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Modeling of Color Design on Furniture Surfaces with CNC Laser Modification

Modeliranje dizajna boje površine namještaja CNC laserskom modifikacijom

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ABSTRACT • *Today, handcrafted furniture surface treatment techniques are less used due to application difficulties and high costs. Recently, the use of CNC router processing machines has resulted in a revival of these techniques. However, since this method is insufficient in micro-processes and color modifications that require precision, these processes have started to be performed with lasers. In this research, the beech wood surface was processed using a CNC laser processing machine with a carbon dioxide gas tube by applying different engraving power and engraving speeds. Product design and manufacturing parameters were determined in the CIE L*a*b* color system using the regression modeling method. A sample application was made by applying laser engraving to a furniture surface designed according to the obtained parameters. As a result of the study, it has been explained that using L* color group regression modeling method and CAD/CAM supported laser technology in furniture top surface color design processes is suitable for industrial engineering approach. It has been determined that many surface color design techniques can be applied with laser to furniture designed for CNC laser production.*

KEYWORDS: *laser pyrography; furniture surfaces; color design*

SAŽETAK • *Primjena ručnih tehnika površinske obrade namještaja smanjila se zbog otežane izvedbe i visokih troškova. Ručne su se tehnike nedavno pokušale oživjeti obradom CNC glodalima. Međutim, CNC glodanje nije odgovarajuća tehnika za mikroprocese i modifikacije boja koje zahtijevaju preciznost, pa su se ručne tehnike počele provoditi laserima. U ovom je istraživanju površina bukovine obrađena CNC laserom s plinskom cijevi od ugljikova dioksida, uz primjenu različite snage i brzine graviranja. Dizajn proizvoda i proizvodni parametri određeni su u sustavu boja CIE L*a*b* primjenom metode regresijskog modeliranja. Na površini namještaja laserskim je graviranjem izrađen uzorak dizajniran prema dobivenim parametrima. Rezultatima istraživanja utvrđeno je da je primjena L* komponente boje u regresijskom modeliranju, potpomognuta CAD/CAM laserskom tehnologijom, prikladna u procesima dizajniranja boje površine namještaja unutar inženjerskog pristupa u industriji. Utvrđeno je da se na namještaju dizajniranom za CNC lasersku proizvodnju laserom mogu provoditi mnoge tehnike dizajniranja boje površine.*

KLJUČNE RIJEČI: *laserska pirografija; površine namještaja; dizajn boje*

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1 INTRODUCTION
1. UVOD

One of the most important issues in laser wood surface treatment is to be able to explain the reaction methodology of wood surfaces against laser beams. Laser engraving on wooden surfaces is generally done to increase the commercial and aesthetic value of furniture or wooden products. Furniture surface decoration is the evaluation of furniture with color, shape, painting and motifs by using various techniques in order to add beauty without disturbing its function. Furniture, which has been in continuous development since ancient times, continued to change in terms of technology, concept and function at the beginning of the 20th century. With the 20th century, industrial society was formed and manual labor lost its previous validity. In the 20th century, it is seen that furniture design movements and architectural movements overlap and affect each other (Çifçi and Demirarslan, 2021). Technology offers the opportunity to reach the development of art techniques, which have become a part of culture and innovations, in a practical, fast and easy way. While art is affected by the development of technology, industry and industrial products also benefit from art and design (Aytepe, 2013). In order to produce the parts of the furniture designed with CAD systems in the computer environment, the designs of these parts can be directed to the CAM systems. In the laser cutting and engraving processes of wood and wood-based materials, the probability of faulty production is less than in the machining made with traditional techniques and using cutters in CNC (router) machines. In addition, in laser processing of wood materials, very precise and microprocesses that cannot be performed on CNC machines with cutters can be easily performed (Karabıyık, 2016).

