ACTA FACULTATIS XYLOLOGIAE ZVOLEN, 64(2): 87−96, 2022
Zvolen, Technická univerzita vo Zvolene
DOI: 10.17423/afx.2022.64.2.09

INFLUENCE EFFECT OF WOOD LASER ENGRAVING MODE ON AESTHETIC PERCEPTION OF IMAGES

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ABSTRACT

The effect of laser machine resolution, image format, and way of template processing on the aesthetic value of engravings made on birch wood are mentioned in the paper using an expert evaluation method. It is proposed to point out the following components of the aesthetic value of engravings to analyze the effect of factors: contrast, detailing, and perception integrity of the image. It is demonstrated that the weight coefficients of the aesthetic value components can be considered the same. The resolution, as well as engraving power and speed, considerably influence the quality of the engraved images. It is demonstrated that it is reasonable to set the laser machine resolution in the range of 300-850 dpi to engrave tone images on birch wood. When the resolution is below 300 dpi, the energy absorbed by the wood surface appeared to be insufficient for heating up the surface up to the pyrolysis temperature and reproducing light-and-shade gradations on the light image regions. These regions are perceived as solid. Recommendations for selecting the laser machine resolution and image format can be useful for designers of charred materials to increase the competitiveness of their products.

Key words: laser engraving, computer template, wood, hue, birch, perception

INTRODUCTION

In the decorative art, photography, movies, and television products the three-dimensionality of flat images is achieved with the help of light-and-shade. On wood, leather, plastics, and other charred materials the light-and-shade effect is produced due to the change in the material color when heating it. Laser engraving is successfully used for it (CHERNYKH *et al.* 2018). The charring spot A is formed in the area of laser beam exposure when the wood pyrolysis temperature T_p is reached (Figure 1).

In the scheme, axis X corresponds to the wood surface. In the areas located to the left and right of the charring spot A the surface temperature smoothly increases in the spot direction from the initial workpiece temperature up to the wood pyrolysis temperature T_p (line 1), and the optical density remains constant and equals the natural optical density of the initial workpiece D_f, i.e., the optical density of the engraved image hue (line 2).

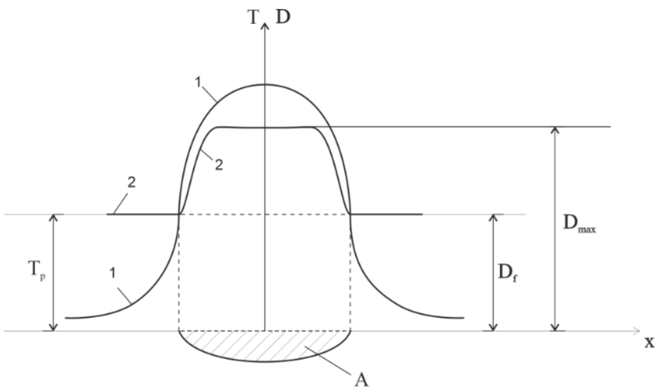

Fig. 1. Scheme of heating temperature T and optical density D distribution in the area of laser radiation pulse outside and inside the charring spot A: 1 – character of heating temperature distribution on the workpiece surface, 2 - character of optical density distribution.

In the charring spot the wood heating temperature increases from the periphery to the center (continuation of line 1). Due to the heating nonuniformity the spot is lighter at the edge and darker in the middle. With the increasing heating temperature, the same way as during thermal modification (BARCIKOWSKI *et al.* 2006, CHERNYKH *et al.* 2013, 2014, 2018), the optical density increases (continuation of line 2) up to some maximum value D_{max} limited by the hue limit of thermally processed wood (YAKIMOVICH *et al.* 2016, ZYKOVA *et al.* 2021). The hue limit has different values for different species, it does not reach 100% - the maximum possible saturation of black color in CMYK system, i.e. 0% of brightness in LAB system. The wood heating temperature and, consequently, its hue saturation during laser engraving depend on the absorbed density of energy W_p found with the following formula:

$$W_p = P_c * \frac{t}{S} * (1-K_0), \text{ J/cm}^2 \quad (1)$$

Where: P_c – average density of the pulse radiation, W;
t – radiation time, s;
S – radiation area, cm^2;
K_0 – coefficient of the laser pulse reflection by the wood.

