

CAD-CAM-CAE IN WOOD INDUSTRY. A CASE STUDY FOR PERFORATED ORNAMENTS PROCESSED ON CNC ROUTER

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Abstract:

The paper investigates the CNC routing protocol by using advanced software for designing, simulation and processing wooden based materials, in order to obtain perforated decorations. The tests were performed on specimens made of three types of materials, namely spruce wood, poplar plywood and MDF. Aspire software, developed by Vectric was used to design a simple tool path formed by a straight line and a curved one and to simulate the milling process and also to transfer the information to the CNC router. A visual assessment of the surface quality was afterwards done, in order to make the correlation between the surface quality and the processing parameters. The processed parameters selected in the software are the spindle speed, feed speed and depth of cut. Further experimental plan was designed based on 3^k full factorial design of experiment.

Key words: CAD-CAM-CAE; CNC router; tool path; feed speed, spindle speed, depth of cut.

INTRODUCTION

The perforated ornaments are composed of geometric shapes and complex curved lines, which can be processed nowadays by milling on CNCs. The first step is to design the ornament on dedicated software, as 2D or 3D drawing. In the last decade softwares such as Inventor, SolidWorks, Top Solid, bCabinet, Cabinet Vision are mostly used to design furniture and have the advantage of transferring the processing information to the equipment, after simulation of the processes.

Computer-aided design (CAD) has its origin in the first numerical control system created by Dr. Patrick Hanratty in 1957. The most popular CAD tool for professional engineers includes AutoCAD, but now this technology benefits considerably from modern enhancements to software and engineering. Both CAD and computer-aided manufacturing (CAM) have become interlinked as the technologies evolved over the last several decades (Michigan State University, 2020). While Computer-aided engineering (CAE) tool refers to the use of specific software to simulate the different conditions on the design of a product or structure and helps in analyzing and optimizing the designs created in CAD software, CAM software translates CAD designs into instructions for machines, bringing the benefit of increasing the productivity and optimizing the production processes.

Furniture industry benefits in the last decade by an industrial revolution, which is called the Fourth Industrial Revolution or Industry 4.0. This is the response of renouncing to the uniformity of mass-produced products of the 20-th century and meeting the demand for customized products. Industry 4.0 is a concept which embraces digital technologies able to create communication flows between machines, internal and external value chain actors. The main benefit is the ease of monitoring the activities, operation and processes of machines, materials, workers and even products themselves, and to collect, analyze and utilize data in real-time decision making (Nagy et al. 2018). This will provide companies with the means to respond to the growing complexities of manufacturing and enable greater possibilities for product innovation and business model transformation.

As recommended (Finzer 1999) when work with high speed machining, four approaches in the machining process have to be made simultaneously. These approaches are the optimization of the machining

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parameters, the choice of the right cutting edge material and cutting tool and the use of proper machining strategies.

Research on CNC milling of solid wood has also been extended to wooden-based materials. Face milling is the machining operation frequently used in engraving parts of MDF and in furniture manufacturing. The results from CNC milling of the MDF (Sütcü and Karagöz 2012) showed the effects of the spindle speed, feed rate, stepover and depth of cut on the surface roughness of the MDF panels. The results demonstrated that the surface roughness decreases with increasing spindle speed and increases with increasing stepover, feed rate and depth of cut. Also, higher density layers have achieved a better surface finish. Other research work (İşleyen and Karamanoglu 2019) have shown that the significant machining parameters affecting the surface roughness were the feed rate, spindle speed, and tool diameter ($p < 0.05$) and there was no significant influence of axial depth of cut on this parameter. Also, it was concluded that the surface roughness decreased with increasing spindle speed and decreasing feed rate and increased with the increase of tool diameter.

Spindle speed of 18,000 rpm and feed rate of 2 m/min resulted with minimum surface roughness values of MDF, Ayous and Beech wood (İşleyen and Karamanoglu 2019). The lowest surface roughness values were found in 10000 rpm spindle speed and 5000 mm/min feed rate for spruce and chestnut wood and 18000 rpm spindle speed and 7000 mm/min feed rate for larch and iroko wood and the highest values in the all of wood species were obtain from 10000 rpm spindle speed and higher feed rate of 9000 mm/min. (Çakiroğlu et al. 2019).