Studies on color design by laser modification of wood surfaces are not new. Jurek and Wagnerova (2021) investigated the transfer of non-vector photographic images in different color tones to the wooden surface by laser engraving. Kubovsky and Babiak (2009) investigated the changes in the color system of maple (*Acer pseudoplatanus, L.*) and beech (*Fagus sylvatica, L.*) wood surface according to different irradiation doses in the CIE *L*a*b** color system. The changes of scanning speed, scanning power and nozzle height parameters in the CIE *L*a*b** color system in laser engraving of poplar wood were investigated using the mathematical modeling method according to the response surface method (RSM) (Li *et al*., 2018). Reinprecht and Vidholdov (2021) analyzed the effects of CO_2 laser etched surfaces on adhesion resistance after coating with a polymer layer of polyvinyl acetate (PVAc) and polyurethane (PUR) at different irradiation doses for the modification of European beech (*Fagus sylvatica L.)* and Norway spruce (*Picea abies L.)* wood surfaces. CIE *L*a*b** color measurements were performed on samples obtained from beech, ash, linden and spruce tree species to evaluate aesthetic changes due to different laser beam intensity and the number of laser points (points/inch) on the surface (Petutschnigg *et al*., 2013). In order to examine the photodegradation of wood, two different lasers (KrF- and XeCl-laser) were etched and the changes in wood color resulting from heat treatment after laser irradiation were investigated by DRIFT (Diffuse Reflectance Infrared Fourier Transform) spectroscopy and color measurement of the changes on the wood surface (Mitsui *et al*., 2005). Color changes on aspen, birch, spruce, pine, red beech, oak, alder, birch, plywood and MDF surfaces using different power and speed laser combinations were visually examined (Teivonen, 2016). The color changes of the effect of CO_2 laser engraving speed at different rates on sycamore maple (*Acer pseudoplatanus L.*) were investigated by making CIE *L*a*b** color measurements (Petru and Lunguleasa, 2017). Gurau *et al*. (2017) investigated the effects of CO_2 laser beam power output and scanning speed on the surface roughness and color changes in samples obtained from beech (*Fagus sylvatica*) wood. The effects of CO_2 laser modification of beech wood surfaces modified with Aspergillus niger and Penicillium brevicompactum molds using different (J/8) radiation dose and power were investigated in the CIE *L*a*b** system (Vidholdova *et al*., 2017). The color changes of the effect of CO_2 laser engraving speed and irradiation dose (Joule) at different rates on beech wood were investigated by making CIE *L*a*b** color measurements (Kacik and Kubovsky, 2011). Kudela *et al*. (2020) investigated the variation of color, roughness and waviness parameters of the beech wood surface depending on the CO_2 laser engraving power and raster density. Kubovsky and Kacik (2014) investigated the changes in color and wood chemical components caused by irradiation dose of lime (*Tilia vulgaris L.*) tree with CO_2 laser beam at different rates.

Until today, many studies on color design on wood surface treatment with laser have been made. Studies on the effect of laser surface modification of wood on color changes have generally focused on color change rate parameters. These studies have generally remained at the experimental level and their application in furniture design and production process has not been explained. In this study, experimental studies were carried out on a medium-sized CNC laser machine, which is widely used, by using beech wood, which is frequently used in industrial production. In line with the findings, furniture surface decoration color design and application were made with the regression modeling method, which is important in industrial production. An original study was carried out by presenting the material, machine, production method, design and manufacturing processes required by the industrial production sector as a whole.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

In the study, beech wood with a density of 721 kg/m³ in air-dried condition at 12 % humidity was used. The samples were prepared from randomly selected 1st class wood material, with smooth fibers, no knots, no cracks, no difference in color and density, and sapwood parts. Experimental specimens measuring 10 mm × 100 mm × 100 mm were cut and sanded with 120 grit sandpaper. In material processing, engraving processes were carried out on the experimental samples in a CNC laser machine with a maximum power output of 130 watts, a carbon dioxide gas tube, 2 inch (50.8 mm) focal length lens, water-cooled, 1.5 mm nozzle diameter and 10.6 µm wavelength.