At the wavelength of 10.6 μm used in laser machines for wood engraving, the reflection coefficient for different wood species is from 0.2 up to 0.8-0.9.
Measuring devices of pulse lasers show the value not of the average but of pulse power P_i, by which it is possible to find the average power

$$P_c = P_i * \tau * f, \quad (2)$$

Where: τ – duration of radiation pulse, s;
f – frequency of pulse repetition, Hz.

The laser machine operator controls the heating temperature and, consequently, the hue in the charring spot area by setting definite values of the pulse power P_i (in percent from the maximum power P_{max} of the machine) and charring time t, moreover, the time is set indirectly via the speed of the laser head movement V. The values of P_i and V are selected in compliance with the known recommendations (PHOTOGRAPHV, PLATON, YSTO GROUP) and due to the work experience.

Laser wood processing is successfully applied to complete a lot of production tasks – ablation of wood surface and wood materials of biological protection, cutting, marking and engraving (BARCIKOWSKI *et al.* 2006, ELTAWAHNI *et al.* 2013, HERNANDES-CASTAFIEDA *et. al.* 2011, HILL 2006, CHITU *et. al.* 2003, MARTINEZ-CONDE *et. al.* 2017, VIDHOLDOVA *et. al.*

2017). When engraving, the aesthetic effect is produced due to color change in the radiation regions and emergence of contrast between the hue and image. This phenomenon was studied by BARCIKOWSKI *et al.* 2006, CHERNYKH *et al.* 2013, 2014, 2018, GURAU *et al.* 2017, JUREK *et al.* 2021, KUKOVSKÝ *et al.* 2009, 2016, LIN *et al.* 2008, PETRU *et al.* 2015, PETUTSCHNIGG *et al.* 2013, SIKORA *et al.* 2018, VIDHOLDOVA *et. al.* 2017, YAKIMOVICH *et al.* 2016, ZYKOVA *et al.* 2021. In the abovementioned papers the processes taking place in wood under the laser action and influencing its color, characteristics of wood modified with laser in LAB and CMYK coordinates are mainly studied, the influence of engraving power P and speed V on color change of different wood species is demonstrated, the engraving depth and roughness of the engraved surface are investigated. Consumers of engraved products are interested in different issues: aesthetic value, faximility of the engraved image (usually photographs) on the selected product format, which are studied insufficiently in the indicated papers. The aspects focused on the satisfaction of consumers' needs are considered in this paper.

MATERIALS AND METHODS

The aesthetic value of the engravings was investigated using the help of expert evaluation method of five series of images obtained by engraving on the samples of the birch wood with 12% humidity with the sizes of 23x210x315 mm. The aesthetic value is a complex notion consisting of several components. Its three components are highlighted in the paper, which can be controlled when processing the template and selecting the elements of the engraving mode. They comprised the engraved image contrast in respect to the background, visibility of the image small elements (detailing) and perception integrity of the image.

Therefore, apart from the aesthetic value (aesthetic perception), the research parameters included contrast, detailing and perception integrity, characterizing in complex, in our opinion, the aesthetic value of the engravings.

As the research variable factors, the change in which results in the change in the studied parameters, the following formats of the engravings were selected: A6, A7, A8, A9 and A10; resolution R of the laser machine – 300, 500, 600, 760 and 1000 dpi – and the template preparation method, i.e. creation of light-and-shade gradations on the template, - raster (samples 1.1, 1.2 and 1.3) and contour filling (samples 3.2 and 3.3).

Fig. 2 Images on sample 1.3

The factors influencing aesthetic perception and contrast were accepted as constant (YAKIMOVICH *et al.* 2016) – power P_i (10 W), engraving speed (1000 mm/s) and template resolution (300 ppi) because their influence is known.

