For example, it is frequently preferred in the coating of brochures, catalogs, posters, business cards, packages, labels, wood, plastic, glass and similar products (Çark 2022, Kocacikli 2023, Mohanraj *et al.* 2018, Özman 2008, Parraman & Adams-Foster 2011, Sang *et al.* 2020).

In recent years, it has been observed that WTP and UV printing techniques are newly used in the furniture industry. However, quality tests performed according to the areas of use of WTP or UV printed samples are not sufficient or accessible.

The film layer on surfaces with a protective layer (lacquer paint) or decorative coating (WTP, UV Printing, Serigraphy etc.) degradation over time. Therefore, paint, coating and varnish manufacturers perform tests such as hardness, gloss, color, adhesion and roughness to examine the effectiveness of protective coatings prior to commercialization. In addition, these layers are subjected to natural or artificial aging processes before the tests and the deformation effects are examined (Cayton & Sawitowski 2005, Rutherford *et al.* 1997, Shi *et al.* 2011, Mitani *et al.* 2024, Yang *et al.* 2024).

Standard scrub testers are used to measure the resilience of protective coatings to domestic chemicals. In the literature, It has been noted that alternative testers (color and gloss tester, scanning electron microscopy (SEM), scale, stereo microscope etc. are used to measure the layer changes that occur after the tests conducted with these testers (Fitzner & Aßmus 2005, Kok & Young 2014, Marazioti *et al.* 2024, Martinez *et al.* 2014, Redsve *et al.* 2003).

Despite the widespread use of spectrophotometric color measurements following scrub and chemical resistance tests, current evaluation approaches remain predominantly point-based, localized, and operator-dependent. Such conventional measurements are limited in their ability to represent the entire surface, particularly in artificially printed decorative layers such as UV-printed and water transfer-printed MDF boards, where color degradation may occur heterogeneously across the surface. Furthermore, these methods often require additional instrumentation, manual repositioning, and post-test handling, which reduce accessibility and industrial applicability in routine quality control environments. Therefore, there remains a clear need for an accessible, surface-representative, and industry-compatible method capable of quantitatively evaluating scrub-induced color changes over the whole printed surface rather than at isolated measurement points.

Image processing techniques has been widely used recently to improve the quality of wood-based composite sheets and wooden surfaces. This technique was developed to detect surface defects and evaluate the overall homogeneity of the surface. In the study presented by Zhao, which is one of the studies carried out in recent years in the literature, wood species classification was proposed using colored wood surface images. First, a new 2D wood image measuring machine was designed. Then, after converting the color image into a unified grayscale image in the Red-Green-Blue (RGB) color model, the gray histogram was created using the classification feature. Thirdly, a new snake model is proposed to perform the curve deformation. Finally, pattern recognition is performed by comparing the initial and final snake model histogram curves. It is experimentally proven that it can effectively distinguish intra-species color change and inter-species color change (Ercetin *et al.* 2024, Kukreja *et al.* 2024, Zhao 2013).

A pattern recognition system to identify traded Amazonian timber species was developed by Vieira *et al.* in 2022. Ten different species and twenty images were used, with three polishing processes applied for each timber species. The image recognition system used was a textural segmentation method associated with Haralick features and classified by Artificial Neural Networks. (Vieira *et al.* 2022).

In the research conducted by Iglesias *et al.* in 2024, a novel approach utilizing tester vision for the in-line evaluation of surface roughness on wood and wood-based materials in automated production settings was proposed. This method relies on extracting features from a gray-level co-occurrence matrix from images processed using edge detection techniques. The models, developed from images of sanded medium-density fiberboard, were used to predict surface roughness values, and their results were compared with direct measurements obtained through a confocal scanning device and a pencil-type surface profiler (Iglesias *et al.* 2024).

Another investigation introduces a methodology that employs Convolutional Neural Networks (CNNs) in combination with image analysis techniques to assess damage in timber structures. Initially, CNNs are applied to categorize images into three primary categories: fissures, knots, and intact areas. Subsequently, through image analysis techniques, precise characteristics of these imperfections were quantified, incorporating metrics such as crack length, width, angle, dimensions of the defective region within the knots, and color attributes (Ehtisham *et al.* 2024, Tatar *et al.* 2025).

A recently introduced method work introduced a CNN model based on transfer learning to identify surface irregularities in finished wooden objects, including blemishes, porosity, color mismatches, cracks, and knots. The model used image gradients based on the Canny operatör (Martinez *et al.* 2024, Ragb & Nagabooshanam 2024).

While previous studies on image processing in the field of wood science have predominantly concentrated on detecting natural defects and characterizing the inherent anatomical features of wood surfaces, there remains a notable research gap concerning artificially printed decorative patterns. In particular, the quantitative evaluation of scrub- or chemically induced color degradation in UV-printed and water transfer-printed MDF surfaces is generally performed using point-based spectrophotometric measurements or auxiliary instruments such as gloss meters and microscopes, which provide localized data and may not fully represent heterogeneous surface alterations. The proposed methodology directly addresses this limitation by integrating the Image Processing Based Scrub Tester (IPBST) with a dedicated image analysis software capable of capturing and analyzing the entire surface area before and after scrubbing. Unlike conventional post-test point measurements, this approach enables surface-wide, non-contact, and digitally repeatable colorimetric characterization under controlled scrub conditions. By shifting the focus from localized assessment to full-field image-based evaluation of artificially printed decorative layers, the study offers a more representative and industry-applicable framework for assessing color stability and degradation in wood-based composites.

Building on this premise, the objective of this research was to conduct a comprehensive color analysis by utilizing image-processing techniques to quantify the overall color shifts occurring after abrasion procedures on WTP- and UV-printed wood-based composite sheets. As highlighted in the reviewed literature, image-processing approaches have demonstrated strong capability in surface characterization, defect detection, and texture-based evaluation of wood materials, particularly when spatial heterogeneity is present. In contrast to conventional point-based spectrophotometric measurements, which provide localized data and may fail to capture non-uniform degradation patterns induced by scrub and chemical exposure, image-based analysis enables full-field, surface-representative assessment. In line with this rationale, the "Image Processing Based Scrub Tester (IPBST)" was developed and manufactured to emulate the reaction of the samples against domestic chemicals and to accelerate observable damage formation under controlled conditions. UV-printed and WTP samples were scrubbed using the IPBST in accordance with ASTM D1308-20 (2020) and TS EN ISO 11998 (2006) standards with various domestic chemicals.

To overcome the limitations associated with localized and post-test color measurements, this study adopts an image-based evaluation framework that enables whole-surface assessment of scrub-induced alterations. Unlike conventional point-based approaches, which may overlook spatially heterogeneous degradation patterns on printed decorative layers, image-based analysis allows the characterization of color changes across the entire exposed area under controlled conditions. Such a surface-representative and remotely operable evaluation strategy enhances measurement consistency and reduces operator dependency, thereby improving methodological robustness in industrial quality control contexts. Accordingly, the objective of this study is to develop and validate an integrated image-processing-based system for the quantitative assessment of scrub-induced color changes on UV-printed and water transfer-printed wood-based composite surfaces.

Materials and methods

Materials: preparation of samples

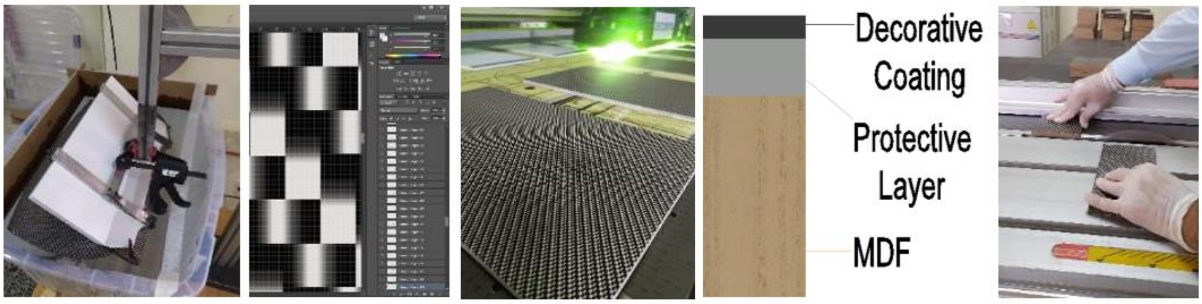
Various types of MDF widely utilized in the furniture industry were employed, including 8 mm thick, first-class MDF, bright white PVC-coated MDF, pre-finished lam MDF sheets, high gloss acrylic-coated MDF and raw MDF sheets. Each 520×310 mm sample was conditioned in a chamber set at 23±2 °C and 50±3 % relative humidity, as specified in (TS EN 322 1999), until achieving a stable weight and 9-10 % moisture content. A protective coating using glossy white polyurethane, cellulosic, acrylic, and water-based lacquer paints was then applied to all raw MDF sheet surfaces following (ASTM D3023-98 2017) (Figure 1a) (Budakçı 2003, DYO 2023). The lacquered samples were initially brought to a moisture content of 9-10 % in room conditions (Figure 1b), followed by further conditioning within the climate-controlled chamber (Figure 1c) (Korkmaz *et al.* 2025).