2.2 Methods
2.2. Metode

The factorial experimental design method was preferred in the study. With this method, it was possible to evaluate each of the variable factors together with each other and to determine the extent of the effect of each variable on the event. In addition, as a result of the interaction of the variables with each other, different behaviors that the factors may show can be determined. There are many factors that affect laser processing performance. According to the information obtained from the experimental studies carried out so far, it is aimed to determine the effect of the factors that the user is allowed to access, by keeping the factors belonging to the system constant. In this study, 10 %, 40 % and 70 % laser power and engraving speeds of 200, 350 and 500 mm/s were applied to wood samples in a CNC laser machine, taking into account the limitations of machine processing functions. There are 2 variable parameters in the experimental design and each of them takes 3 different values. According to the specified levels, Taguchi orthogonal design is the full factorial design, with 27 data for each type of laser engraving and can be called L27(23). This notation indicates that the number of experiments is 27, with 2 factors having 3 different levels.

In the tests performed, the experimental data were evaluated using SPSS statistics version 22. The interaction of the laser engraving speed and laser engraving power dependent variables and the color independent variable were analyzed. For each analysis performed, multiple linear regression analysis was preferred to determine whether there was a significant difference. Preliminary estimates made to achieve optimum yield quality in production are calculated according to the regression Eq. 1.

$$\hat{Y} = \beta_0 + \beta_1 \cdot X_1 + \beta_2 \cdot X_2 \tag{1}$$

Where;

$\hat{Y}$ – dependent variable (color value),

β_0 – donstant beta value,

β_1 – 1st independent variable (engraving power) beta value,

X_1 – value of 1st independent variable (Engraving Power Watt%),

β_2 – 2nd independent variable (engraving speed) beta value,

X_2 – value of 2nd independent variable (engraving speed mm/s) defined.

2.3 Color measurement
2.3. Mjerenje boje

For color measurements, CIELAB color range was defined by the International Commission on Illumination (CIE) in 1976 according to the principles specified in ASTM D 2244. In this system, color is represented as a point in 3 dimensions on the *x*, *y* and *z*

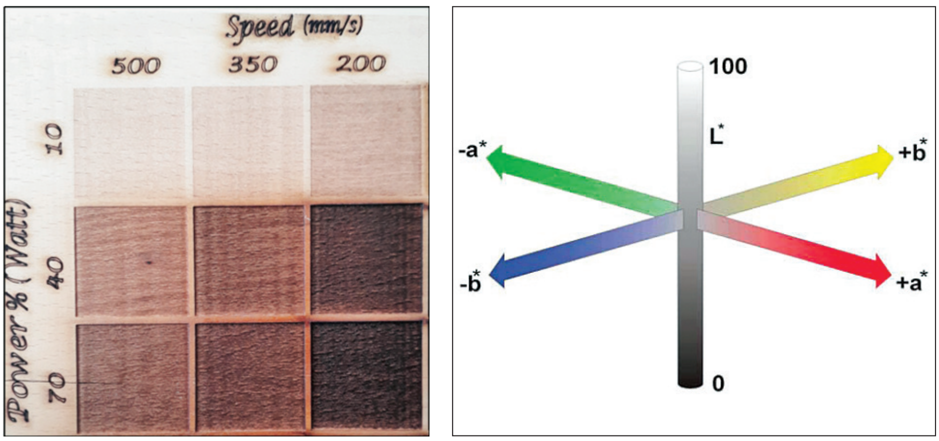

Figure 1 (a) Example of laser engraving experiment, (b) structure of axes *L**, *a**, *b** in the coordinate system CIELAB (Kubovsky and Babiak, 2009)
Slika 1. (a) Primjer eksperimenta laserskoga graviranja, (b) struktura osi *L**, *a**, *b** u koordinatnom sustavu CIELAB (Kubovsky i Babiak, 2009.)

axis. In the CIE *L*a*b** color system, the differences in colors and their locations are determined according to the *L**, *a**, *b** color coordinates. Here, *L** is on the black-white (*L**=0 for black, *L**=100 for white) axis, *a** is on the red-green (red is positive, green is negative) axis, *b** is on yellow-blue (yellow is positive, blue is negative) axis. In addition, in the *bi**, *br**, *ai**, *ar*, *Li**, *Lr** notations, *i* shows the treated experimental measurement value and *r* shows the untreated reference value. Figure 1.a shows the sample of the experiment which was measured. In the color area shown in Figure 1.b, the *L** coordinate constitutes the vertical axis (*y*), the *a** coordinate constitutes the horizontal (*x*) axis, and the *b** coordinate constitutes the (*z*) axis.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The laser engraving colors obtained according to the speed (*S*) and laser processing power (*P*) test factors in laser engraving applied to the parallel directions of the wood laser engraving samples are shown in Table 1.