All samples were obtained from one workpiece (edged board). It was planed off and ground on two sides on planing and grinding machines, respectively. Then the board was cut into five samples. Five images of different formats (A6 – A10) (see Figure 2) were engraved on each of the samples with laser engraver Mercury III (USA) with the constant resolution R, particular for each of five samples. Sample 1.1 was engraved with R = 300 dpi, samples 1.2 and 3.2 – with R = 500 dpi, and samples 1.3 and 3.3 – with R = 600 dpi. On sample 1.3 shown in Fig. 2 (its scan is demonstrated in the figure) not five but seven images were engraved: five similar to other samples of the images of different formats from A10 to A6 (at the bottom in Fig. 2) and two additional (at the top in Fig. 2). Five lower images were engraved with the same resolution R equal to 600 dpi. And left upper one was engraved the resolution of 1000 dpi, right upper one – 760 dpi. Additional images were obtained to study the influence of large values of resolution R onto the research parameters at similar engraving conditions – on one and the same workpiece, i.e. with unchanged wood properties, unchanged format (A7), as well as P and V to improve the experiment accuracy.

The figure also demonstrates the sample number and engraving mode, common for all images on all 5 samples, as mentioned before – P=10 W and V=1000 m/sec.

The original peculiarity (Figure 3) is the big number of details, the picture is placed at an angle and is completely asymmetrical, there is the main object – the face located in the right upper corner; thus, the visual center is shifted up. An additional object is used for harmonic perception – the branch with flowers placed at the body level – of rather light region, there are also many light elements smoothly shading both into the grass background and light background of the sky.

The original is characterized by a wide range of grey color gradations, from white to saturated black, the availability of light-and-shade transitions, diagonal location of the portrait and big number of small elements similar in size (single-sized) – buds and petals.

The required details need to be set to engrave on wood, therefore, the following parameters of brightness/contrast were set up in Photoshop: brightness was minus 52, contrast – minus 26.

To transform the original into the rasterized template the image was converted into a 1-bit one, the hue was formed due to the change in the concentration of pixels. The way of data presentation – half-tone raster, ruling of 30 lpi, angle of raster location – 45 degrees, since the image on the original was located at an angle, and shape of raster point – a circle, were set up.

CorelDRAW and the operation "fast trace" were used for the image obtained by filling.

The engraving by both variants of the template was performed in raster graphics.

Fig. 3 Image original

23 experts took part in the survey. The weight coefficients of the aesthetic value components of the engravings – contrast, detailing and integrity – were defined according to Table 1 by the methodology given in the paper (CHERNYKH *et al.* 2013). The weight coefficients were evaluated by sample 1.3 with the format A6, the aesthetic value of which obtained the high appraisal.

The investigation parameters were evaluated in the 5-point system:

Criteria of contrast evaluation: 5 – contrast image; 4 – average contrast of the image; 3 – insufficient contrast of the image; 2 – contrastless image.

Criteria of detailing evaluation: 5 – high degree of detail transference; 4 – high degree of detail transference but there are insignificant shortcomings; 3 – average degree of detail transference; 2 – low degree of detail transference.

Criteria of image perception integrity evaluation: 5 – image is perceived as integral, without distortions; 4 – image is perceived as integral but there are insignificant deviations; 3 – image is not perceived as integral and is split into separate pictures; 2 – image is not integral and has considerable distortions.

Criteria of aesthetic perception evaluation in total: 5 – image has the highest degree of aesthetic attractiveness; 4 – image looks beautiful but has insignificant shortcomings; 3 – level of image aesthetic attractiveness is average with shortcomings; 2 – image is not attractive aesthetically; it has considerable shortcomings negatively influencing the perception.

RESULTS AND DISCUSSION

The average values of the research parameters for the group of experts were found based on the interrogation. The results are shown in graphs (Figures 4-7).

It was found that the weight coefficients of the aesthetic value components have similar values (see Table 1), therefore, the contribution of contrast, detailing and integrity of the image to the formation of the engraving aesthetic value can be considered the same.