(a) (b) (c)

Figure 1: (a) Application of lacquer paint, (b) Setting painted samples to dry in room temperature conditions, (c) Preparing coated and lacquered samples under controlled conditions.

The MDF substrate was selected for this study due to its nearly homogeneous surface characteristics. In contrast, wood-based materials with natural textures, such as Scots Pine, Beech, and Poplar, exhibit heterogeneous surface layers when compared to MDF. This heterogeneity arises from the distinct anatomical features of springwood and summerwood, which differ in their dye absorption capacities. Consequently, in order to obtain a uniform and professional-quality surface finish, lacquer coatings and their associated finishing systems were applied to MDF substrates.

Water transfer printing (WTP) and ultraviolet (UV) printing coatings were applied to the prepared MDF-based composite specimens under controlled laboratory conditions. An automated self-contained immersion system was specifically designed, produced, and utilized for the WTP process (Figure 2a). A 30 µm PVAc-based WTP film featuring a carbon fiber pattern was applied to the sample sheets using this device, with a 45º dipping angle, 100 cm/min speed, and dipping times between 5 and 10 seconds (Kaçamer & Budakçı 2023). A UV printing device, widely applied in glass coating applications, was used for the UV printing techniques. The carbon pattern design was prepared in Adobe Photoshop before the printing process (Figure 2b) (Adobe 2023, Kurniawan & Lubis 2022). The ink ejection head was operated at a speed of 52 m/min, the UV curing lamp was set to 1000 W Hg, and the nozzle-to-sample distance was maintained at 3 mm during the UV printing process (Figure 2c) (Kaçamer *et al.* 2024).



(a) (b) (c) (d) (e)

Figure 2: (a) Water Transfer Printing, (b) Motif design, (c) Ultra Viole printing, (d) Surface layer of samples, (e) Cutting of samples.

Samples with WTP and UV printing (Figure 2d), representing contemporary decorative coatings, were cut to dimensions of 100×100 mm (Figure 2e). Altogether, 840 samples were created, categorized into 84 distinct groups, each intended for two different color measurement techniques. For each experimental group, 10 replicate samples were prepared. Thus, the number of effective materials was prepared to ensure the reliability of the results.

Aging process with scrubbing

The scrub resistance tests were conducted using an Image Processing Based Scrub Tester (IPBST) under controlled laboratory conditions (Figure 3) (Budakçı *et al.* 2023, Katırcıoğlu *et al.* 2025). The device was configured to simulate the effects of domestic cleaning agents on coated surfaces through a standardized reciprocating abrasion mechanism. During testing, parameters such as applied load, stroke length, cycle number, and chemical exposure conditions were maintained in accordance with the relevant scrub resistance standards TS EN ISO 11998 (2006). Each specimen was subjected to a defined number of scrub cycles while ensuring consistent contact pressure and uniform chemical distribution across the surface. Pre- and post-test surface conditions were recorded through the integrated imaging system to enable subsequent color change analysis.

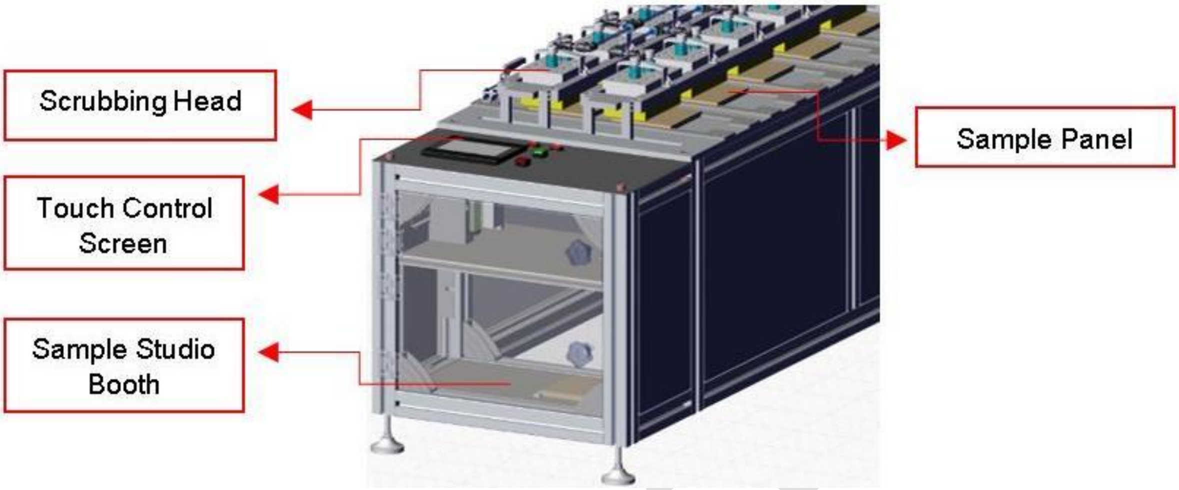


Figure 3: Image Processing Based Scrub Tester (IPBST).

Before the scrubbing procedure, digital images of the sample sheets were captured using the studio cabin attached to the machine. Subsequently, the samples were subjected to different domestic cleaning agents with the IPBST. Over the course of the process, a scrubbing head unit weighing 135±1 g was used to contact the coated surfaces, following the TS EN ISO 11998 (2006) standard. A dish sponge was used as an abrasive cleaning pad. The cleaning heads executed 200 smooth linear motions along the–Z and +Z axes at a frequency of 37±2 cycles per minute (Kaçamer *et al.* 2025). There is no difference between the TS EN ISO 11998 (2006) Turkish standard and the Geneva origin ISO 11998 (2006) standard. Lemon juice, ethyl alcohol, liquid dish soap, acetone, bleach, and cola were selected as the scrubbing agents based on the ASTM D1308-20 (2020) standard, by applying 5 mL of each to the surface of each individual sample (Figure 4a). The domestic chemicals were used directly as supplied (as is) without any dilution or modification, simulating real-life usage and adhering to standard protocols (Figure 4b).

(a) (b)

Figure 4: (a) Bleach-based scrubbing, (b) Domestic chemicals produced according to certain standards in the industry.

Digital pictures of each sample were recorded before and after the scrubbing procedure performed with various domestic cleaning agents using the IPBST. Color measurements were carried out using two approaches: (i) a spectrophotometric method based on the BYK-Gardner Spectro Guide 45/0 instrument, and (ii) an image processing-based color assessment technique developed within the scope of this study. For both approaches, pre- and post-scrubbing measurements were recorded under controlled conditions to enable comparative color evaluation.

Method: Image processing based color test

In the proposed IPBST study, background removal was applied to the images captured before and after the scrubbing process in order to accurately measure the changes occurring on the sample surfaces. This step aimed to eliminate the platform ground on which the sample was placed, thereby restricting the analysis to the region containing only the sample surface.

Background removal was performed using thresholding-based segmentation. This approach minimized environmental and platform-related interference, ensuring that the color measurements reflected solely the alterations caused by the scrubbing process on the sample surface.

The CIE L*a*b* color space was used to evaluate color changes in the images in a manner consistent with human perception. For this purpose, the RGB images acquired before and after the scrubbing process were converted to the CIE L*a*b* color space. The conversion was performed using the rgb2lab function in the MATLAB R2021b Image Processing Toolbox. Through this transformation, L* (lightness), a* (red-green), and b* (yellow-blue) channel values were obtained for each pixel.

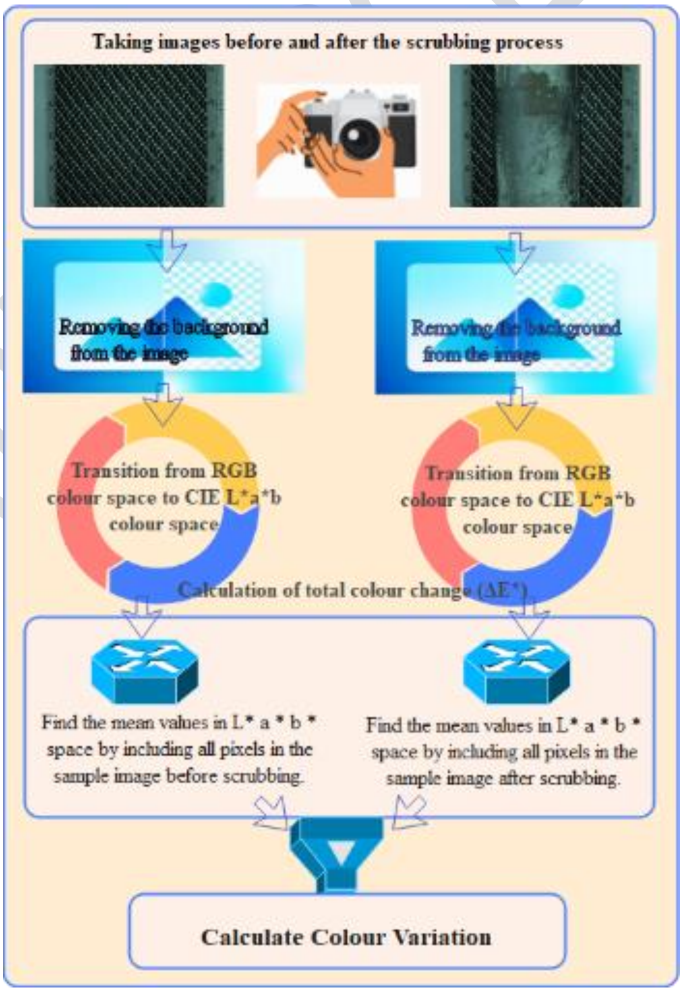


Figure 5: Schematic representation of the steps of color change determination.

