





## Article

# Adding Value to Maple (*Acer pseudoplatanus*) Wood Furniture Surfaces by Different Methods of Transposing Motifs from Textile Heritage

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**Abstract:** The present paper is part of an ongoing research project carried out to find methods to transpose traditional motifs from Romanian textile heritage to furniture ornamentation, as an additional method of preserving the motifs besides conventional conservation. Modern technology, such as Computer Numerical Control (CNC) routing or laser engraving can revive furniture ornamentation, eliminating manual labor and long execution time. Three methods were applied to transpose a bicolored motif from a traditional Romanian blouse from Transylvania onto the surface of maple wood furniture. The first method utilized was nitrogen laser engraving, in which ten power settings between 10 W and 150 W were applied and color measurements were carried out on the resulting engraved surfaces. Following the International Commission on Illumination (CIE Lab) system analysis, two laser power settings were selected to engrave the ornament on a maple wood surface for an accurate reproduction. The second method employed a staining solution applied on flat wood surface, followed by routing the model on a CNC machine and further coating with lacquer. The third method consisted of CNC routing the model on the wood surface, then coloring the engraved ornament followed by surface sanding to remove color from the flat wood surface and, finally, lacquering. The ornaments transposed onto maple wood surfaces were aesthetically assessed, the technologies were analyzed, and the details of the processed ornaments were highlighted by Stereo Microscope investigation. The conclusions showed that each method adds value to the wood surface by original ornamentation and can be applied as furniture decoration.

**Keywords:** heritage; ornament; color; laser engraving; maple wood; furniture



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## 1. Introduction

The dominance of symbols and motifs on furniture can be seen as a continuous recycling of ideas or knowledge from the past, which means a mixture of old and new ideas, i.e., tradition and innovation. This is true for Romanian, European, as well as universal spaces. Thus, the public learns about motifs and symbols, learns to love them and wishes to live with them. This can serve together with heritage conservation to perpetuate the motifs. The value of textile heritage is shown by the historical information shared by Romanian weavers which reveals the techniques of old craftsmanship and the materials and the coloring methods used [1]. Researchers in the field [2] focus on identifying the proper policies of promoting, developing and preserving craft heritage, based on actual techniques and technologies. Today, digital techniques and software possibilities offer the potential of capturing a multitude of cultural expressions, one of them being textile heritage and the motifs associated with it [3–5]. Digitizing heritage textiles and making information accessible to interested parties is a way to protect cultural heritage [6]. Computer-aided design (CAD), Geographic Information Systems (GIS), Scanning Electron Microscopy (SEM) image analysis, X-ray techniques, 3D scanning, CorelDraw vector graphics, or Adobe

Illustrator are programs that help in the digitization of old artifacts for the reconstruction, preservation or non-destructive testing of their state of conservation [4,6–9].

For furniture ornamentation, different techniques are applied depending on the material type. Painting, for example, has the role of protecting an object, or simply decorating a surface [10,11]. Antique ornamentation techniques such as carving, engraving or inlay are rarely used today for modern furniture, but up-to-date technologies such as computer numerical control (CNC) routing and laser engraving could revive them, replacing the exhausting manual work and long execution time needed before.

The optimization of CNC processing parameters is very important in finishing processes such as coating and painting, therefore a significant amount of research is focused on the surface quality required for wood finishing [12–15], investigated by measuring the roughness parameters. On the other hand, due to the heat effect, laser engraving induces changes in the wood's chemical and anatomical structure, resulting in carbonization and structural damage, affecting the lightness, which considerably decreases with the increasing power of the laser beam [16,17]. Laser deep engraving is considered by some authors [18] to be one of the most promising technologies used in wood carving operations, but careful selection of the wood species and the process parameters is required to avoid wood carbonization and to obtain homogeneous carving. The aesthetic perception of the wood surface with an engraved image depends both on the image and background color, so studies on the appropriate contrast between them were carried out by comparing the black color percentage of the engraved pattern and background measured in the Cyan, Magenta, Yellow, Key (CMYK) palette from zero to 100% [19,20]. The color differences between laser scanned areas on beech wood surfaces were determined depending on lightness and changes in basic colors of red and yellow [21] and also using replica scanning and processing in software such as Photoshop [22]. Changes in color were also noticed in the case of laser cutting fresh poplar wood [23], which were associated with damages in wood cells (as disrupted and frayed cells), more visible in early wood.

Increased attention has been given by researchers to the investigation of color differences in the case of laser engraving. A method used by researchers [17,21,24–26] to quantify the color induced by the CO<sub>2</sub> laser is the three-dimensional colorimetric system L\*a\*b\* (CIELab), established by the CIE (International Commission on Illumination), and the color difference, calculated as the distance between two points in the CIELab system [24], is presented. The color study on five wood species engraved by a laser [20] concluded that the best aesthetic perception is achieved on light wood species, rendering high contrast between the pattern and background. The color changes on light wood species were explained by the Fourier transform infrared spectroscopy (FTIR) analysis conducted on poplar, maple, spruce and lime wood changes, due to CO<sub>2</sub> laser irradiation with different values of exposure energy [25–29]. Investigations have shown that at a low irradiation dose, the lignin degrades, whilst at high irradiation dose, lignin condensation occurs and the hemicellulose degrades. To optimize the quality of laser engraved wood surfaces, another study [30] developed a calibration system to control color shades with a combination of laser power and optic focus, adjusted to control the chemical processes divided into wood burning and wood carbonization.

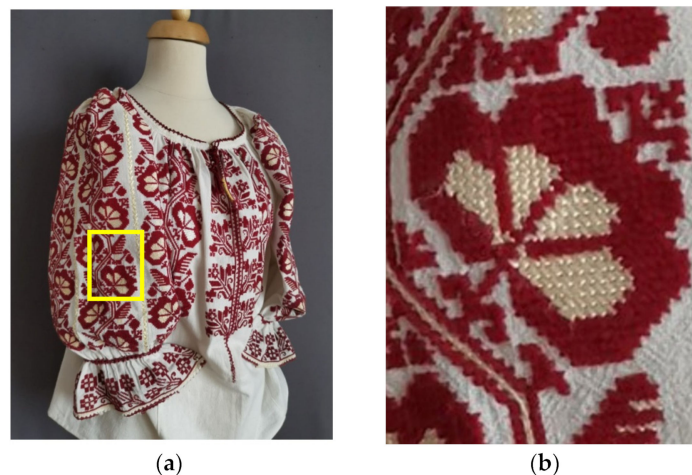
As resulted from the literature, an important step in accurately reproducing a color image by laser engraving is to keep the lightness difference between the original colors and the laser engraved ones. The research of the present paper proposes decorating the maple wood (*Acer pseudoplatanus* L.) surface with an ornament taken from the textile heritage of the Transylvania region using three methods: laser engraving, CNC milling and further coloring the ornament, coloring the basic surface and milling afterwards, followed by transparent varnishing. Based on the conclusions of other researchers with regard to light wood species [20], maple wood was selected for the experiment because it has a fine, even texture and a light golden color, which helps to obtain an adequate contrast with laser engraved surfaces and a good aesthetic perception. The original motif was bicolored in beige and burgundy. The model was digitally drawn using CorelDRAW X17 software.