The latest research trends focus on developing mathematical models and computational procedure for optimization of feed rate at CNC routing operations of wooden furniture parts taking into consideration characteristics of solid wood connected with changes in cutting forces and obtained surface quality along with cutting direction (Gawronski 2013). Nowadays furniture industry benefits by advanced softwares to control the milling parameters and tools on CNC routers, easing the possibility of studying their influence when processing various materials.

The present paper shows the controlled method of CNC milling, starting with design of the tool path, continuing with the simulation of the process and ending with the processing of the samples on CNC, as a CAD-CAM-CAE application using Aspire software developed by Vectric. Three types of materials were used, namely spruce wood, MDF and poplar plywood. After milling on CNC Router, the samples were scanned with high resolution and the surface quality was visually analyzed, as a first step of the proposed research. The next step is to vary the milling parameters such as spindle speed, feed rate and depth of cut and to quantify the quality of the processed surface by measuring the roughness parameters.

OBJECTIVES

The present study is an example of applying CAD-CAM-CAE tool in furniture industry as a case study for perforated ornaments using advanced software Aspire developed by Vectric. The study is applied on three types of materials: spruce wood (*Picea Abies*), poplar (*Populus Alba*) plywood and MDF. The quality of the samples surfaces generated by CNC machining was visually investigated after scanning them with high resolution. The improper surfaces will show fiber breakings and irregularities of trajectory. A further experimental design is afterwards set.

METHOD, MATERIALS AND EQUIPMENT

First, the design of the tool path was done, using the CAD tool of the software. The design was a simple one, composed of a straight line and an arc of a circle with a radius of 151 mm (Fig. 1).

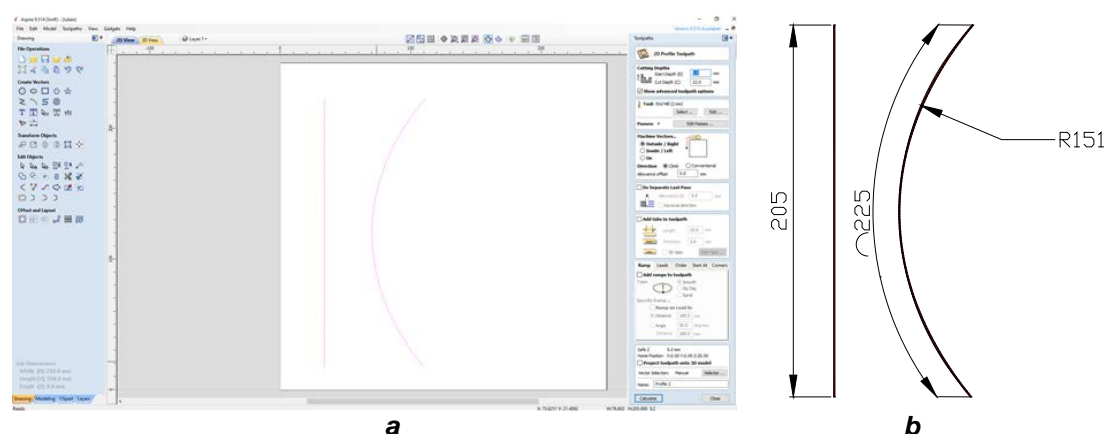


Fig. 1.
CAD tool of the software used to design the tool path (a) and the tool path sizes (b).

The next step is to choose the tool and set up its geometry, cutting parameters, feeds and speeds (Fig. 2). Tapered ball nose tool with a diameter of 6 mm have been chosen for the milling operation on CNC Router.