In accordance with the relevant step of the image processing workflow shown in **Figure 5**, pixel-based color analysis covering the entire sample surface was performed following the background removal procedure. For each image, the mean L*, a*, and b^* values were calculated by averaging all pixels within the sample region. The equations used are as follows:

$$L_o^* = \frac{1}{MxN}\sum_{i=1}^{MxN} L_{oi}^* \quad (1)$$

$$a_o^* = \frac{1}{MxN}\sum_{i=1}^{MxN} a_{oi}^* \quad (2)$$

$$b_o^* = \frac{1}{MxN}\sum_{i=1}^{MxN} b_{oi}^* \quad (3)$$

$$L_s^* = \frac{1}{MxN}\sum_{i=1}^{MxN} L_{si}^* \quad (4)$$

$$a_s^* = \frac{1}{MxN}\sum_{i=1}^{MxN} a_{si}^* \quad (5)$$

$$b_s^* = \frac{1}{MxN}\sum_{i=1}^{MxN} b_{si}^* \quad (6)$$

Where the subscripts "*o*" and "*s*" denote the original (before scrubbing) and scrubbed (after scrubbing) images, respectively, and *MxN* is the total number of pixels in the sample region.

The differences in lightness and chromatic components were then calculated as:

$$\Delta L^* = L_s^* - L_o^*,\ \Delta a^* = a_s^* - a_o^*,\ \Delta b^* = b_s^* - b_o^* \quad (7)$$

A positive Δa^* value indicates that the scrubbed surface appears redder than the original, a positive Δb^* indicates a yellower appearance, and a positive ΔL^* indicates a lighter surface.

The total color difference ΔE^* was computed using the Euclidean distance formula:

$$\Delta E^* = \sqrt{\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2} \qquad (8)$$

This metric integrates the three color dimensions into a single value representing the overall perceptual color change.

It should be noted that the analysis was conducted on the mean values of the entire sample surface. While this approach effectively captures the overall color shift resulting from the scrubbing process, it does not account for intra-surface color heterogeneity. This simplification was deliberately adopted, as the primary objective of the study was to assess the macroscopic and uniform change across the surface rather than localized variations.

The image acquisition cabin in the designed and manufactured IPBST device was designed to be closed during image acquisition so that it would not be affected by environmental conditions. The inner quadrilateral dimensions were 18x18cm, the distance between the camera and the sample was 20 cm, the cabin wall surfaces were white, and the platform where the sample to be imaged was placed was adjusted according to the dimensions of the sample on the cabin floor, and then fixed placement was achieved in each measurement. These technical arrangements were made to ensure the repeatability of our image processing technique. The highest sensitivity was achieved by ensuring that the camera saw the sample at 90°. The light intensity inside the cabin was fixed, and a 12-volt sunlight-enabled LED lamp was used. In order to avoid light reflection problems on the sample, an LED lamp of 18cm length was placed on the ceiling and 4 sides of the cabin at equal intervals and lengths. In order to increase the accuracy of the measurement results performed with the image processing algorithm in the proposed study, an 8MP industrial camera and an 8MP lens were used, and large-sized images were studied in 1440x1080 bmp format.

Image acquisition and color analysis were performed once per sample under fixed and controlled cabin conditions. Since the established conditions (fixed distance, fixed angle, constant illumination, and consistent positioning) were designed to eliminate variation across repeated measurements, a single measurement per sample was considered sufficient and was preferred for experimental efficiency.

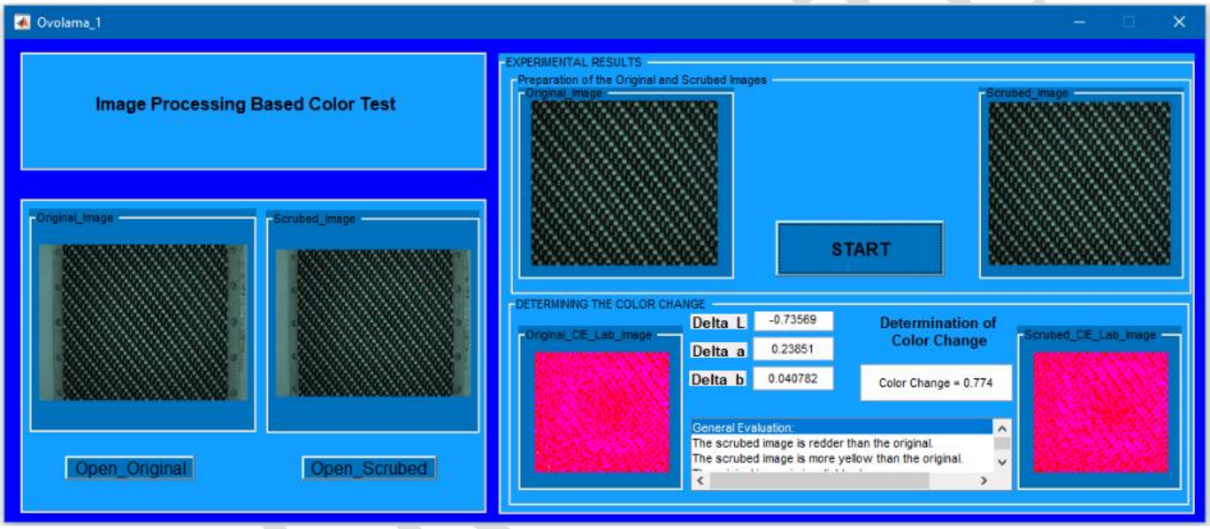
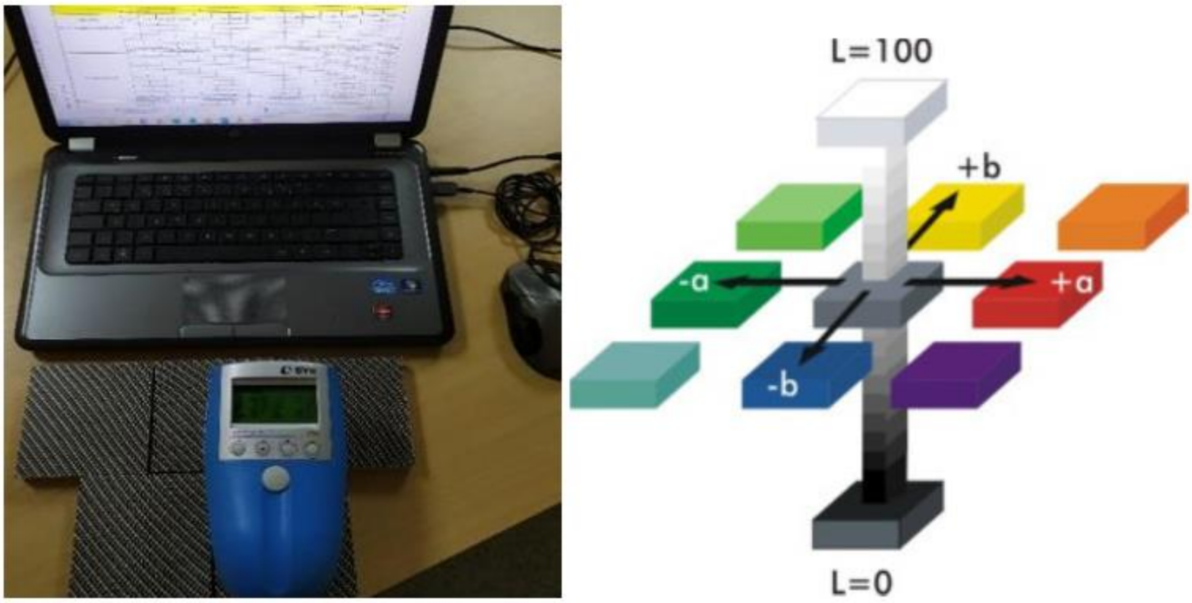


Figure 6: The Matlab GUI designed for the color testing technique based on image processing.