In the untreated natural state of the beech massif, the white value (*L**) on the black and white axis was measured as 76.21, the yellow value (*a**) on the blue-yellow axis was 7.27 and the red value (*b**) on the green-red axis was measured as 19.94. In laser engraving of wood surface, power increments in all parameters decreased the white value and increased the black value. This situation changed inversely with the engraving speed increments. In other words, the engraving speed increments increased the whiteness value in all parameters. These results have been confirmed in many studies. For example, it has been stated that the scanning speed negatively affects the *L** change in laser engraving of poplar wood (Li *et al*., 2018). In the laser engraving of wooden surfaces, the engraving speed increments did not have any effect on the *a** and *b** color values in engravings with a power of 10 %. This situation has also been explained by the changes in the wood surface in engraving with XeCl-lacelet to examine the photodegradation of wood (Mitsui *et al.*, 2005). On the other hand, engraving speed increments increased both the *a** value and the *b** value in engravings with 40 % and 70 % power. In other words, while the engraving speed at high powers increased the yellow and red color values, it decreased the green and blue color values. This was confirmed in a study made to evaluate the aesthetic changes due to different laser beam intensity and the number of laser points (points/inch) on the surface of samples obtained from beech trees (Petutschnigg *et al*., 2013). In wood surface engraving, the color changes in the green-red axis showed the same behavior as the changes in the blue-yellow axis in all parameters. In another study, it was stated that the trends in the blue-yellow and green-red axis of beech wood surfaces treated with laser engraving were the same (Jurek and Wagnerova, 2021). However, in another study, it was stated that the yellow and red tendency of the beech wood surface increased with laser engraving power increments (Kudela *et al*., 2020). This may be due to operating under 10 % power. As the wood cell structure has not yet been degraded by full laser irradiation, it has been explained that complete carbonization cannot occur (Kubovsky and Kacik, 2014). In laser engraving of the wood surface, *b** yellow color values were lower than an untreated reference value, below the engraving speed of about 300 mm/s when processing at 40 % engraving power. The same situation occurred in the color changes under the effect of laser engraving speed at different rates on Sycamore maple (*Acer pseudoplatanus L.*) (Petru and Lunguleasa, 2017). In this study, the engraving power increased both the blue and green color ratio of the

Table 1 Wood surface laser engraving colors
Tablica 1. Boje za lasersko graviranje površine drva

N	*P*, W	*S*, mm/s	*L**	*a**	*b**	*N*	*P*, W	*S*, mm/s	*L**	*a**	*b**
1	Control		76.67	7.31	19.72	16	40	350	33.79	13.71	24.71
2	10	500	68.54	9.92	29.42	17	40	200	22.66	9.16	14.07
3	10	350	65.87	10.65	30.42	18	70	500	34.97	14.75	25.61
4	10	200	59.36	11.66	30.09	19	70	350	29.02	12.44	20.4
5	40	500	43.77	15.38	31.71	20	70	200	20.91	7.87	11.79
6	40	350	34	13.85	25.14	21	Control		75.72	7.32	19.41
7	40	200	24.64	9.29	14.11	22	10	500	66.7	10.38	26.82
8	70	500	35.38	14.43	26.07	23	10	350	62.18	11.00	26.26
9	70	350	28.63	12.41	19.94	24	10	200	52.98	11.97	26.18
10	70	200	21.36	7.61	11.35	25	40	500	36.08	14.53	26.06
11	Control		76.77	7.18	20.71	26	40	350	25.85	10.94	17.31
12	10	500	68.97	9.81	27.93	27	40	200	15.38	5.36	7.71
13	10	350	66.14	10.38	28.54	28	70	500	30.65	12.63	20.55
14	10	200	58.2	12.13	29.95	29	70	350	24.26	9.71	14.79
15	40	500	41.99	15.47	30.99	30	70	200	15.79	4.15	6.34