Table 1. Weight coefficients of the aesthetic perception components of the engravings.

No	Criterion name	Criterion description	Weight coefficient
1	Contrast	The contrast is expressed between the background, light and dark elements of the engraving	0.34
2	Image integrity	The image is perceived as integral without splitting into separate parts and distortions in comparison with the original	0.33
3	Visibility of small elements	Small elements of the image are distinctive, they do not blend with each other and larger elements	0.33

With the increased resolution R of the laser machine, i.e., the number of pulses on the area unit, the amount of energy W_p absorbed by wood increased proportionally and, consequently, the heating temperature of the radiation areas as well as their contrast, which is confirmed by the graph (Figure 4, line 1). With the increased contrast the small elements became more distinctive, therefore, the detailing also improved (line 2). The perception integrity (line 3) at first started increasing and then practically did not change.

Despite the increase in all highlighted components, aesthetic value of the engraving – contrast, detailing and integrity of the image, especially contrast, the aesthetic value at high resolution R did not increase but even somewhat decreased (in our case, based on the graph, approximately at R≥ 850 dpi, line 4).

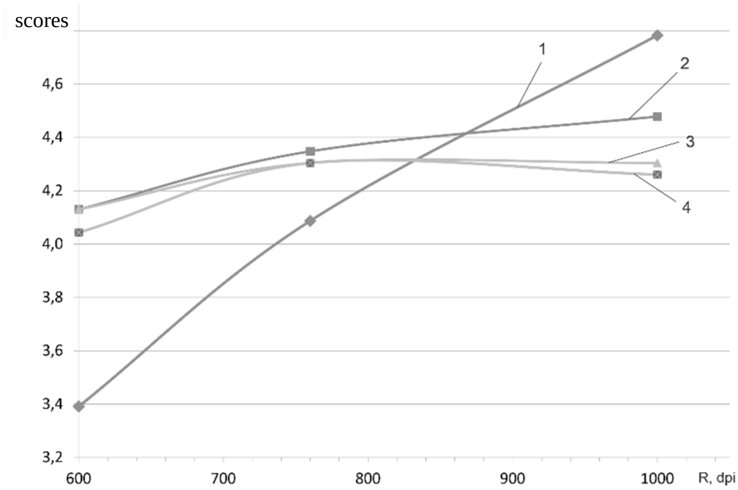

Fig. 4 Dependence (in scores) of the contrast (1), detailing (2), perception integrity (3) and aesthetic value (4) of the engravings on resolution R (dpi) of the laser machine; image format A7 (in Figure 2)

The abovementioned can be explained by the fact that at high R values in particular areas of the engraving, namely, in the left eye area of the portrait, the wood hue limit was reached, and the considerable part of the marked area is perceived as solid and separate elements of the image become invisible. As a result, the hue correlations between its separate parts, peculiar for the original, disrupt decreasing the engraving aesthetic perception. It follows from the foregoing that the components of the aesthetic value of the engravings selected by us – contrast, detailing and perception integrity – do not completely characterize the aesthetic value of the engravings at high resolutions R. Then all dark parts of the engraving, in which the hue limit is reached, are perceived as solid by a human despite the difference in the hue of dark parts of the original and template. This conclusion dovetails with the results of the paper (ZYKOVA *et al.* 2021, CHERNYKH *et al.* 2014). Based on the results of these works it can be assumed that even at low values of resolution R when the value of the absorbed energy W_p is insufficient to obtain the pyrolysis temperature T_p on the wood surface, the image light areas will be also perceived as solid. The hue relations of these areas will differ from the hue relations of the original and template, the engraving aesthetic value will decrease.

In the range of average values of resolution R from 300 up to 600 dpi the improvement of the aesthetic value and its components proportionally to the resolution value was observed (Figure 5), moreover, the engravings whose templates were made by filling, received a somewhat higher score of the experts than those whose templates were made by the half-tone raster.