As illustrated in Figure 6, the Matlab Graphical User Interface (GUI) was employed to analyze and determine the color change (MathWorks 2023). First, the sample was positioned within the imaging cabinet, where its image was captured and documented. Following the scrubbing procedure, the sample is placed back in the cabinet and the image is taken and recorded. By pressing the “Open_Scrubed” button, the image of the sample after scrubbing is opened for measurement. Once the user selects the sample images from the file and clicks the "START" button, the entire image processing workflow—including background removal, RGB to CIE La*b* conversion, pixel-based averaging, and ΔE* calculation—is executed fully automatically without any further operator intervention. The digitally recorded ΔE* values, representing total color change in samples after and before scrubbing, are displayed on the right side of the demo software interface. In addition, the color differences between two images are expressed numerically and verbally.

Color testing with industrial tester

To validate the image-based color measurement approach implemented in the IPBST, surface color measurements were additionally performed using a BYK-Gardner Spectro Guide 45/0 spectrophotometer (BYK-Gardner GmbH, Geretsried, Germany, model CD-6834) (Figure 7a). The spectrophotometric measurements were used as a reference method to enable cross-validation of the image-processing-based results. Both measurement approaches were applied to the same sample surfaces under controlled laboratory conditions, and measurements were conducted on corresponding surface regions before and after the scrubbing procedure to ensure comparability between instrumental and image-based data. Color measurements were assessed using the *CIE L* a * b ** color system according to the principles specified in ASTM D2244-21 (2022) (Figure 7b). Before conducting color measurements, the tester was calibrated to a white reference, with values set as L = 94,95 ± 0,3 b = 0,58 ± 0,3 and a = -1 ± 0,3.



(a) (b)

Figure 7: (a) Taking color measurement values of sample sheets, (b) *CIE L*a*b** color system (Kaçamer 2024, Aytin *et al.* 2021, Özcan 2008).

Color measurements of samples coated with UV printing and WTP techniques before and after the scrubbing process were taken as given in Equation 8, Equation 9, Equation 10. The overall color variations on the samples following the scrubbing procedure were computed using the ΔE* Equation, as depicted in the figure below.

$$\Delta a^* = a^*O - a^*S \quad (8)$$

$$\Delta L^* = L^*\ O - L^*S \quad (9)$$

$$\Delta b^* = b^*\ O - b^*S \quad (10)$$

The subscript "S" used in these equations shows the values after the scrubbing process, and the subscript "O" shows the values before the scrubbing process. The overall color variation of the samples (ΔE*) was determined using Equation 7.

Statistical evaluation

The data collected for this study were analyzed using the SPSS 24 (IBM Corp., Armonk, NY) and CoStat statistical software (Costat 2023, IBM 2021). A four-factor factorial analysis of variance (ANOVA) was performed to evaluate the effects of domestic chemical type, decorative coating type, color measurement technique, and protective layer type on the measured color parameters. The model included all main effects as well as two-way, three-way, and four-way interaction terms to examine potential interaction patterns among the factors across sample groups. Post hoc comparisons were conducted following significant ANOVA results. Duncan's Multiple Range Test (DMRT) was applied to determine homogeneous groupings among treatment means when multiple factor levels were compared, due to its suitability for identifying ordered differences among group means. In addition, the Least Significant Difference (LSD) procedure was employed for pairwise comparisons in cases involving a limited number of group levels. Both tests were performed at a 95% confidence level ($\alpha = 0.05$).

Additionally, Pearson correlation analysis was performed to evaluate the association between the color measurement results obtained using the IPBST and those obtained from the industrial color measurement device. Statistical significance was assessed at a confidence level of 99% ($\alpha = 0.01$).

Results and discussion

ANOVA test results

The four-factor factorial ANOVA revealed that domestic chemical type, decorative coating type, color measurement technique, and protective layer type significantly influenced the measured color parameters, with several significant two-way, three-way, and four-way interaction effects observed among the factors ($p < 0.05$). The findings are presented in Table 1.

Table 1: ANOVA Outcomes Related to Color Measurement Analysis.

Factors	Sum of Squares	Degrees of Freedom	Mean Square	F Value	Level of Significance
Color Measurement Techniques (A)	2035,90	1	2035,90	554,16	0,00*
Protective Layer Type (B)	2456,79	6	409,47	111,45	0,00*
Decorative Coating Type (C)	10997,61	1	10997,61	2993,50	0,00*
Domestic Chemical Type (D)	177706,19	5	35541,24	9674,18	0,00*
Interaction (AB)	142,16	6	23,69	6,45	0,00*
Interaction (AC)	3,09	1	3,09	0,84	0,35
Interaction (AD)	121,96	5	24,39	6,64	0,00*
Interaction (BC)	5906,01	6	984,33	267,93	0,00*
Interaction (BD)	13561,95	30	452,06	123,05	0,00*
Interaction (CD)	69566,07	5	13913,21	3787,12	0,00*
Interaction (ABC)	254,86	6	42,47	11,56	0,00*
Interaction (ABD)	1026,88	30	34,22	9,31	0,00*
Interaction (ACD)	93,51	5	18,70	5,09	0,00*
Interaction (BCD)	28969,97	30	965,66	262,85	0,00*
Interaction (ABCD)	832,08	30	27,73	7,55	0,00*
Error	5554,82	1512	3,67		
Total	319229,88	1679			

*Statistically significant at the 95 % confidence level.

Based on the ANOVA results (Table 1), the interaction between the color measurement techniques and decorative coating type (AC) did not significantly affect the cumulative color alteration values, while all other factors and their interactions were determined to be significant. The results of the Duncan's multiple range test (DMRT), conducted using the LSD critical value for the factors of domestic chemical type, color measurement techniques, decorative coating type and protective layer type, are presented in Table 2.

Table 2: DMRT findings related to the influences of decorative coating type, color measurement techniques, protective layer type and domestic chemical type.

Color Measurement Techniques	x̄	HG	LSD
Image Processing Based Color Measurement	5,55	B	± 0,18
BYK – Gardner Spektro Guide 45/0	7,75	A*	
Decorative Coating Type	x̄	HG	LSD
WTP	9,21	A*	± 0,18
UV Printing	4,09	B	
Protective Layer Type	x̄	HG	LSD
Acrylic Lacquer Painted Sample	6,33	B	
Cellulosic Lacquer Painted Sample	6,20	B	± 0,34
Water Based Lacquer Painted Sample	6,08	BC	
Polyurethane Lacquer Painted Sample	6,38	B	
PVC MDF Sample	9,59	A*	
MDF Lam Sample	5,85	C	
High Gloss Acrylic MDF Sample	6,13	BC	
Domestic Chemical Type	x̄	HG	LSD
Bleach	2,69	B	
Acetone	29,64	A*	± 0,31
Coke	1,73	D	
Alcohol	1,87	CD	
Dishwashing Liquid	2,10	C	
Lemon juice	1,88	CD	

*: the maximum cumulative color alteration value; HG: homogeneity group; x̄ : Mean value

Based on the findings presented in Table 2, the maximum cumulative color alteration value at the measurement techniques level was observed with the BYK-Gardner Spectro Guide 45/0 tester (7,75), whereas the minimum change was noted with the image processing-based color measurement technique (5,55). At the board type level, the maximum cumulative color alteration value was determined in PVC-coated MDF samples (9,59), and the minimum in MDF Lam samples (5,85). At the decorative coating type level, the maximum cumulative color alteration value was determined in WTP-applied samples (9,21), while the minimum was in

UV-printed samples (4,09). At the domestic chemical type level, the maximum cumulative color alteration value was determined in samples rubbed with acetone (29,64), and the minimum in samples rubbed with cola (1,73).

It is thought that the high color change in PVC coated MDF samples is due to the lack of a solid bond between the decorative coating films (WTP and UV printing) applied to their surfaces and the PVC layer, which has a thermoplastic structure. In the literature, it is emphasized that the contact surface should be increased to help better adhesion of paint or coating type covering structures that are planned to be applied to the PVC foil surface later, and that for this, first sanding and then primer coat painting should be done (Aytaş 2021, Çavdar & Soncu 2018, Maden & Kamber 2018, Özden 2020, Soncu 2019).

As the coating layer applied in the WTP method is made of water-soluble polyvinyl acetate (PVAc), domestic chemicals have destroyed this film much more easily. In the UV printing process, the use of polymers sensitive to UV rays and the chemical structure of the layer becoming irreversible with UV rays have increased the resistance of the layer to domestic chemicals.

DMRT comparative results acquired via the BYK-Gardner spektro guide 45/0 and the image analysis-based color measurement technique

Table 3a and Table 3b presents a statistical comparison (DMRT) to analyze the color differences between sample groups. The study employed both the BYK-Gardner Spectro Guide 45/0 tester and a novel image processing-based color techniques to quantify the cumulative color changes on the samples. The data obtained by these two techniques are organized according to the factors of domestic chemicals type, protective layer type, measurement techniques and decorative coating type.