The file was then imported in AutoCAD LT 2017 and transferred to CNC router and laser equipment with nitrogen assist gas for machining. In order to set appropriate laser beam powers for reproducing the original colors, a preliminary color study on the laser engraved surfaces with laser beam powers between 10% and 100% was carried out, using CIELab system analysis and the lightness difference was compared to that of the original colors. Milling the same motif on the CNC router and applying two methods of coating in order to highlight the ornament resulted in two other assessment criteria of the aesthetic function of the ornament. A microscopic evaluation of the processed surfaces, both by laser engraving and by milling and coloring, have completed the research.

The present paper is part of an ongoing large research project aimed to find methods for the use of traditional motifs of Romanian textile heritage for furniture decoration as a possible way to perpetuate them for future generations.

## 2. Materials and Methods

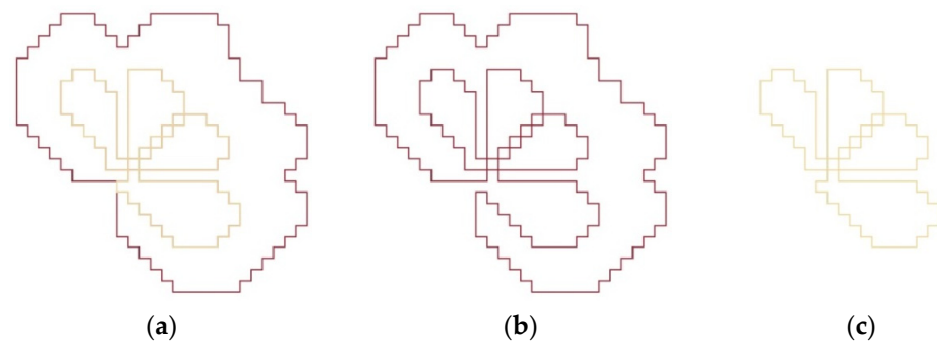
A traditional Romanian motif cross stitched on a woman blouse (named “ie”) from the textile heritage of Transylvania was collected as a picture from the owner of the original object (Figure 1). The motif decorates the sleeves, and it is symmetrically placed in vertical strings on the front part of the blouse. It represents a geometric interpretation of a plant and in Romanian folklore it symbolizes luck, the flow of life and the connection between the earth and the sky.



**Figure 1.** “Ie”, traditional woman’s blouse from a private collection from Transylvania region: (a) Ensemble view; (b) Detail of the stitched model.

In order to prepare it for wood surface ornamentation, the model was first rendered in vector format using the professional graphics software CorelDRAW X17 (Figure 2a). The file was then imported in AutoCAD LT 2017 and transferred to the OmniBEAM 150 Laser Machining Tool (LMT) with nitrogen assist gas, manufactured by COHERENT, INC., Santa Clara, CA, USA, which was used for laser engraving the wood, and to the 3-axis CNC router, model ISEL GFV type (Eiterfeld, Germany), which was used for milling the ornament on the wood surface.

Maple wood (*Acer pseudoplatanus* L.) panels with sizes of 300 mm × 200 mm × 18 mm, mean density of 615 kg/m<sup>3</sup> and moisture content of 11% were used as the base of ornamentation and for the preliminary study, with regard to the selection of an appropriately powered laser beam for laser engraving. Before processing the motif, the panels were sanded with 60 grit size to ensure the surface was sufficiently flattened in the range ± 0.15 mm, and then prepared for varnishing by sanding the wood surface with 100 and 120 grit sizes.

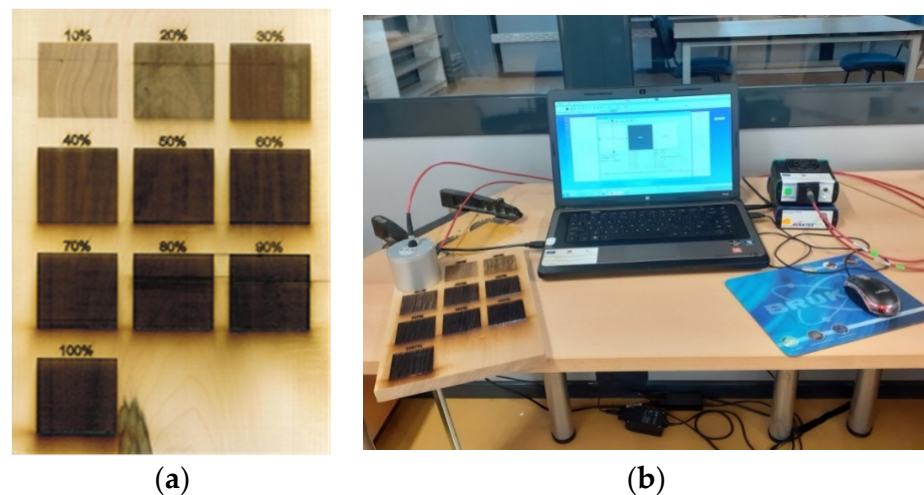


**Figure 2.** The drawing and the decomposition of the detail from the model: (a) complete contour; (b) burgundy contour; (c) beige contour.

### 2.1. Laser Engraving

As seen in Figure 1, the original motif is bicolored and for this reason, in order to be processed separately with different powers of the laser beam, the two decomposed parts of the motif were saved in two vector format files, one for each color, as seen in Figure 2b,c.

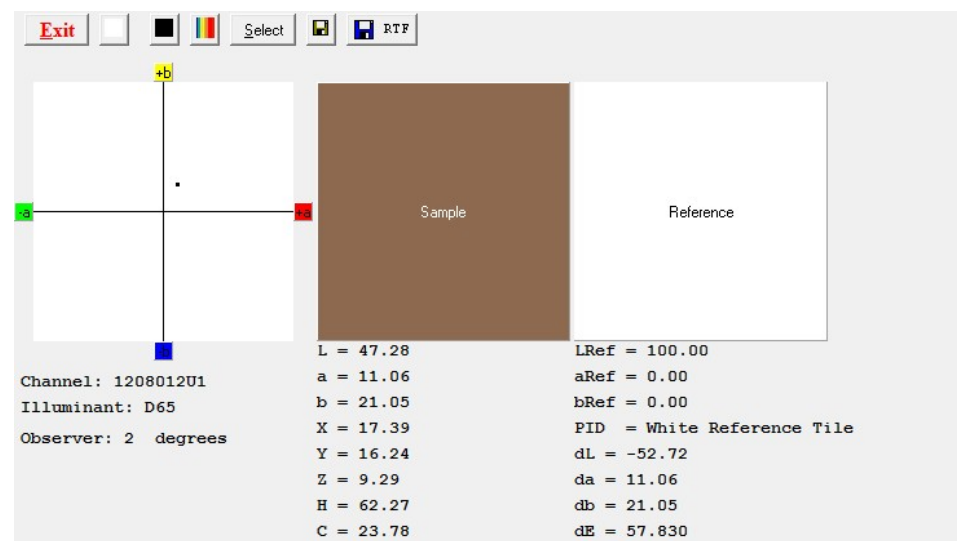
For the preliminary study conducted to decide the optimum laser beam powers to be used for the two colors, ten squares of 50 mm × 50 mm were engraved on one surface of the maple panel with LMT assisted by nitrogen gas, starting with 10% and ending with 100% of the maximum power of the machine of 150 W (Figure 3a) and with an increment of 10% for each square. Color measurements were afterwards made on each square, using a spectrometer AvaSpec-2048 USB2, an AvaLight Hal light source and an integrating AVA sphere interconnected by glass fibers. The AvaSoft 7.7.2 with color measurement application developed by AVANTES, Apeldoorn, Netherlands was employed for measurements (Figure 3b).