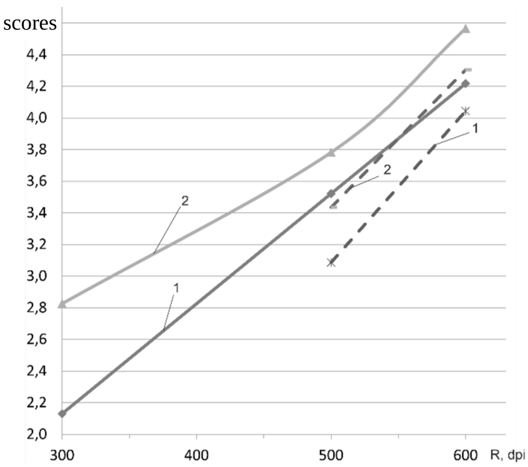

Fig. 5 Dependence of the contrast (1) and aesthetic value (2) of the engravings on resolution R; image format A6; template preparation by raster (solid lines) and filling (dotted lines)

The image format sizes significantly influence the research parameters. With the increased area S of the format, small elements became larger visually and more distinctive, the picture detailing improved (line 3 in Figure 6), the image was perceived as more integral (line 1), the aesthetic value also increased (line 2). The nonuniform change in the parameters with the increased format area was observed. The most intensive growth of the parameters, especially detailing, was observed in the transition area from format A9 to format A8, when small details of the image (buds and petals) became visible with a human eye, thus resulting in the qualitative change in the picture perception, its integrity and aesthetic value.

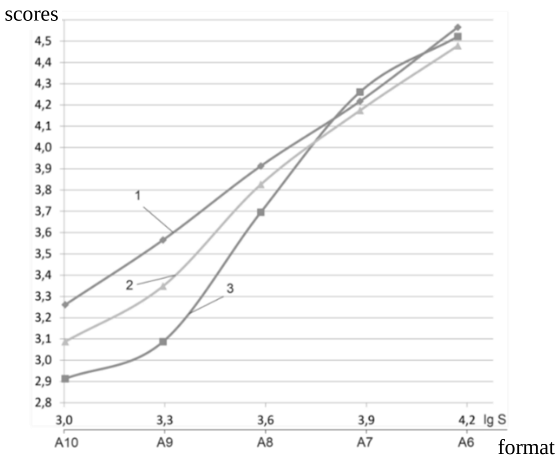

Fig. 6 Dependence of the integrity (1), aesthetic value (2) and detailing (3) of the image on the engraved surface area; sample 1.3

Further increase in the format area did not result in the sharp growth of the parameters as the transition from the area amount increase to new perception quality already took place, previously invisible and poorly visible details of the image became visually distinctive.

This effect was also observed on other samples (Figure 6). The abovementioned allows making the practical conclusion on the production feasibility of engravings from birch wood with the format not less than A8. Smaller engravings will have significantly lower aesthetic value. For wood of other species, for instance, beechwood and (or) images with not great number of small elements the boundary of quantity transition (format area S) to qualitatively new perception can shift to the format with smaller area. Nevertheless, the availability of such boundary will always take place. Its determination for images having different saturation with small elements and (or) made on other wood spices can be the subject of further research.

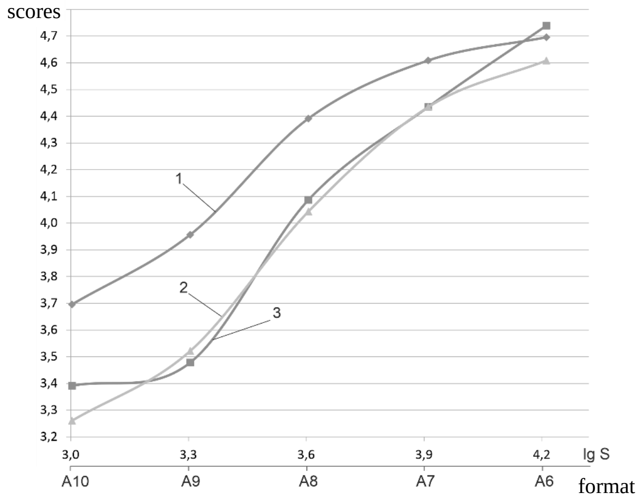

Fig. 7 Dependence (in scores) of the integrity (1), aesthetic value (2) and detailing (3) of the image on the engraved surface area; sample 3.3

CONCLUSION

Technologically controllable components of the aesthetic value of the engravings made with laser on wood – contrast, detailing and integrity of the image are proposed.