Table 3a: DMRT outcomes related to variations in the total amount of color change across the factors of measurement techniques, decorative categories, domestic chemical types and protective layer variants.

Protective Layer Type	Decorative Coating Type	Domestic Chemical Type	Color Measurement Techniques			
			Image Processing Based Color Measurement		BYK-Gardner Spektro Guide 45/0	
			x̄	HG	x̄	HG
Cellulosic Lacquer Painted Sample	WTP	Acetone	19,22	K	35,46	G
		Alcohol	0,93	&r-zA-J	2,21	&&A
		Bleach	0,10	&&J	2,19	&&AB
		Dishwashing Liquid	1,48	&j-zA-J	2,99	R-Za-k
		Lemon juice	0,82	&u-zA-J	2,62	W-Za-p
		Coke	0,79	&w-zA-J	1,88	&d-zA-H
	UV Printing	Acetone	26,99	J	31,65	H
		Alcohol	0,50	&&C-J	2,49	W-Za-u
		Bleach	1,69	&f-zA-J	4,64	N-R
		Dishwashing Liquid	1,58	&h-zA-J	3,16	R-Za-j
		Lemon juice	0,74	&xyzA-J	1,92	&b-zA-G
		Coke	0,64	&zA-J	2,18	YZ&A-C
Polyurethane Lacquer Painted Sample	WTP	Acetone	55,69	A*	49,04	BC
		Alcohol	1,22	&n-zA-J	1,91	&b-zA-G
		Bleach	0,46	&&D-J	2,40	X-Za-x
		Dishwashing Liquid	0,50	&&C-J	2,97	R-Za-l
		Lemon juice	0,90	&s-zA-J	2,88	U-Za-n
		Coke	0,76	&w-zA-J	2,20	YZ&AB
	UV Printing	Acetone	0,47	&&D-J	3,30	R-Za-g
		Alcohol	0,64	&zA-J	3,65	Q-Za
		Bleach	2,11	Z&A-D	7,45	K
		Dishwashing Liquid	1,69	&f-zA-J	2,95	S-Za-l
		Lemon juice	0,59	&zA-J	4,43	N-V
		Coke	0,54	&&A-J	4,53	N-U
Acrylic Lacquer Painted Sample	WTP	Acetone	52,02	B	50,18	B
		Alcohol	0,81	&v-zA-J	3,75	Q-Z
		Bleach	0,18	&&IJ	3,86	P-Y
		Dishwashing Liquid	1,26	&m-zA-J	4,63	N-S
		Lemon juice	0,45	&&D-J	3,57	Q-Za-c
		Coke	0,33	&&E-J	4,38	N-V
	UV Printing	Acetone	0,83	&u-zA-J	2,94	T-Za-m
		Alcohol	0,65	&zA-J	2,61	W-Za-q
		Bleach	1,94	&b-zA-G	5,47	M-P
		Dishwashing Liquid	1,76	&e-zA-J	2,26	X-Za-z
		Lemon juice	0,57	&&A-J	2,22	X-Z&A
		Coke	0,66	&zA-J	4,60	N-T
Water Based Lacquer Painted Sample	WTP	Acetone	48,87	CD	49,05	BC
		Alcohol	0,86	&s-zA-J	2,60	W-Za-r
		Bleach	0,11	&&J	2,53	W-Za-s
		Dishwashing Liquid	0,67	&zA-J	2,48	X-Za-v
		Lemon juice	0,70	&yzA-J	4,58	N-T
		Coke	0,70	&yzA-J	3,10	R-Za-k
	UV Printing	Acetone	0,76	&xyzA-J	3,09	R-Za-k
		Alcohol	0,67	&zA-J	2,94	T-Za-m
		Bleach	1,96	&b-zA-F	7,31	K
		Dishwashing Liquid	1,73	&e-zA-J	3,59	Q-Zab
		Lemon juice	0,64	&zA-J	3,20	R-Za-i
		Coke	0,26	&&G-J	3,76	Q-Z
MDF Lam Sample	WTP	Acetone	46,83	EF	47,75	CD
		Alcohol	1,05	&p-zA-J	1,89	&c-zA-II
		Bleach	0,22	&&H-J	2,88	U-Za-n
		Dishwashing Liquid	0,84	&t-zA-J	3,49	Q-Za-d
		Lemon juice	0,98	&p-zA-J	3,25	R-Za-h
		Coke	0,71	&yzA-J	1,81	&d-zA-I
	UV	Acetone	1,12	&o-zA-J	4,17	O-W
		Alcohol	0,45	&&D-J	2,22	X-Z&A

* : the maximum cumulative color alteration value; HG: homogeneity group; x̄ : Mean value

Table 3b: DMRT outcomes related to variations in the total amount of color change across the factors of measurement techniques, decorative categories, domestic chemical types and protective layer variants.

Protective Layer Type	Decorative Coating Type	Domestic Chemical Type	Color Measurement Techniques			
			Image Processing Based Color Measurement		BYK-Gardner Spektro Guide 45/0	
			x̄	HG	x̄	HG
	Printing	Bleach	1,84	&d-zA-I	6,33	LM
		Dishwashing Liquid	1,54	&i-zA-J	3,14	R-Za-j
		Lemon juice	2,20	&&AB	2,75	V-Za-o
		Coke	0,33	&&E-J	2,62	W-Za-p
High Gloss Acrylic MDF Sample	WTP	Acetone	50,44	BC	52,04	A*
		Alcohol	1,13	&o-zA-J	3,90	P-X
		Bleach	0,19	&&IJ	1,71	&f-zA-J
		Dishwashing Liquid	0,67	&zA-J	3,36	R-Za-f
		Lemon juice	0,57	&&A-J	2,54	W-Za-s
		Coke	0,59	&zA-J	2,42	X-Za-x
	UV Printing	Acetone	1,43	&k-zA-J	5,05	M-Q
		Alcohol	0,72	&yzA-J	3,05	R-Za-k
		Bleach	1,96	&b-Za-f	5,59	M-O
		Dishwashing Liquid	1,12	&o-zA-J	2,61	W-Za-r
		Lemon juice	0,50	&&C-J	2,95	T-Za-m
		Coke	0,47	&&D-J	2,36	X-Za-y
PVC MDF Sample	WTP	Acetone	45,33	FG	49,83	B
		Alcohol	0,93	&q-zA-J	2,52	W-Za-t
		Bleach	0,29	&&F-J	2,49	X-Za-v
		Dishwashing Liquid	1,03	&p-zA-J	1,29	&l-zA-J
		Lemon juice	0,53	&&B-J	3,10	R-Za-k
		Coke	0,39	&&E-J	1,74	&e-zA-J
	UV Printing	Acetone	51,88	B	44,56	F
		Alcohol	3,41	Q-Za-e	2,83	V-Za-n
		Bleach	1,78	&e-zA-J	5,90	L-N
		Dishwashing Liquid	1,64	&g-zA-J	2,44	X-Za-w
		Lemon juice	0,50	&&C-J	1,99	&&A-E
		Coke	0,54	&&A-J	3,25	R-Za-h
LSD ± 1,68						

* : the maximum cumulative color alteration value; HG: homogeneity group; x̄ : Mean value

As demonstrated by the data in Table 3a and Table 3b, the maximum cumulative color alteration value was determined in samples measured using the image processing-based color measurement techniques on polyurethane lacquered MDF surfaces after WTP was applied and acetone scrubbing was performed *(ΔE* = 55,69)*. The highest cumulative color difference value *(ΔE* = 52.04)* was observed on high-gloss acrylic-coated MDF surfaces after WTP application followed by acetone scrubbing (Figure 8). The lowest cumulative color alteration *(ΔE** = 0,10) was observed for cellulose lacquered MDF samples after WTP application and bleach scrubbing.

(a) (b)

Figure 8: (a) Sample with acetone scrubbing applied to sample after WTP was applied, (b)After WTP was applied to the sample surface, it was scrubbed with bleach.