**Figure 3.** Sample of the preliminary study and equipment used to measure the color: (a) Maple wood sample; (b) Spectrometer AVANTES.

A control sample of maple wood was used as a color reference. For each engraved square, five color measurements were performed at different points on the surface, and ten measurements were carried out for the control sample. The CIELab three-dimensional colorimetric system was used for the color analysis (Figure 4). The three CIELab color parameters:  $L$ —lightness, which varies from 0 (black) to 100 (white); the chromatic coordinate  $a$ , varying from negative values for green to positive values for red on the green-red-axis and the chromatic coordinate  $b$ , varying from negative values for blue to positive values for yellow on the blue-yellow axis, were measured. In the CIELab space (Figure 4), axes  $a$  and  $b$  together create the chromaticity plane.





**Figure 4.** An example of color measurement results, including  $L$ ,  $a$ ,  $b$  CIELab parameters.

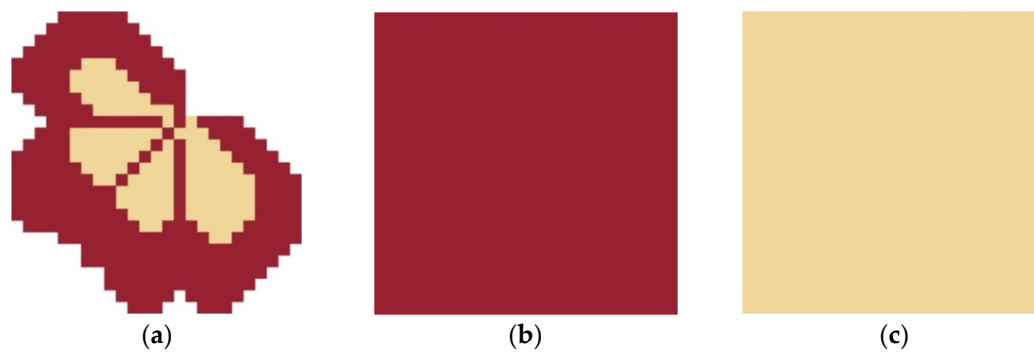
The mean values of  $L$ ,  $a$ ,  $b$  for the ten color measurements of the control sample and five measurements of each laser engraved square surface, alongside the standard deviations were calculated. In order to evaluate the difference between two colors, the color difference  $\Delta E$  was calculated as the distance between two points in the CIELab color space, according to Equation (1):

$$\Delta E = \sqrt{dL^2 + da^2 + db^2} \quad (1)$$

where:  $dL$  is the difference in lightness,  $da$  is the difference in red-green coordinate  $a$ ,  $db$  is the difference in the yellow-blue coordinate  $b$ , and  $\Delta E$  is the total color difference in the two colors to compare [24]. Differences between the average values measured on the laser engraved wood surfaces and the average values measured on the control sample surface were employed to calculate the resulting color differences as a function of the laser power.

The calculated color difference values were used as a basis to select the appropriate laser processing parameters to obtain engraved motifs with color differences as close as possible to those existing on the real model on the clothing object. If close calculated  $\Delta E$  values are obtained for both the original colors of the motif and for the laser engraved surface, then similar contrasts are expected for the original and the laser engraved motif. The laser beam powers rendering colors with similar contrast as the original motif will be further employed to process the entire ornament on the maple wood surface.

In order to measure the color difference ( $\Delta E$ ) between the original colors of the motif taken from the textile heritage, first the contour in vector format of the drawing was filled in colors selected from Figure 1b using the graphic program (Figure 5a). Squares of 50 mm × 50 mm drawn and filled with the two colors (Figure 5b,c) were printed on an A4 format of white cardboard. For burgundy and beige squares, five measurements of  $L$ ,  $a$  and  $b$  values were made at different points. For the white cardboard (considered to be the control sample), ten measurements of  $L$ ,  $a$  and  $b$  values were made. The mean values of the resulting measurements and the standard deviations were calculated afterwards.

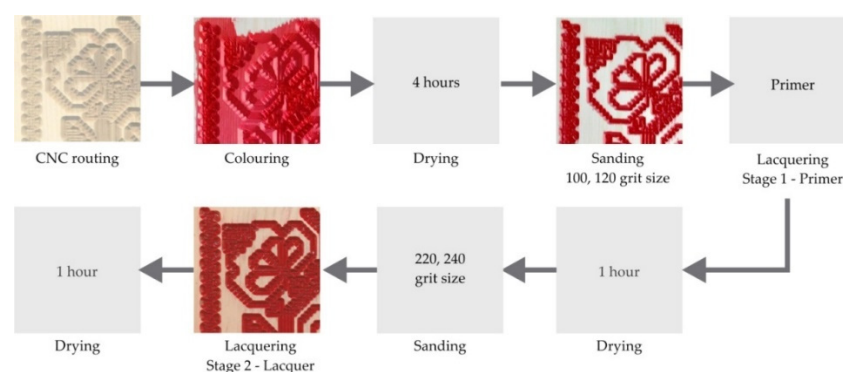


**Figure 5.** The digital combination for the detail of the traditional motif: (a) The full drawing; (b) The selected color for burgundy, RGB (red, green, blue) 152, 33, 49; (c) The selected color for beige, RGB 240, 214, 153.

### 2.2. CNC Milling, Coloring and Lacquering

The dxf file of the ornament in Figure 5 was imported from the AutoCAD program in the CNC router software for the milling operation. The contour of the ornament was CNC routed using two methods. For the first one (Engrave), a constant cutting depth of 3 mm was applied to both closed contours and open contours of the drawing. The second method (V-Carve) could be applied only for closed contours, with variable cutting depths between 1 mm and 3 mm for the interior surface of the ornament and 3 mm for the contour. The processing parameters used to process the ornament by CNC routing were as follows: spindle speed of 15,000 rpm and feed speed of 6 m/min. A double cutting edge CMT Orange V-Grooving Router Bit angled 90° made of super strength Fatigue Proof® steel with Tungsten carbide-tipped cutting edges was used for the experiment.