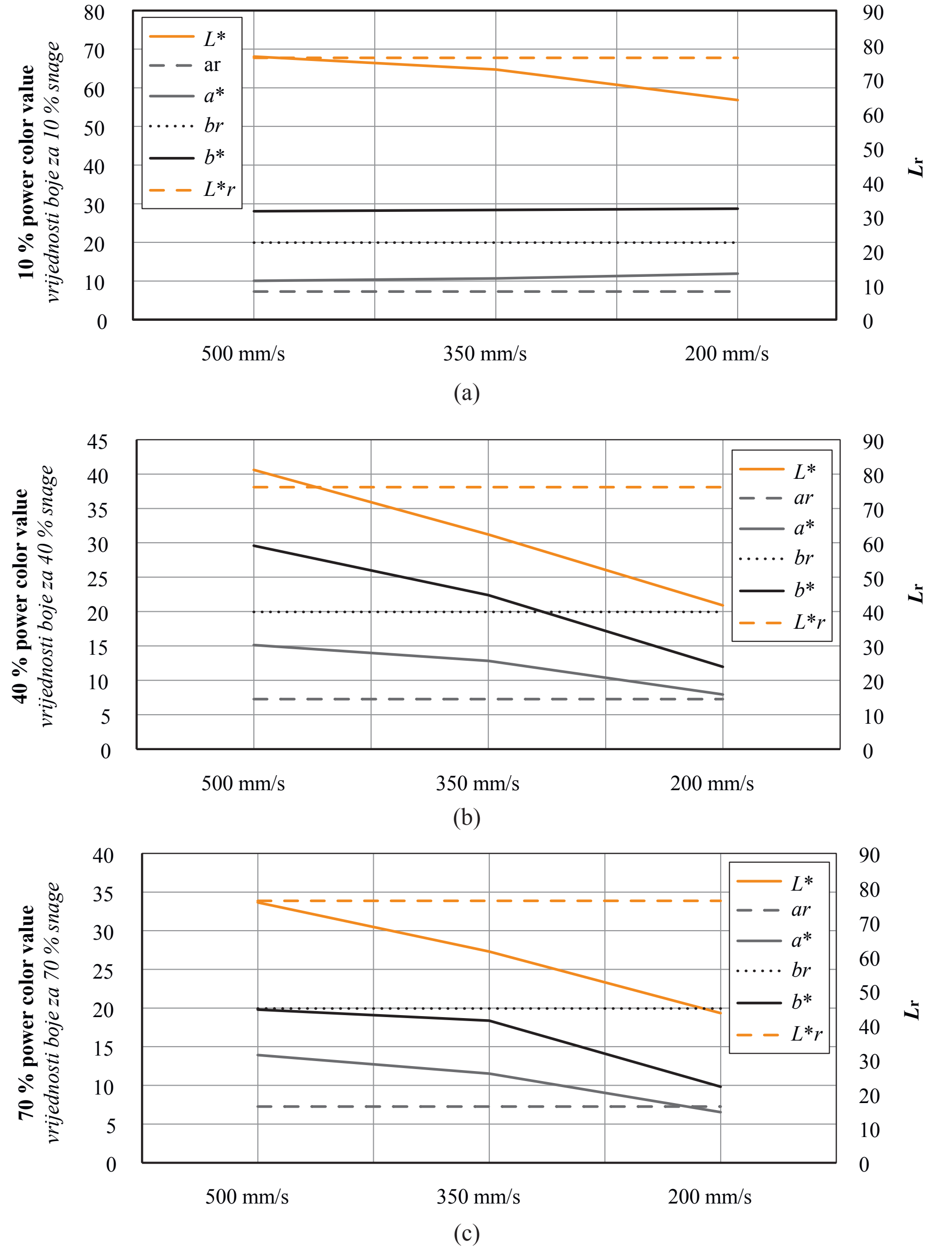

Figure 2 Surface engraving color changes at (a) 10 % power, (b) 40 % power, (c) 70 % power
Slika 2. Promjene boje gravirane površine pri (a) 10 % snage, (b) 40 % snage, (c) 70 % snage