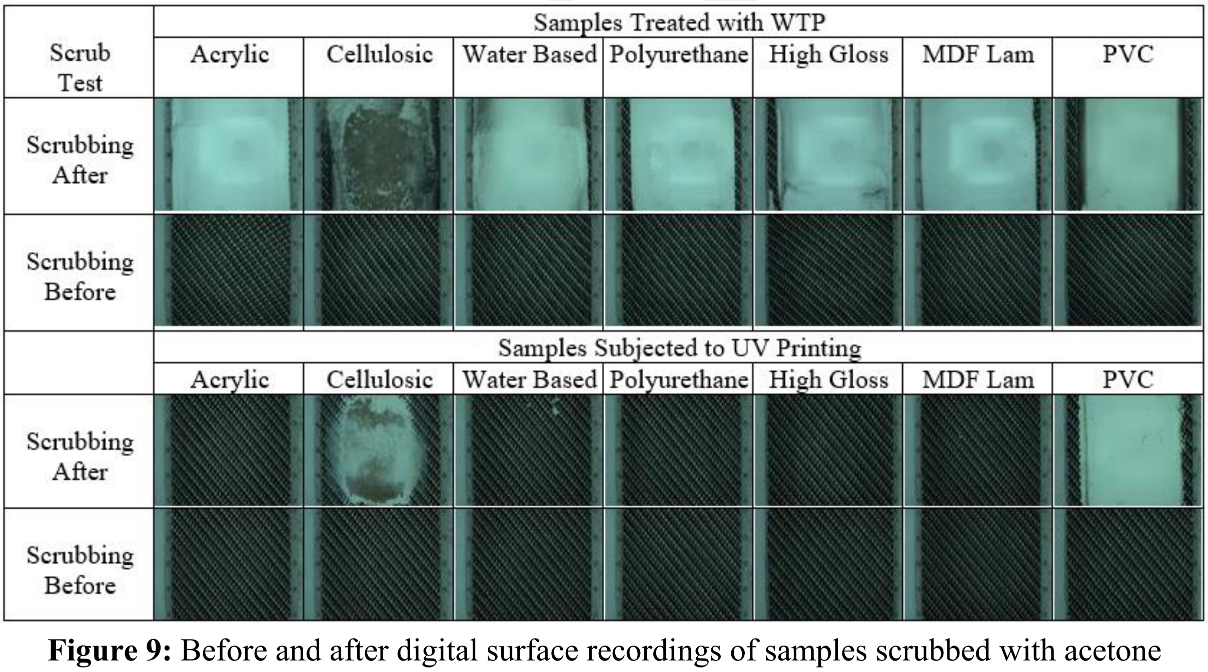


Figure 9: Before and after digital surface recordings of samples scrubbed with acetone (Kaçamer *et al.* 2024).

Acetone scrubbing resulted in pronounced surface alterations across the tested samples, with the magnitude of color change varying according to the type of protective coating. Acetone scrubbing caused pronounced degradation of the coating film across all tested MDF substrates, as illustrated in Figure 9. In cellulose lacquered and PVC coated MDF samples subjected to UV printing, the acetone treatment resulted in complete abrasion of the decorative film and full exposure of the underlying protective layers. s (Figure 9). A similar effect was observed for WTP applied samples on cellulose acquered surfaces, where the protective paint layer was severely damaged.

The findings indicate that cumulative color alteration values were generally high following acetone scrubbing. This outcome is primarily related to the contribution of the L* parameter within the total color difference calculation, as defined in Equations 7 and 8. Since L* constitutes one of the three orthogonal components of the CIELAB color space and directly enters the ΔE formulation, even moderate variations in L* significantly affect the magnitude of cumulative color alteration. After the acetone rubbing process, the complete abrasion of the decorative coating films (UV printing and WTP) exposed the white color of the protective coating on the board surfaces, which significantly influenced and raised the cumulative color alteration value.

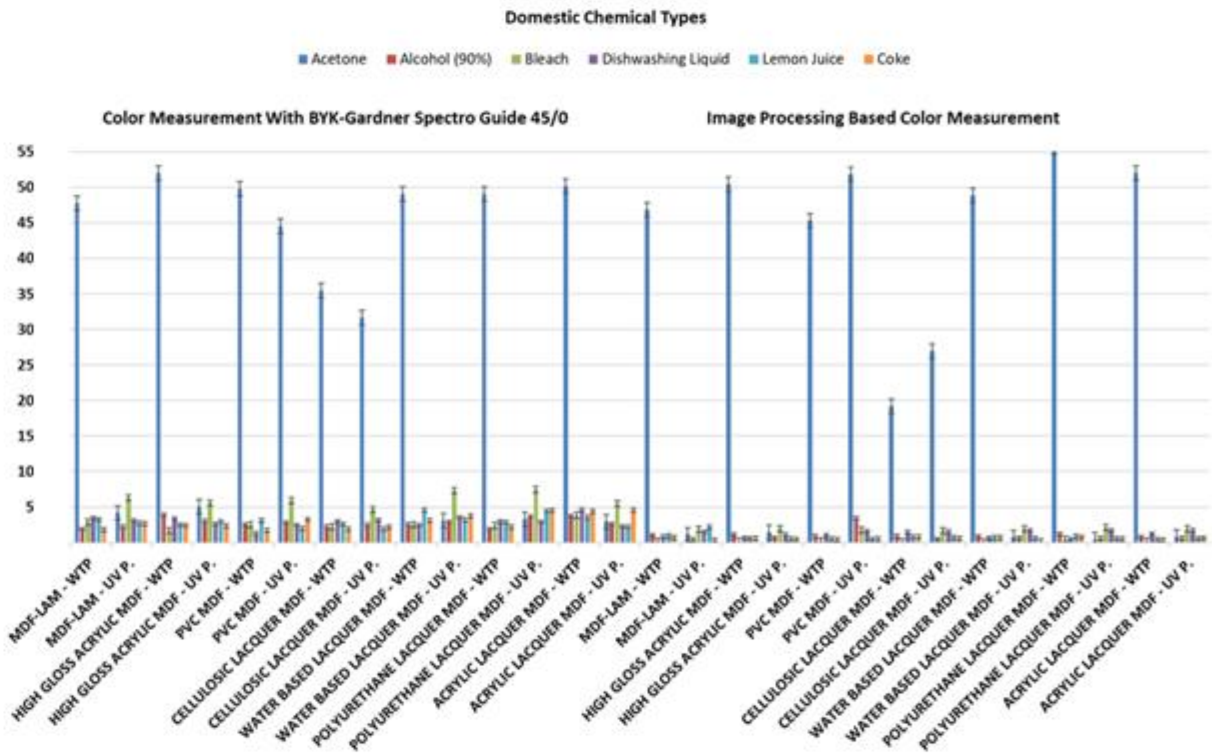


Figure 10: Relationships between groups of cumulative color alteration amount data obtained with two different measurement techniques.

Measurements made with the BYK-Gardner Spectro Guide 45/0 tester showed a strong similarity in the maximum and minimum cumulative color alteration data obtained in samples scrubbed with domestic chemicals when contrasted with the results yielded by the image processing-based color analysis (Figure 10).

A comparative analysis of correlation between color measurement techniques

The correlation analysis demonstrated the level of agreement between the BYK-Gardner Spectro Guide 45/0 measurements and the image processing–based color measurement techniques in quantifying cumulative color alteration on WTP and UV printed-treated surfaces after exposure to common domestic chemicals. The magnitude and direction of the correlation coefficients reflect the analytical consistency between the two approaches. The corresponding results are presented in Table 4.

Table 4: Assessing the correlation of color measurement techniques: BYK-Gardner spectro guide 45/0 and image processing.

Number of Samples (n)	The Pearson Correlation Coefficient (r)	The P-Value
1680	0,97	0,000*

*: Statistically significant at p < 0,01.

Table 4 presents the results of Pearson correlation analysis, demonstrating a strong positive correlation (r = 0,97, p <0,01) between the two-color measurement techniques. This significant relationship is further visualized in Figure 11.

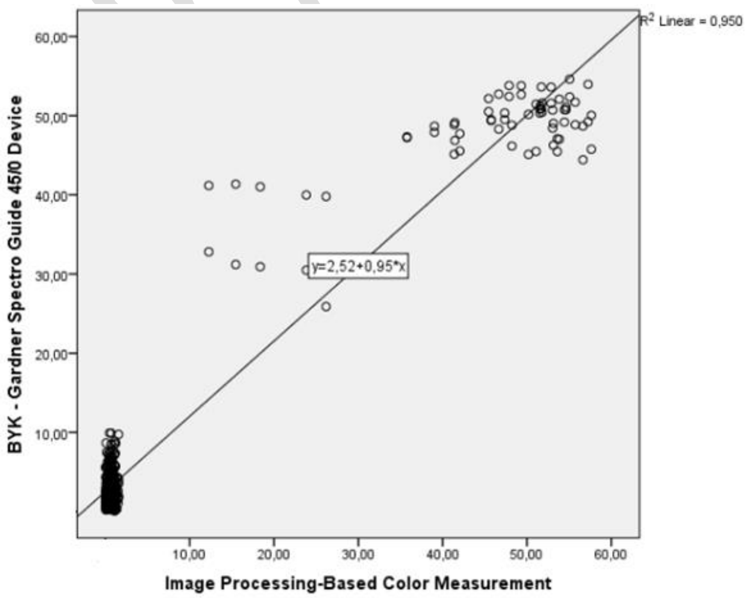


Figure 11: A Comparative analysis of color data obtained from two distinct measurement techniques.

Figure 11 depicts a strong positive correlation between the data generated by image processing-based color analysis and the BYK-Gardner Spectro Guide 45/0 tester, suggesting that image processing-based techniques may serve as a viable alternative to traditional color techniques.