Two coating methods were applied in order to highlight the aesthetic value of the ornament on the wood surface. The first one employed a staining solution (walnut stain) applied on the flat wood surface, followed by routing the model on the CNC router and further coating with a nitrocellulose lacquer. The second method consisted of CNC routing the model on the wood surface, then coloring the engraved and V-carved ornament, followed by wood surface sanding for removing the color spots from the background and, finally, lacquering. The entire technological process of this method is shown in Figure 6.



**Figure 6.** Technological process of coloring and coating the wood surface after CNC routing.

### 2.3. Microscopic Investigation

After laser engraving the maple wood surface with squares at different laser beam powers, in the preliminary study, two of them were selected on the criteria of achieving a similar color difference, as between the original motif colors (beige and burgundy). The two engraved squares on the wood panel were microscopically investigated with a stereo-microscope NIKON SMZ 18 produced by Nikon Instruments, Melville, United States, with minimum 22.5× and maximum 405× magnification. NIS-Elements Imaging Software was used for image capture, measurement and analysis. The objective of the microscopic

investigation was to measure the depths of the wood burning by laser processing and to determine if sanding the flat wood surface (with grit sizes of 100 and 120), necessary to prepare it for lacquering, will affect the ornament. In parallel, measurements of the thickness of the panel were made before and after sanding with 100 and 120 grit sizes. The measurements were carried out in six points with the digital caliper, recording the minimum, maximum and mean values of the sanding thicknesses.

For the colored surfaces, a microscopic investigation was carried out to detect if sanding operations with grit sizes of 100 and 120 can entirely remove the color spots on the flat surface.

### 3. Results

#### 3.1. Laser Engraving

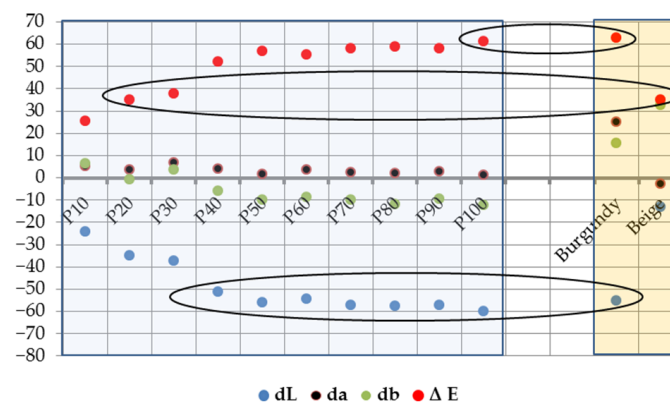
Table 1 presents the average values of  $L$ ,  $a$ ,  $b$ , as resulted from the color measurements of the ten laser engraved squares and of the two colors of the traditional motif printed on cardboard. Identification codes of the colors of each square were given, indicating the percentage of the total power of the laser beam applied for engraving, starting with 10% (P10) and ending with 100% (P100). Blank values represent the measurement results of the control samples for the two types of measured items (maple wood, white cardboard).

**Table 1.** Color analysis. Average experimentally recorded data  $L$ ,  $a$ ,  $b$  and standard deviations.

Measured Items	Investigated Area	Average $L$	Average $a$	Average $b$
Laser engraved squares on maple wood	Blank	85.15 (0.73) <sup>2</sup>	4.08 (0.35)	16.43 (1.79)
	Square 10% (P10) <sup>1</sup>	61.14 (3.74)	9.29 (0.45)	22.63 (0.54)
	Square 20% (P20)	50.28 (0.62)	7.68 (0.37)	15.79 (1.10)
	Square 30% (P30)	47.96 (1.86)	10.83 (0.40)	20.20 (1.36)
	Square 40% (P40)	33.74 (0.94)	8.22 (0.60)	10.37 (1.53)
	Square 50% (P50)	29.01 (0.54)	5.64 (0.47)	6.50 (0.48)
	Square 60% (P60)	30.58 (0.54)	7.64 (0.55)	7.56 (1.87)
	Square 70% (P70)	27.83 (0.86)	6.34 (1.11)	6.40 (1.73)
	Square 80% (P80)	27.43 (0.80)	6.20 (0.65)	4.46 (2.03)
	Square 90% (P90)	27.88 (0.79)	6.93 (0.41)	7.01 (1.67)
	Square 100% (P100)	25.07 (0.45)	5.20 (0.86)	4.00 (2.83)
Traditional motif on cardboard	Blank	93.93 (2.03)	4.03 (0.16)	−10.01 (0.29)
	Burgundy	38.54 (0.07)	29.24 (0.33)	5.72 (1.13)
	Beige	81.02 (0.15)	1.13 (0.33)	22.52 (0.23)

<sup>1</sup> 10% represents the percentage of 10% of the total power of the laser beam of 150 W, used to engrave the wood. It is also coded as P10. <sup>2</sup> Values in the parenthesis are standard deviations.

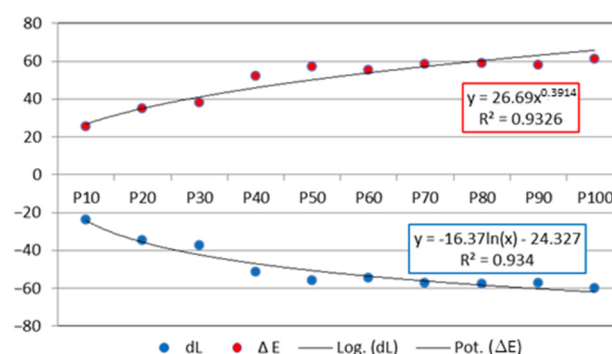
Furthermore, the differences in lightness ( $dL$ ), redness ( $da$ ) and yellowness ( $db$ ), as well as the total color difference ( $\Delta E$ ) between the laser processed wood surfaces and control wood, respectively, the original motif color and control cardboard were calculated. A graphic representation of the results is shown in Figure 7. At a first glance, it can be noticed that both  $dL$  and  $\Delta E$  values are very close for the laser engraved squares with powers higher than 40% of the total power of the laser beam (60 W). The results show also similarities of the lightness difference ( $dL$ ) versus controls for the burgundy color and the laser engraved squares with powers exceeding 40% of the total power of the laser beam (marked on the diagram in Figure 7). Instead, no similar values for  $dL$  were found for the beige color and the laser engraved ones. In the diagram from Figure 7, the closest values of  $\Delta E$  for the laser engraved colors and the motif colors are also circled. Thus, close values were found for the burgundy and laser engraved square with 100% power of the laser beam. For the beige color, powers of 10% and 20% of the total laser beam power conducted to similar color differences.