The character of their dependencies on the laser machine resolution and area of the images, in general, coincides with the aesthetic value dependence on the same factors, which allows judging of the adequate presentation of the aesthetic value of the engravings with the proposed parameters. The exceptions are both the high resolution values (over approximately 850 dpi for birch wood) and low resolution values. The restrictions are connected, on the one hand, with reaching the hue limit at high resolution values and excessive absorbed density of energy, and, on the other hand, at low resolution values – with the insufficient heating of the wood surface for the pyrolysis beginning.

The sizes of images significantly influence the aesthetic value of engravings, which is connected with the visibility of tiny details by the human eye. With many small elements of the image, its format A8 and the larger in area are recommended for birch wood.

The way of template processing (by raster and filling) did not demonstrate a significant influence on the aesthetic value of the engravings in the investigated range of values of the factors.

REFERENCES

BARCIKOWSKI, S., KOCH, G., ODERMANTT, J. 2006. Charakterisation and Modification of the heat affected zone during laser material processing of wood composites. In HolzalsRoh und Werkstoff, 64: 94-103.

CHERNYKH, M., KARGASHINA, E., STOLLMANN, V. 2013. Assessing the impact of aesyhetic properties characteristics on wooddecorativeness. In Acta Facultatis Xylologiae Zvolen. 55(1):13-26.

CHERNYKH, M., CHURAKOV, I., DRYKOVA, A., 2014. Preparation of images for Laser engraving on wood. In Design. Materials. Technology.2014.№4(34), 57-59.

CHERNYKH, M., KARGASHINA, E., STOLLMANN, V. 2018. The use of wood veneer for Laser engraving production. In Acta Facultatis Xylologiae Zvolen, 60(1); 121-128. DOI: 10.17423/afx.2018. 60.1.13

CHITU L., CERNAT, R., BUCATICA, I., PUIU, A., DUMITRAS, D.C. 2003. Improved technologies for marking of different materials. In Laser Physik 13(8), 1108-1111.

ELTAWAHNI, H., ROSSINI, N., DASSISTI, M., ALRASHED, K., ALDAHAM, T., BENYOUNIS, K., OLABI, A., 2013. Evaluation and optimization of laser cutting parameters for plywood materials. In Opt. Lasers Eng., 51(9):1029-1043, ISSN: 0143-8166, DOI: 10.1016/j.optlaseng.2013.02.019

GURAU L., PETRU, A., VARODI, A., TIMAR, M. 2017. The Influence of CO_2 Laser Beam Power Output and Scanning Speed on Surface Roughness and Colour Changes of Beech (*Fagus sylvatica*), In BioResources 12(4):7395-7412, ISSN: 1930-2126, DOI: 10.15376/biores. 12.4.7395-7412

HERNANDEZ-CASTAFIEDA J., KURSAD, H., LI, L. 2011. The effect of moisture content in fibrelaser cutting of pine wood. In Opt. Lasers Eng., 49(9-10):1139-1152, DOI: 10.1016/j.optlaseng. 2011.05.008

HILL, C. A. S. 2006. Wood Modification: Chemical, Thermal and Other Processes. In John Boe Wiley &Sons, Lid, Chichester, UK. DOI: 10.1002/0470021748

JUREK M., WAGNEROVA, R. 2021. Laser beam calibration for wood surface colour treatment. In European Journal of Wood and Wood Products 79(5):1097-1107. DOI: 10.1007/s00107-021-01704-3

KUBOVSKY, I., BABIAK, M. 2009. Color changes iadided by CO_2 laser irradiation of wood surface. In Wood Research 54(3), 61-66.