Conclusions

Acetone scrubbing resulted in the highest cumulative color alteration values among the samples treated with WTP or UV printing. These significant color changes were consistent with measurements obtained using both the image processing-based techniques developed in this study and the BYK-Gardner Spectro Guide 45/0 instrument.

It has been determined that the coating film used in WTP application is not resistant to acetone in any way since it is a water-soluble PVAc material. The WTP coating on surfaces treated with water-based lacquer, polyurethane and acrylic was removed under the influence of acetone, yet the underlying protective paint layer remained intact. However, acetone completely corroded both the cellulosic lacquer paint layer and the WTP or UV printed decorative coating film on the MDF sheet surface. The magnitude of color changes varied depending on coating system and substrate structure.

WTP or UV printing applied to PVC coated MDF surfaces gave low durability against the scrubbing process with domestic chemicals. For businesses producing in the coating sector, it is not recommended to apply WTP or UV coating to MDF boards with PVC coating on their surfaces. Because the bonding/adhesion properties of the surface of this type of board are very weak. Instead, it is recommended to apply WTP or UV coating to the surface of MDF boards painted with polyurethane or acrylic.

The results demonstrated that the L^* value, representing lightness, had a decisive influence on the overall ΔE^* calculation. Samples backed with a white primer layer exhibited more pronounced detectable color shifts, emphasizing the importance of substrate optical properties in color performance assessment. This finding highlights the critical role of the lightness component in accurately capturing and quantifying color changes in decorative coatings.

Acetone, commonly used in household cleaning, has been found to be harmful to coatings, paints, or varnishes found on furniture surfaces. Literature reviews confirm that acetone is a common solvent in paint-related products. However, in the manufacturing sector, this can be used as an advantage due to its suitability for decorative coatings, WTP, UV printing, and the removal of incorrectly coated surfaces using cellulosic paint.

A strong agreement ($r = 0.97$) was observed between the BYK-Gardner Spectro Guide 45/0 measurements and the image processing–based technique. This high level of consistency demonstrates that the image-based approach provides reliable and comparable results for quantifying cumulative color alteration, supporting its applicability as an alternative color assessment method.

Image processing-based color analysis demonstrated a significant advantage over conventional devices, completing measurements up to three times faster than the BYK-Gardner Spectro Guide 45/0. By enabling rapid and cost-effective quantification of total color change, this approach provides an innovative and practical alternative to traditional industrial testing instruments, offering substantial benefits for both researchers and the paint and coating industry.

Overall, the study demonstrates that solvent type, coating chemistry, and substrate structure jointly determine decorative surface durability, while also establishing image processing–based color analysis as a reliable and efficient tool for industrial and research applications in the coating sector.

Authorship contributions

M. B.: Conceptualization, methodology, investigation, formal analysis, data curation, writing – original draft, supervision, project administration, funding acquisition. S.K.: Conceptualization, methodology, investigation, formal analysis, data curation, writing – original draft, writing – review & editing, visualization, project administration, funding acquisition. F. K.: Conceptualization, methodology, investigation, formal analysis, software, data curation, writing – original draft, writing – review & editing, visualization, project administration.

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To ensure measurement accuracy and operational reliability, a calibration certificate in accordance with TS EN ISO 11998:2006E was obtained from the Ankara-Ostim Laboratories of the Turkish Standards Institute.

Declaration of interest

The authors declare no conflict of interest.

References:

Adobe. 2023. Resmi Adobe Photoshop | Photography and design software. https://www.adobe.com/tr/products/photoshop.html.

ASTM. 2020. Standard Test Method for Effect of Household Chemicals on Clear and Pigmented Coating Systems. ASTM D1308-20. 2020. ASTM International, West Conshohocken, PA, USA.

ASTM. 2022. Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates. ASTM D2244-21. 2022. ASTM International, West Conshohocken, PA, USA.

ASTM. 2017. Standard Practice For Determination Of Resistance Of Factory-Applied Coatings On Wood Products To Stains And Reagents. ASTM D3023-98. 2017. ASTM International, West Conshohocken, PA, USA.
Aytaş, H.A. 2021. Improving the Paintability Holding by Changeing the Mechanical Surface Tension of the Polyamide Material. Master's Thesis, Marmara University, Türkiye.
Aytin, A.; Çakıcıer, N.; Çiftçi, S.; Akter, M. 2021. The Effect of Water-Based Varnish Color Barrier on Color Change and Hardness of Natural Wood Veneer. *Düzce University Journal of Forestry Faculty*, 17(1), 62–75. https://izlik.org/JA39AB97TD
Budakçı, M. 2003. Pneumatic adhesion test device design, production and testing in wood varnishes. PhD Thesis, Gazi University, Türkiye.
Budakçı, M.; Katırcıoğlu, F.; Kaçamer, S. 2023. Image Processing Based Scrub Tester. Tübitak 1005, Project No: 221O551.
Cayton, R. H.; Sawitowski, T. 2005. The impact of Nano-materials on coating technologies. Technical Proceedings of the 2005 NSTI Nanotechnology Conference and Trade Show, 2, 8-12.
Costat. 2023. CoStat-Free Statistics Software (for linear, polynomial, multiple, and non-linear regression, nonparametric tests, GLM ANOVA, multiple comparisons of means, analysis of frequency data, correlation, descriptive statistics, etc.). http://cohortsoftware.com/costat.html
Çark, Ö. 2022. Innovation Management Strategies. Organizational Behavior and Management in Family Businesses, 192.
Çavdar, K.; Soncu, S. 2018. Analyse of the surface preparetion methods before painting of plastics used in automotive industry. *Adana Science and Technology University Journal of Science* 1(2): 1-12. https://dergipark.org.tr/en/download/article-file/614095
Du, Q.; Zhang, L.; Zhang, J. Y. 2013. The Application Profile of Water Transfer Printing in the Product Design. *Applied Mechanics and Materials* 274: 216-219. https://doi.org/10.4028/www.scientific.net/AMM.274.216
DYO. 2023. Haziran 6. TDS, MSDS ve Sertifikalar. https://endustriyel.dyo.com.tr/sektorler/mobilya-boyalari/tds-msds-ve-sertifikalar
Ehtisham, R.; Qayyum, W.; Camp, C. V.; Plevris, V.; Mir, J.; Khan, Q. Z.; Ahmad, A. 2024. Computing the characteristics of defects in wooden structures using image processing and CNN. *Automation in Construction* 158: e105211. https://doi.org/10.1016/j.autcon.2023.105211
Ercetin, A.; Der, O.; Akkoyun, F.; Gowdru-Chandrashekarappa, M. P.; Şener, R.; Çalışan, M.; Olgun, N.; Chate, G.; Bharath, K. N. 2024. Review of Image Processing Methods for Surface and Tool Condition Assessments in Machining. *Journal of Manufacturing and Materials Processing* 8(6): 244. https://doi.org/10.3390/jmmp8060244
Fitzner, A.; Aßmus, U. 2005. Recommendation for the quality assessment of the product performance of all-purpose cleaners. *SOFW Journal* 131(9): 54.
IBM. 2021. Mayıs 21. Downloading IBM SPSS Statistics 24 (CT738,CT763,CT761,CT762). https://www.ibm.com/support/pages/downloading-ibm-spss-statistics-24
Iglesias, F.; Aguilera, A.; Padilla, A.; Vizán, A.; Diez, E. 2024. Application of computer vision techniques to estimate surface roughness on wood-based sanded workpieces. *Measurement* 224: e113917. https://doi.org/10.1016/j.measurement.2023.113917
Kaçamer, S. 2024. Investigation of The Use of Hydrographic Coatıng (Water Transfer Printing) and Ultraviolet (UV) Printing Process on Furniture Surfaces. PhD Thesis, Bolu Abant Izzet Baysal University, Türkiye.
Kaçamer, S.; Budakçı, M. 2023. Application parameters of water transfer printing on wood-based panel surfaces. *BioResources* 18(1): e1025. https://doi.org/10.15376/biores.18.1.1025-1040