**Figure 7.** Comparison between colors depending on the power of the laser beam, using CIELab three-dimensional colorimetric system analysis.

As noticed in Table 1, the lightness values ( $L$ ) and redness (positive  $a$ ) of the maple wood control sample were close to those of the white control sample (85.15 compared to 93.93 for  $L$  and 4.08 compared to 4.03 for  $a$ ). These data confirm the conclusion of other researchers [20] that the aesthetic perception is better for the light species, where the contrast between the background and laser scanned surfaces is higher. Additionally, the positive values of  $a$  and  $b$  in Table 1 for the maple wood control sample and laser engraved wood surfaces show that the color differences depend on lightness and changes in basic colors of red and yellow, as for the case of laser scanned beech wood surfaces [21]. Comparing the control sample results from Table 1, except  $a$  and  $L$ , which have narrowed values, the white sample used as the control for the original colors of the motif had a negative  $b$  value, showing the intervention of blue in the color composition.

A detailed analysis on the values of lightness ( $dL$ ) and total color difference ( $\Delta E$ ) is presented in the diagram from Figure 8. The trends of the two curves for  $\Delta E$  and  $dL$  are mirrored to the horizontal axis. While the lightness decreases, the color differences increase. Both the increased and the decreased curves have a much smaller slope after applying a laser power higher than 40% of the maximum 150 W. The best-fit curves determined by nonlinear regression are power function with  $R^2 = 0.93$  for  $dL$  and logarithmic function with  $R^2 = 0.93$  for  $\Delta E$ . The terms of the functions also prove the mirrored position to the horizontal axis of  $dL$  and  $\Delta E$ .



**Figure 8.** Lightness decrease and total color differences for the laser engraved squares with different powers of the laser beam.

Even if similarities of  $\Delta E$  were found between the colors of the original motif and of the laser engraved ones, due to the fact that the control samples are different in terms of lightness and  $b$  value, the contrast between burgundy and beige is not achieved by the corresponding laser engraved surfaces. In order to achieve a contrast between the engraved colors as close as possible to the contrast of the original colors of the motif to be reproduced, contrast between colors was assimilated with the difference between

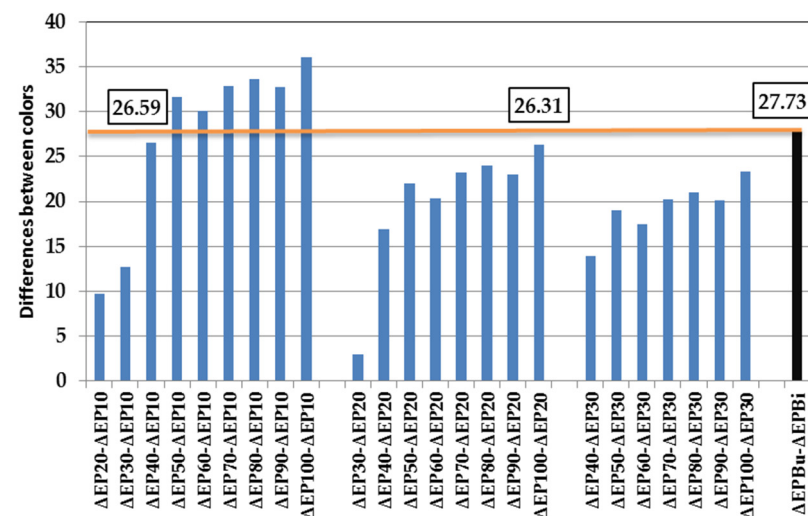


the  $\Delta E$  values of the respective colors, each calculated versus the corresponding control. These contrast assimilated differences were calculated both for the original motif colors and for the laser engraved surfaces (Table 2). In the case of laser engraved surfaces the contrast assimilated differences were calculated considering as comparison values the colors resulting by engraving with powers of 10%, 20% and 30% of the maximum laser power. For a better comparison of these calculated values, the diagram in Figure 9 is presented.

**Table 2.** Color contrast analysis, expressed by the difference between  $\Delta E$  values.

Color Investigation	Investigated Color	$\Delta E_{Pn}^*$	Difference $\Delta E_{Pn} - \Delta E_{P10}$ ( $n \geq 20$ )	Difference $\Delta E_{Pn} - \Delta E_{P20}$ ( $n \geq 30$ )	Difference $\Delta E_{Pn} - \Delta E_{P30}$ ( $n \geq 40$ )	Difference $\Delta E_{(Burgundy-Beige)}$
Laser engraved squares	Square 10% (P10)	25.34	0	0	0	0
	Square 20% (P20)	35.05	9.71	0	0	0
	Square 30% (P30)	37.99	12.65	2.94	0	0
	Square 40% (P40)	51.93	26.59	16.88	13.94	0
	Square 50% (P50)	57.03	31.69	21.98	19.04	0
	Square 60% (P60)	55.40	30.06	20.35	17.41	0
	Square 70% (P70)	58.24	32.90	23.19	20.25	0
	Square 80% (P80)	58.99	33.65	23.94	21.00	0
	Square 90% (P90)	58.10	32.76	23.05	20.11	0
	Square 100% (P100)	61.36	36.02	26.31	23.37	0
Traditional motif	Burgundy	62.85	0	0	0	27.73
	Beige	35.12	0	0	0	0

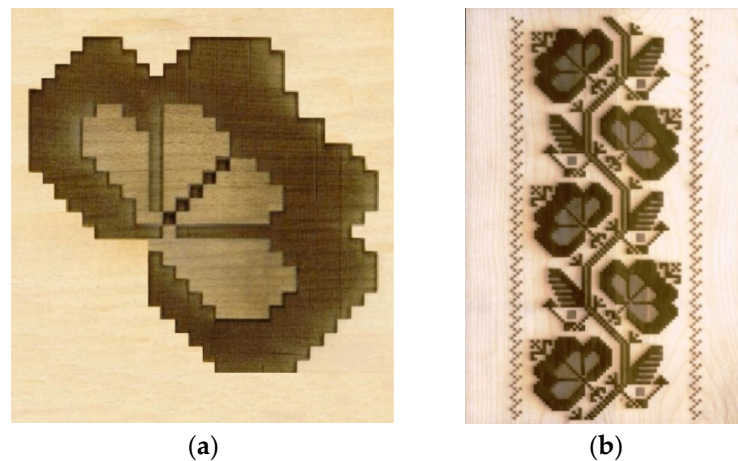
Note:  $\Delta E_{Pn}^*$ —color difference versus control for surfaces processed with laser power of n% from the maximum one.



**Figure 9.** Comparison between the contrast assimilated differences of  $\Delta E$  values, for original colors: burgundy (Bu) and beige (Bi) and the shades of brown corresponding to the laser engraved surfaces; contrast difference values for the laser processing variants rendering contrast close to the contrast between the original colors are presented.