wooden surface. The same results were obtained in the modification of beech wood surfaces with laser using different (J/8) radiation doses and power (Vidholdova *et al*., 2017). In this study, the color changes of the laser-treated surfaces of the beech massif at different engraving speed parameters at 10 % engraving power are shown in Figure 2a, color changes at different engraving speed parameters at 40 % engraving power are shown in Figure 2b, and at 70 % in Figure 2c. The color changes are shown at different engraving speed parameters and at a specific engraving power.

Multivariate linear regression analysis was performed to determine the effect of engraving power and engraving speed variables on color changes in wood surface laser engraving. The analysis results of the laser engraving process are shown in Table 2 below.

According to the analysis results in Table 2 above, laser engraving power negatively and significantly affected the color of whiteness (L^*) in the black-white axis on the laser engraving surface with an effect size of 80 % (pr^2 = 0.802). In other studies, it has been reported that the color changes on the wood surface of beech (*Fagus sylvatica, L.*) are the mostly L^* color changes according to different (J·cm^{-2}) irradiation doses (Kubovsky and Babiak, 2009). The laser engraving speed affected the white color on the laser engraving surface positively and significantly with an effect size of 41 % (pr^2 = 0.412). The regression analysis model was 95 % reliable (p<0.05), and 68 % of the whiteness color change (R^2=0.723) was performed by the scratch power and engraving speed variables. Based on the data in Table 2 above, the mathematical modeling re-

Table 2 Regression analysis results
Tablica 2. Rezultati regresijske analize

Dependent *Zavisne varijable*	*L**			*a**			*b**		
	β	*pr*	*p*	*β*	*pr*	*p*	*β*	*pr*	*p*
Constant / *konstanta*	46.993	-	0.000	6.372	-	0.000	17.567	-	0.000
Engraving power, W % *snaga graviranja,* W %	-0.607	-0.896	0.000	-0.004	-0.039	0.850	-0.183	-0.731	0.000
Engraving speed, mm/s *brzina graviranja,* mm/s	0.050	0.642	0.000	0.014	0.616	0.001	0.035	0.712	0.000

Β – Beta, *pr* – Partial correlations, p>0.005 / *β – beta, pr – djelomične korelacije, p>0,005.*

sult of the beech massif was used to theoretically provide optimum laser engraving quality and predict the whiteness color, generating the following regression equation:

L^*=46,993+(*Engraving power**-0.607)+
+(*Engraving speed**0.050)

In wood surface engraving, laser engraving power did not affect the redness (a^*) color on the green-red axis on the laser engraving surface at the 95 % confidence level. Laser engraving speed affected the red color on the laser engraving surface positively and significantly with an effect size of 38 % (pr^2 = 0.379). The regression analysis model was 95 % reliable (p<0.05), and 11 % of the whiteness color change (R^2=0.107) was achieved by the engraving power and engraving speed variables. Since the effect of engraving power is meaningless and the impact value of engraving speed is low, the regression equation was not produced to predict the red color of the beech massif as a result of mathematical modeling.

In wood surface engraving, laser engraving power affected the yellowness (b^*) color of the blue-yellow axis on the laser engraving surface negatively and significantly with an effect size of 53 % (pr^2 = 0.534). The laser engraving speed affected the yellowing color on the laser engraving surface positively and significantly with an effect size of 51 % (pr^2 = 0.506). The regression analysis model was 95 % reliable (p<0.05), and 47 % of the yellowness color change (R^2=0.469) was performed by the engraving power and engraving speed variables. Based on the data in Table 2 above, the mathematical modeling result of the beech massif was used to theoretically ensure optimum laser engraving quality and predict the turban color, generating the following regression equation:

b^*=17.657+(*Engraving power**-0.183)+
+(*Engraving speed**0.035)

3.1. Design and implementation
3.1. Dizajn i implementacija

CNC laser machine works with a computer hardware loaded with CAD (Computer Aided Design) program and CAM (Computer Aided Manufacturing) programs that convert CAD drawings into machine codes. In this study, a case study was conducted to determine the applicability of CNC laser wood surface decoration with regression modeling method. The steps of design and production process of CNC laser operations on the wooden box made of beech massif used in the experiment are explained below.