Kaçamer, S.; Budakçı, M.; Katırcıoğlu, F. 2025. Image Processing Based Scrub Tester Design and Production. *Drvna Industrija* 76 (1): 69-77. https://doi.org/10.5552/drvind.2025.0205
Kaçamer, S.; Katırcıoğlu, F.; Budakçı, M. 2024. Determining Abrasion Resistance of Decorative Coated Wood-Based Panels Using Retinex Model. *BioResources* 19(1): 1058-1078. https://doi.org/10.15376/biores.19.1.1058-1078
Katırcıoğlu, F.; Budakçı, M.; Kaçamer, S. 2025. Determination of Gloss in Decorative Coated Woodbased Composite Boards by Image Processing Method. *BioResources* 20(3): https://doi.org/10.15376/biores.20.3.5731-5753
Kocacikli, M. 2023. An alternative technique by using digital photography and UV printing for fabricating a custom made ocular prosthesis. *The International Journal of Artificial Organs* 46(3): 135-140. https://doi.org/10.1177/03913988231151447
Kok, M.; Young, T. M. 2014. Evaluation of insect residue resistant coatings-Correlation of a screening method with a conventional assessment technique. *Progress in Organic Coatings* 77(9): 1382-1390. https://doi.org/10.1016/j.porgcoat.2014.04.020
Korkmaz, M.; Budakçi, M.; Kilinç, İ. 2025. Paint Removal From Marine-Aged Wooden Surfaces Using Agricultural Waste and İts Effects on Morphological Properties. *Wood Material Science & Engineering*, *20*(6), 1352-1361. https://doi.org/10.1080/17480272.2025.2564171
Kukreja, S.; Sahoo, R.; Jain, D.; Arora, V. 2024. Image Processing. In: Computational Science and Its Applications, Apple Academic Press, (ss. 117-143). https://doi.org/10.1201/9781003347484-5
Kurniawan, A.; Lubis, D. S. 2022. Perancangan Corporate Identity Sebagai Media Promosi Pada UMKM Fajar Mebel Berbasis Adobe Photoshop Adobe Premiere Pro Dan Coreldraw. *CIVITAS: Jurnal Studi Manajemen* 4(1): 28-40. https://journals.stimsukmamedan.ac.id/index.php/civitas/article/view/439
Li, Y.; Zhang, F.; Wang, S. 2024. Regulatable interfacial adhesion between stamp and ink for transfer printing. *Interdisciplinary Materials* 3(1): 29-53. https://doi.org/10.1002/idm2.12139
Macherey, M.; Schuhmacher-Wolz, U.; Belz, H.; Delbanco, E. H.; Mohr, K.; Gude, T.; Kaiser, E. 2021. Curing of UV prints-Assessment of possible toxicological hazard for consumers. *Regulatory Toxicology and Pharmacology* 124: e104965. https://doi.org/10.1016/j.yrtph.2021.104965
Maden, H.; Kamber, Ö. Ş. 2018. A Study On The Effects Of Several Surface Treathments By Smoothness An Strenght On The Prototypes Produced By Fdm Technology. *Duzce University Science and Technology Journal* 6(4): 916-929. https://doi.org/10.29130/dubited.418704
Marazioti, V.; Douvas, A. M.; Vouvoudi, E. C.; Bikiaris, D.; Papadokostaki, K.; Nioras, D.; Gogolides, E.; Orfanoudakis, S.; Stergiopoulos, T.; Boyatzis, S.; Facorellis, Y. 2024. The Condition of Contemporary Murals in Sun-Exposed Urban Environments: A Model Study Based on Spray-Painted Mock-Ups and Simulated Light Ageing. *Heritage* 7(8): 3932-3959. https://doi.org/10.3390/heritage7080186
Martinez, M. R. B.; Dayrit, K. M. D.; Yumang, A. N. 2024. Classification of Red Watermelon Varieties Using Canny Edge Detection and CNN. 2024 IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS), 47-52. https://doi.org/10.1109/I2CACIS61270.2024.10649622
Martinez, T.; Bertron, A.; Escadeillas, G.; Ringot, E.; Simon, V. 2014. BTEX abatement by photocatalytic TiO2-bearing coatings applied to cement mortars. *Building and Environment* 71: 186-192. https://doi.org/10.1016/j.buildenv.2013.10.004

MathWorks. 2023. Image Processing Toolbox. https://www.mathworks.com/products/image.html
Mitani, A.; Kamperidou, V.; Terzopoulou, P. 2024. Surface Treatment of Oak Wood with Silica Dioxide Nanoparticles and Paraloid B72. *Forests* 15(11): e1842. https://doi.org/10.3390/f15111842
Mohanraj, G.; Mao, C.; Armine, A.; Kasher, R.; Arnusch, C. J. 2018. Ink-jet printing-assisted modification on polyethersulfone membranes using a UV-reactive antimicrobial peptide for fouling-resistant surfaces. *ACS Omega* 3(8): 8752-8759. https://doi.org/10.1021/acsomega.8b00916
Neral, B.; Šostar-Turk, S.; Vončina, B. 2006. Properties of UV-cured pigment prints on textile fabric. *Dyes and Pigments* 68(2-3): 143-150. https://doi.org/10.1016/j.dyepig.2005.01.022
Özcan, A. 2008. The Determination of Rough Paper Surface Effect on L*A*B* Values. *Istanbul Commerce University Journal of Science* 7(14): 53-61.
Özden, E. 2020. Electrostatic Powder Coating Process Parameters' Optımization with Experimental Design Methods and Their Industrial Applications. Master's Thesis. Balıkesir University, Türkiye.
Özman, A. 2008. Health and safety considerations in printing, Master's Thesis, Dokuz Eylül University, Türkiye.
Panozzo, D.; Diamanti, O.; Paris, S.; Tarini, M.; Sorkine, E.; Sorkine-Hornung, O. 2015. Texture mapping real-world objects with hydrographics. *Computer Graphics Forum* 34(5): 65-75. https://doi.org/10.1111/cgf.12697
Parraman, C.; Adams-Foster, S. 2011. Traditional approaches using new technologies: Case studies of printed wallpaper using UV inkjet printing. Procedings of the Second Conference on Creativity and Innovation in Design, 297-306. https://doi.org/10.1145/2079216.2079258
Ragb, H.; Nagabooshanam, V. 2024. Wooden Texture Anomaly Detection: Leveraging Convolutional Neural Networks and Image Gradients. *TechRxiv* 2024: 1-5. https://doi.org/10.36227/techrxiv.171294949.94424137/v1
Redsve, I.; Kuisma, R.; Laitala, L.; Pesonen-Leinonen, E.; Mahlberg, R.; Kymäläinen, H.-R.; Hautala, M.; Sjöberg, A.M. 2003. Application of a proposed standard for testing soiling and cleanability of resilient floor coverings. *Tenside, Surfactants, Detergents* 40(6): 346-352. https://doi.org/10.1515/tsd-2003-400607
Rutherford, K. L.; Trezona, R. I.; Ramamurthy, A. C.; Hutchings, I. M. 1997. The abrasive and erosive wear of polymeric paint films. *Wear* 203: 325-334. https://doi.org/10.1016/s0043-1648(96)07369-3
Sang, R.; Manley, A. J.; Wu, Z.; Feng, X. 2020. Digital 3D wood texture: UV-curable inkjet printing on board surface. *Coatings* 10(12): e1144. https://doi.org/10.3390/coatings10121144
Shi, H.; Liu, F.; Han, E.H. 2011. The corrosion behavior of zinc-rich paints on steel: Influence of simulated salts deposition in an offshore atmosphere at the steel/paint interface. *Surface and Coatings Technology* 205(19): 4532-4539. https://doi.org/10.1016/j.surfcoat.2011.03.118
Soncu, S. 2019. Development of Surface Preparation Process Before Painting in Plastic Parts, Master's Thesis, Bursa Uludağ University, Türkiye.
Tatar, A.; Haghighi, M.; Zeinijahromi, A. 2025. Experiments on image data augmentation techniques for geological rock type classification with convolutional neural networks. *Journal of Rock Mechanics and Geotechnical Engineering* 17(1): 106-125. https://doi.org/10.1016/j.jrmge.2024.02.015

TS. 1999. Wood-based panels- Determination of moisture content. TS EN 322. 1999. Turkish Standards Institution, Ankara, Türkiye.
TS. 2006. Paints and varnishes-Determination of wet-scrub resistance and cleanability of coatings. TS. EN ISO 11998. 2006**.** Turkish Standards Institution, Ankara, Türkiye.
Vieira, G. L.; Moutinho da Ponte, M. J.; Pereira-Moutinho, V. H.; Jardim-Gonçalves, R.; Pantoja-Lima, C.; de Albuquerque-Vinagre, M. V. 2022. Identification of wood from the Amazon by characteristics of Haralick and Neural Network: İmage segmentation and polishing of the surface. *iForest-Biogeosciences and Forestry* 15(4): 234. https://doi.org/10.3832/ifor3906-015
Yang, Q.; Wang, N.; Yi, L.; Yan, L. 2024. Construction of decorative, antibacterial, anti-aging and fire-retardant integrative coatings for wood substrates with super protective performances. *Polymer Degradation and Stability* 219: e110620. https://doi.org/10.1016/j.polymdegradstab.2023.110620
Zhang, Y.; Yin, C.; Zheng, C.; Zhou, K. 2015. Computational hydrographic printing. ACM Transactions on Graphics, 34(4), 131:1-131:11. https://doi.org/10.1145/2766932
Zhao, P. 2013. Robust wood species recognition using variable color information. Optik-*International Journal for Light and Electron Optics* 124(17): 2833-2836. https://doi.org/10.1016/j.ijleo.2012.08.058