As seen in Figure 9, engraving with a laser beam of 10% and 40%, or with 20% and 100% of the maximum power will lead to a similar color contrast with the original motif colors of burgundy (Bu) and beige (Bi), differences in  $\Delta E$  values being 26.59 and 26.31, respectively, compared to 27.73. According to the literature review [25–29], high irradiation dose of the CO<sub>2</sub> laser beam leads to wood degradation and carbonization, so the lower powers are preferred. The additional use of a CNC routed ornament with this method was aesthetically appreciated.

Because the drawing of the model was decomposed for the two colors of burgundy and beige (Figure 2), the two colors were processed separately, one after the other on the wood surface. The results are presented in Figure 10.

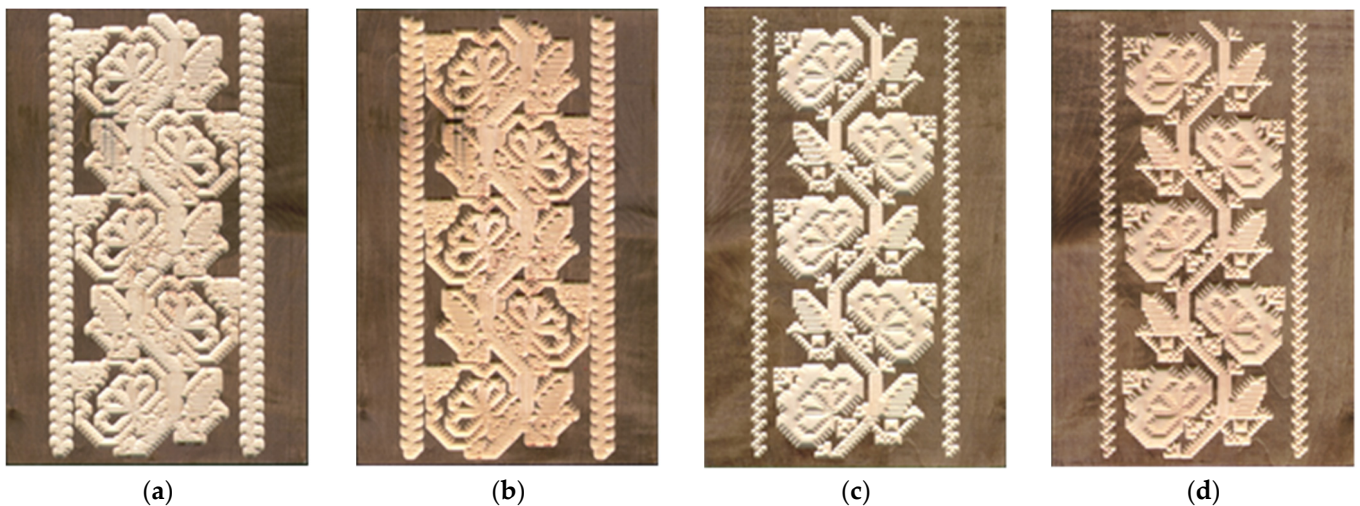


**Figure 10.** Laser engraved model using 40% of maximum power of the equipment for burgundy and 10% of maximum power of the equipment for beige: (a) The selected detail; (b) The complete traditional motif.

### 3.2. CNC Milling, Coloring and Lacquering

#### 3.2.1. Staining and Lacquering

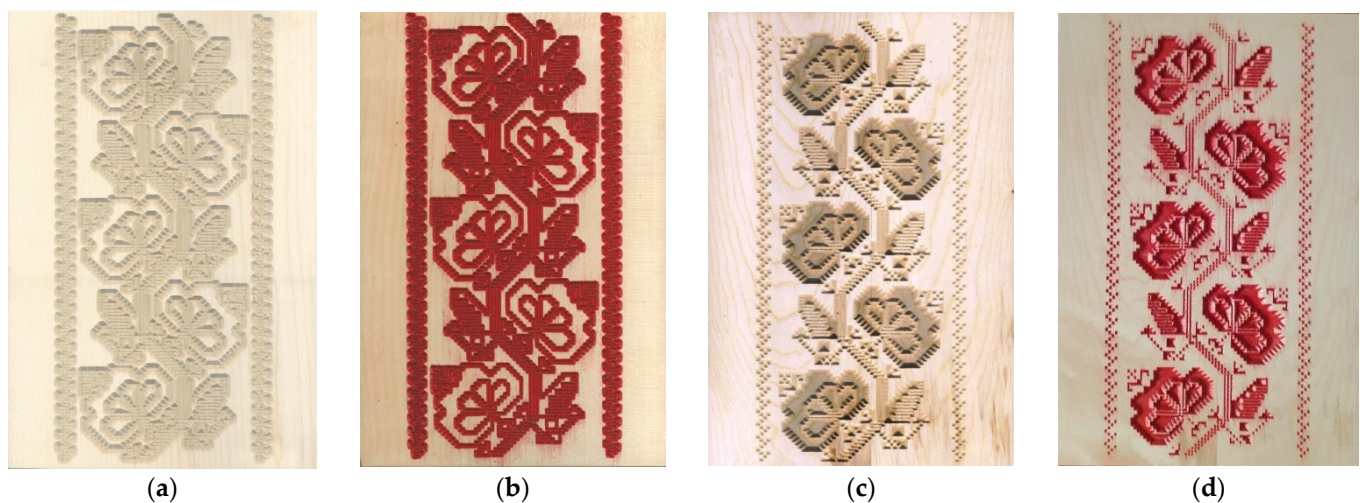
Another method to transpose the ornament on the wood surface is to highlight the contrast between the wood surface and the ornament by staining the background with a dark color and CNC milling the contours of the ornament on the maple wood surface, which is light colored (Figure 11a,c), followed by lacquering the whole surface (Figure 11b,d). The two CNC routing methods applied were engrave (Figure 11a) and V-carve (Figure 11c). By visually analyzing the aesthetics of the processed ornaments, it can be seen that applying the V-carve method, the ornament looks closer to the original one. CNC milling using the engrave method agglomerates the ornamentation surface and the contours seem to overlap.



**Figure 11.** Coloring of the wood surface: (a) CNC engraved motif on colored maple wood; (b) lacquered panel (a); (c) CNC V-carved motif on colored maple wood; (d) lacquered panel (c).

#### 3.2.2. Method of Coloring the Ornament

For this experiment, the same methods (engraving and V-carving) were applied to CNC milling the wood surface and to transpose the motif as ornamentation for furniture or other interior decorations. The technology for coloring the ornament is presented at Subchapter 2.2 and the results are presented in Figure 12.



**Figure 12.** Method of coloring the ornament: (a) CNC engraved motif on maple wood; (b) colored ornament and lacquered panel (a); (c) CNC V-carved motif on colored maple wood; (d) colored ornament and lacquered panel (c).