The engraving paths to be made with the ornament motif forming the wooden box surfaces were drawn in a CAD program. The motif has been transferred to the CAM program in the software of the CNC laser machine as vector. The production design was completed by determining the motif design, and production parameter values were measured according to the box. Since the effect level of the white color (L^*) value in the above regression analysis in the motif design is much higher than the yellow (a^*) and red (b^*) color values, calculations were made over the white color analysis values in the power parameter calculations. As the L^* color is more effective in color designs in other studies, a color design study was carried out based on the L^* value (Jurek and Wagnerova, 2021). For the motif on the box surface, it is aimed to obtain three-stage colors that will create contrast to each other. The white value (L^*) on the black and white axis of the untreated natural state of the beech massif was measured as 76.21. The change of this value in the black direction was obtained as 19.35 at the maximum 200 mm/s engraving speed and 70 % engraving power parameter, as seen in Figure 2.a. It was determined between the maximum (76.21) and minimum (19.35) values according to the mean values in the three targeted white color test findings. These values were determined as 20, 40 and 60 according to the homogeneous distribution. In order to complete the engraving power process with maximum efficiency and in the shortest time, the engraving speed was kept constant at the highest value of 500 mm/s. The speed-power parameter to be applied to the box surface was calculated from the Scratch color regression formula obtained from the above findings.

L^*_1=46.993+(*Engraving power**-0.607)+(*Engraving speed**0.050)

20 =46.993+(*Engraving power**-0.607)+(*Max speed**0.050)

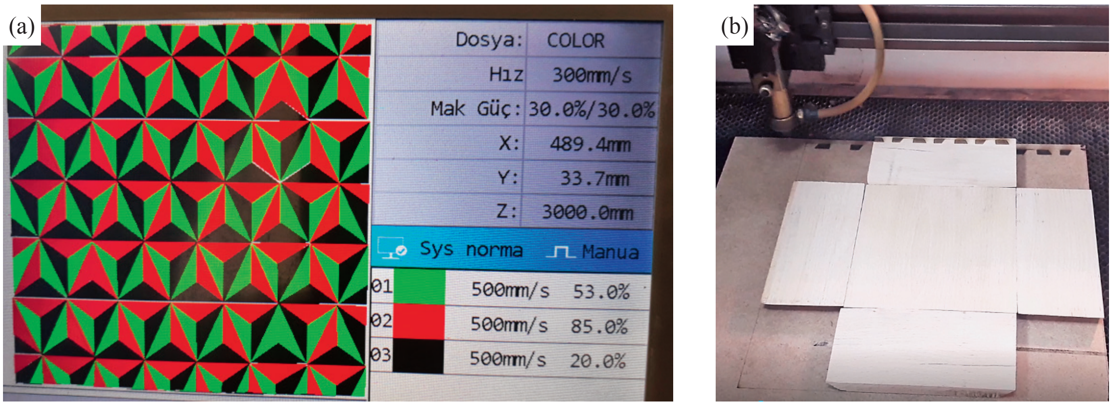

Figure 3 (a) CNC laser product manufacturing design, (b) CAM manufacturing initial stage
Slika 3. (a) Dizajn proizvodnje CNC laserskog proizvoda, (b) početna faza CAM proizvodnje

*Engraving power**-0.607= 46.993+(500*0.050)-20 (Projected white color)

Engraving power= 46.993+5/0.607=85.65

L^*_2=46.993+(*Engraving power**-0.607)+(*Engraving speed**0.050)