KUBOVSKY, I., KAČIK, F., REINPRECHT, L. 2016. The impact of UV radiation on the change of color and composition of the surface of lime wood treated with a CO_2 laser. In Journal of Photochemistry and Photobiology A: Chemistry 322, 60-66. DOI: 10.1016/j,jphotochem.2016.02.022

LIN, C.J., WANG, Y. C., LIN, L. D., CHIOU, C. R, WANG, Y. N., TSAI, M. J. 2008. Effects of feed speed ratio and laser power on engraved depth and color difference of Moso bamboo lamina. In Journal of Materials Processing Technology 198(1-3), 419-425. DOI: 10.1016/ jmatprotec.2007.07.020

MARTINEZ-CONDE A., T. KRENKE, S. FRYBORT, U. MIILLER, 2017. Review: Comparative analysis of CO laser and conventional sawing for cutting of lumber and wood-based materials. In Wood Sci. Technol., 51: 943-966. DOI:10.1007/s00226-017-0914-9

PETRU, A., LUNGULEASA, A. 2015. Effects of the laser power on wood coloration. In International Conference of Scientific Paper AFASES, Brasov, Romania (http://www.afahc.ro/ro/afases/2015/afases_2015/mediu/Petru_Lunguleasa.pdf).

PETUTSCHNIGG, A., STÉCKLER, M., STEINWENDNER, F., SCHNEPPS, J., GIITLER, H., BLINZER, J. HOLZER, H., SCHNABEL, T. 2013. Laser treatment of wood surfaces for ski cores:An experimental parameter study. In Advances in Materials Science and Engineering1-7. DOI: 10.1155/2013/123085

PHOTOGRAV. The Laser Engraving Power Tool [online]. Document Version 2021/10/04T:15:40:00z 2021 [cit.2021-10-04]. Available online: http://www.photograv.com/aspent2/ipsAnd1ricks.aspx/.

PLATON: Might of a portrait. How To Creat Strong High Key Portraits Inspired by Platon`s Portrait Photography Style[online]. Document Version 2021/10/04T:15:40:00z 2021 [cit.2021-10-04]. Available online: http://www.newsinphoto.ru/iskusstvp/pleton-mogushestvo-portreta/.

SIKORA A., KATIK, F., GAFF, M., VONDROVA, V., BUBENIKOVA, T., KUBOVSKY, I. 2018. Impact: of thermal modification on color and chemical changes of spruce and oak wood. In Journal of Wood Science, Volume 64, pp. 406-416. DOI: 10.1007/s10086-018-1721-0
VIDHOLDOVA Z., REINPRECHT, L., IGAZ, R. 2017. The Impact of Laser Surface Modification49. hm of Beech Wood on its ie and Occurrence of Molds, 12(2):7395-7412. DOI: 10.15376/biores.12.2.4177-4186
YAKIMOVICH B. 2016. Influence ar selected laser parameters on quality of images engraved on the wood. In Acta Facultatis Xylologiae Zvolen, 2016, 58(2): 45-50. DOI: 10.17423/afx.2016. 58.2.05
YSTO GROUP. Laser Cut 5.0/5.1/5.3 [online]. Document Version 2021/10/04T:15:40:00z 2021 [cit.2021-10-04]. Available online: http://www. ysto.ru/articles/56-software-for-tools/16-lasercut-rusifikator/. NEWS IN PHOTO.
ZYKOVA M., KASIMOVA V., CHERNYKH M., STOLLMANN V., EVSTAFIEVA G. 2021. Method of computer template adjustment for wood Laser engraving. In ActaFacultatisXylologiaeZvolen, 63(2); 85-92. DOI: 10.17423/afx.2021. 63.2.07

ACKNOWLEDGMENTS

This publication is the result of the project implementation. The comprehensive research of mitigatim and adaptation measures to diminish the negative impacts of climate changes on forest ecosystems in Slovakia (FORRES), IIMS. 3130//T678(100%) supported by the Operational Programme Integrated Infrastructure (OPII) funded by the ERDF.

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