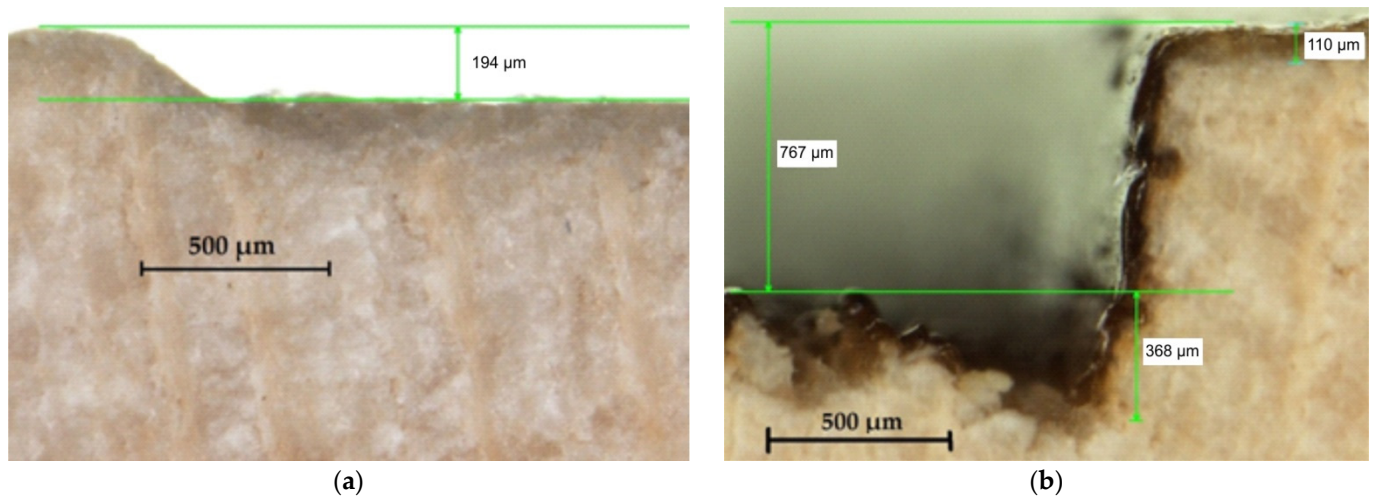
Engraving the wood surface by CNC milling (Figure 12a) and coloring the resulting ornament (Figure 12b) highlights the agglomeration of the machined surfaces and makes it hard to identify the shapes of some parts of the original motif. In addition, the intensity of the red color makes the observation of the ornament tiring. Instead, the V-carving method (Figure 12c) correctly reproduces the shape and outline of the ornament. Coloring in red the routed surfaces (Figure 12d) helps to better observe the ornament and improves the contrast between the light background color of the maple wood and the ornament.

This method opens the possibility of using the whole range of colors instead of red, but dark colors are preferred in order to obtain a stronger contrast between the background and the ornament. In this case, the two colors of the original motif are not present, but the technology of coloring the ornament on the wood surface can be improved by using a jig for each color. CNC routing using the V-carve method is recommended to reproduce the motif on the wood surface when the ornament is intended to be colored, no matter of the color used. Comparing Figures 11d and 12d, in Figure 12d the ornament looks cleaner than in Figure 11d, so coloring the ornament instead of the background seems to better reproduce the original motif.

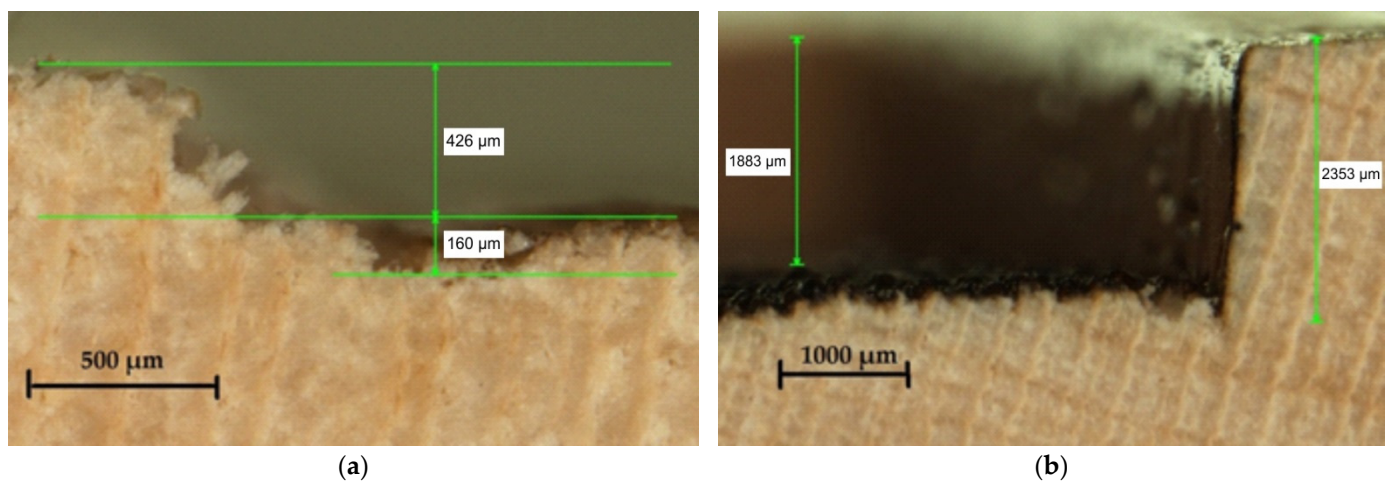
### 3.3. Microscopic Investigation

Analyzing the laser engraved wood surface after the complete traditional motif has been processed (Figure 10b), it was noticed that shades of brown remained on the background surface because of the burns produced by the laser power of 40% of the maximum one in the vicinity of the irradiated area. These brown spots had to be removed before coating, so sanding of the whole surface was applied. Further microscopic investigation focused on measuring the depth of the wood burning after laser irradiation with powers of 10% and 40% on one hand and 20% and 100% on the other hand. These measurements were taken on the squares engraved with corresponding powers on the maple wood surface. These pairs of powers were appropriate to ensure the best contrast of colors for the laser engraved traditional motif. The results are shown in Figure 13a,b for powers of 10% and 40% and in Figure 14a,b for powers of 20% and 100%, respectively.





**Figure 13.** Measured wood burning depth for laser engraved surfaces ( $90\times$  magnification): (a) With power of 10% of the maximum laser beam power of 150 W; (b) With power of 40% of the maximum laser beam power of 150 W.



**Figure 14.** Measured wood burning depth for laser engraved surfaces: (a) With power of 20% of the maximum laser beam power of 150 W ( $90\times$  magnification); (b) With power of 100% of the maximum laser beam power of 150 W ( $30\times$  magnification).