40 =46.993+(*Engraving power**-0.607)+(*Max speed**0.050)

*Engraving power**-0.607= 46.993+(500*0.050)-40 (Projected white color)

Engraving power= 46.993-15/0.607=52.70

L^*_3=46.993+(*Engraving power**-0.607)+(*Engraving speed**0.050)

60 =46.993+(*Engraving power**-0.607)+(*Max speed**0.050)

*Engraving power**-0.607= 46.993+(500*0.050)-60 (Projected white color)

Engraving power= 46.993-35/0.607=19.75

The required engraving power ratios were determined as 85 %, 53 % and 20 % in order to perform the prescribed laser engraving processes with a whiteness value of 20.40 and 60 at 500 mm/s engraving speed. In Figure 3a, the design is ready for production in the CAM program and in Figure 3b, the initial stage of surface processing is shown.

The CAM design, developed with the obtained parameters, was completed and the production phase was started. The completed surface treatment is shown in Figure 4a, the local view of the motif processed at 20 %, 55 % and 85 % speed rates is shown in Figure 4b, and the perspective of the finished wooden box in Figure 4c.

4 CONCLUSIONS
4. ZAKLJUČAK

In this study, the applicability of CNC laser assisted regression modeling method in furniture surface treatments in CIE $L^*a^*b^*$ color system was investigated. The highest values of the effect of laser wood surface treatment parameters on L^*, a^* and b^* color changes were obtained in the L^* black and white axis. While the laser engraving power increased the black color level, the engraving speed decreased the black color. It has been determined that the regression modeling method can be successfully applied over L^* values in furniture surface decoration with CNC laser, provided that material, machine and processing parameters are taken into consideration. The same research can be done for color types with a higher effect level in studies to be carried out on other tree species. However, in this study, both the effect level of the a^* and b^*

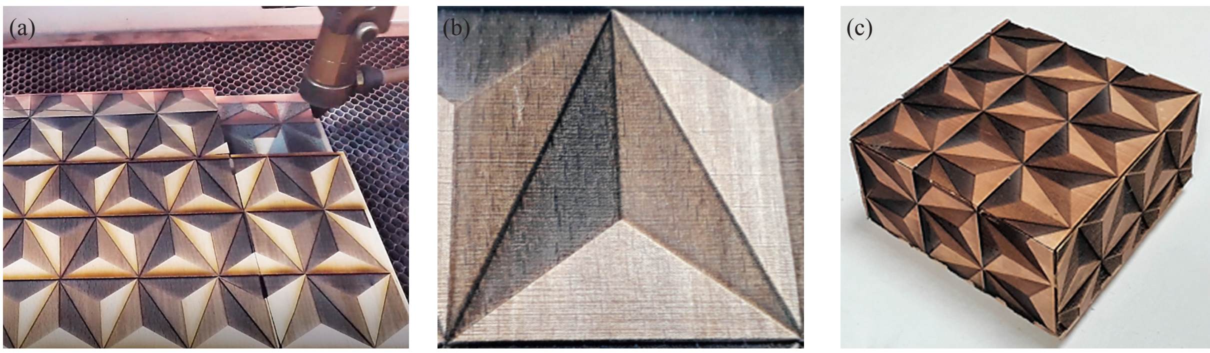

Figure 4 (a) CNC laser engraved surface, (b) Local view of the engraving motif, (c) Assembled wooden box
Slika 4. (a) CNC laserski gravirana površina, (b) lokalni prikaz motiva za graviranje, (c) sastavljena drvena kutija

color groups was low and the regression relationships were low. When a good design is made, the color tones from natural wood color to black on the engraving surfaces add value to the decoration, depending on the processing power of the laser.

If the motif design, color design and production parameter process in laser wood decoration are not well managed, poor images may be encountered in color contrasts on the decoration surface. While it is desired to obtain darker colors, layer differences on the surfaces may be a disadvantage due to the engraving depth. As a result, this study has shown that the regression modeling method of the CNC laser engraving technique can be applied in furniture top surface color design in mass production in accordance with the industrial engineering approach, although it has some limitations.

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