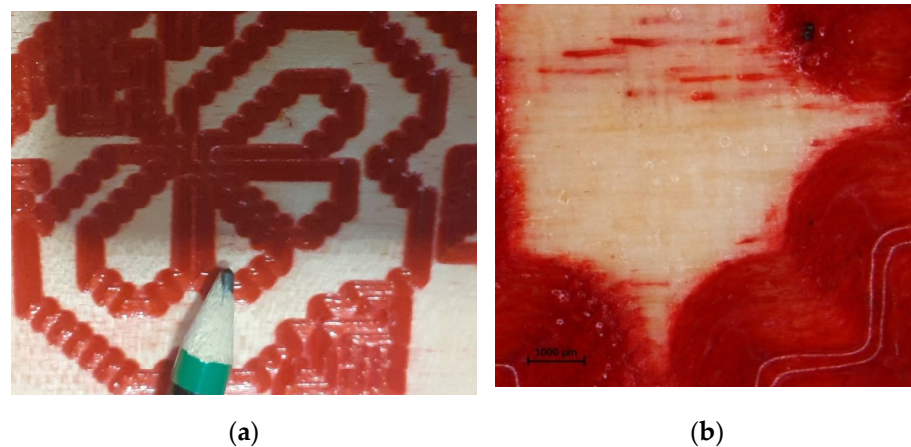
For comparison with the burning depths, the thicknesses of the surface layer removed by sanding the maple wood surface with grit sizes of 100 and 120 were measured. The results are intended to show whether the sanding operations affect the model engraved by the laser beam with the selected powers. The measured values are shown in Table 3. Comparing the results presented in Figures 13 and 14 with those presented in Table 3, it is noticed that the average wood thickness of 0.16 mm and the maximum of 0.18 mm removed by the sanding operation are smaller than the measured values of burn depths produced by laser beam with all selected powers. However, the maximum sanding thickness of 0.18 mm was quite close to the value of burn depth when a percentage of 10% of the maximum power was used (0.194 mm), so the other alternative solution of using 20% and 100% of the maximum power can be used. For this last case, the measured burn thicknesses are 0.426 mm and 1.883 mm, respectively. As seen in Figure 13b, the measured thickness of the burned wood situated on the surface and near the laser engraved area with a power of 40% is 0.11 mm, so the sanding thickness resulted from the experiment is enough to remove it. The results indicate that the sanding operation will not affect the light color of the model obtained by laser engraving with a power of 20% of the maximum of 150 W.

**Table 3.** Measured thicknesses of the maple panels in six points \*, before and after sanding with grit sizes of 100, 120 mm.

-	Measured Thicknesses, in mm					
	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
Before sanding	17.96	17.76	17.78	17.96	17.92	17.99
After sanding	17.79	17.6	17.64	17.78	17.75	17.88
Removed wood thickness, in mm	0.17	0.16	0.14	0.18	0.17	0.11
Mean value (STDEV), in mm	0.16 (0.03)					

\* All six points are situated 10 mm offset to the length (2 points situated at 1/3 distance to the edge for each length) and to the width (1 point situated at the middle point of the distance).

In case of CNC routing and coloring the ornament, red colored spots and marks can be seen on the wood surface (Figure 15a,b) after performing the sanding operations with 100 and 120 grit sizes, so a supplementary sanding has to be carried out to remove the spots.

**Figure 15.** Defects of the wood surface when coloring the ornament: (a) Marked area of the wood surface where colorations occur; (b) Microscopic detail of the marked surface (22.5× magnification).

The milling cut depths for CNC methods of engraving and V-carving are in the range between 1 and 3 mm. In these cases, additional sanding of the surface will not affect the model shape and color, but, on the contrary, will better clean the wood surface and highlight the ornament.

#### 4. Discussion

The experiments conducted in the present research have shown that laser engraving can be considered as one of the technologies to be used in wood carver operations, with applicability in furniture manufacturing and interior decorations. For the real application of laser engraving in wood surface ornamentation, CIELab system proved to be a good instrument to be employed [17,21,24,25] for transposing the original ornament on the maple wood surface, maintaining the contrast between the component colors. The light color of the maple wood allowed good aesthetic perception of the laser engraved model, achieving a high contrast between the decorative pattern and the background [19,20]. The research is in line with other studies that employed digital methods in order to analyze, preserve and reconstitute decorative elements of cultural heritage [4–6].

The experimental study revealed that the sanding operation removes 0.18 mm from the wood surface. The microscopic investigation of the laser engraved areas showed a depth of the superficial wood burning of about 0.11 mm. At the level of laser irradiated areas, the measured wood burning depth was about 0.194 mm for 10% and 0.767 mm for 40% of the maximum power. The conclusion of this part of the study was that the sanding operation will not affect the part of the model engraved with 10% of the maximum power, nor the one engraved with 40%.



The other two methods proposed in the paper have the potential to highlight the CNC engraved and V-carved ornament on the wood surface using the contrast between them by coloring the background in the first case and coloring the ornament in the second case. The best aesthetic value was visually attributed to the V-carved model, which better reproduced the original model. In comparison, using the engraving method, the ornament looks undefined, and the contours seem to overlap.

In the case of coloring the ornament, the microscopic investigation showed that color marks remained on the surface after sanding, so additional sanding operation is needed to clean the surface, without affecting the model. Additional research must be conducted in order to assess the sanding thickness required and to allocate an appropriate technological process for removing the color marks from the wood surface.

The advantage of coloring the model is that this makes it possible to use the whole range of colors and the dark ones will highlight the ornament and create a pleasant visual appearance. The technology of coloring the ornament on the wood surface can be improved by using a jig for each color, in order to more closely reflect the original motif. The best aesthetic value in this case was also attributed to the V-carved model from the same reasons mentioned previously.

Further research must be carried out for transposing traditional motifs to other species of wood used for furniture manufacturing and for finding methods to add value to the ornament by correlating the color of wood with the method of ornamentation, involving up-to-date methods of digitization and machining.

## 5. Conclusions

As digitization techniques and wood processing technologies have become more and more advanced, this might allow the techniques of decorating furniture to be revitalized, offering at the same time the possibility of promoting and preserving elements of cultural heritage that each country possesses.

The research presented in this paper aimed to add value to maple wood furniture surfaces by transposing on them motifs from Romanian textile heritage and employing digitization and CAD methods. The bicolored traditional motif was better highlighted by laser engraving and by CNC routing with the V-carve method. The additional use of a CNC routed ornament with this method was aesthetically appreciated.

Additional research to investigate whether the sanding operation with grit sizes of 100 and 120 affects the integrity of the laser engraved model, especially for a percentage of 10% of the maximum laser beam power, was conducted. The measurements of the sanding thickness and of the burn depths (made on the laser engraved squares with corresponding powers with the help of the stereo microscope) proved that the model is not affected by the sanding operation, no matter of the laser power beam applied. Instead, further research must be conducted in order to improve the sanding technology for cases where the ornament is CNC routed and the model is colored, so the red stains and marks that remain on the wood surface to be removed.

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