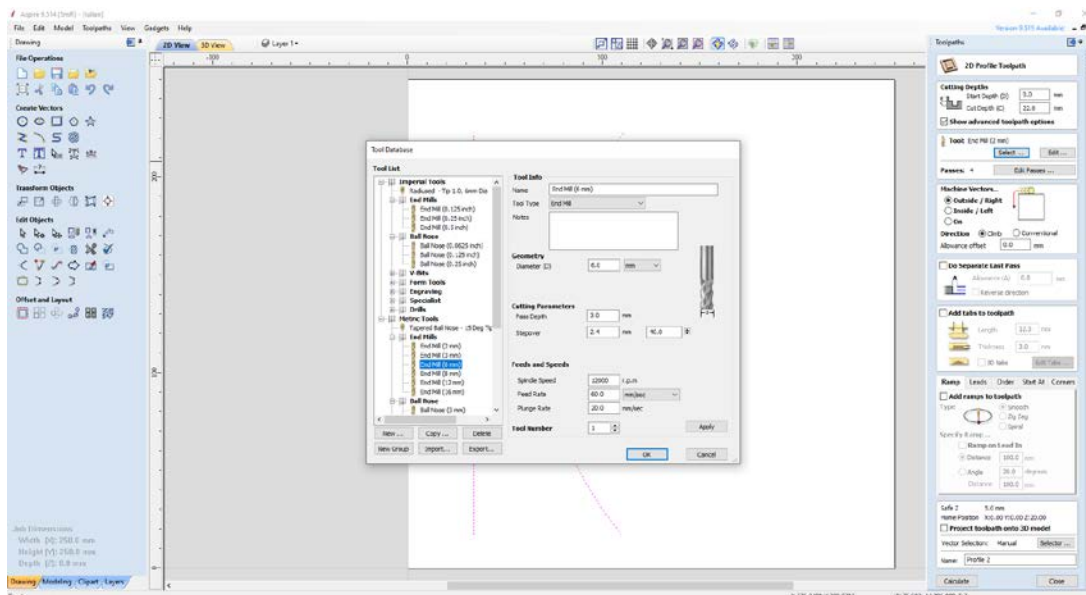


Fig. 2.
Selection of tool, cutting parameters, feeds and speeds.

The cutting parameters, feeds and speeds have been chosen differently for the different materials tested and according to previous researchers' conclusions (Çakiroğlu et al. 2019). All these parameters together with the samples types and sizes are presented in Table 1.

Table 1

Samples and milling parameters set up

Material	Sizes of the sample (Length x Width x Thickness), in mm	Spindle speed, in r.p.m.	Pass depth, in mm	Feed rate, in m/min	Plunge rate, in m/min
Spruce wood	380 x 178 x 13	12000	3	2	0.9
Poplar plywood	358 x 224 x 3	12000	3	3	0.9
MDF	398 x 188 x 8	18000	3	3.5	0.9

After material setup, the software calculates the estimated processing time, allowing thus the optimization of the process. The tool path is automatically generated (Fig. 3a) and the simulation of the process starts, as seen in Fig. 3b.

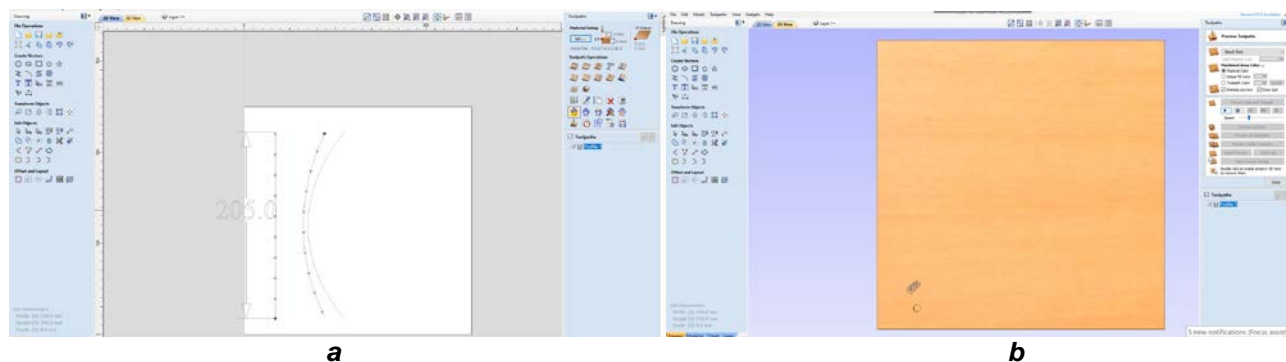
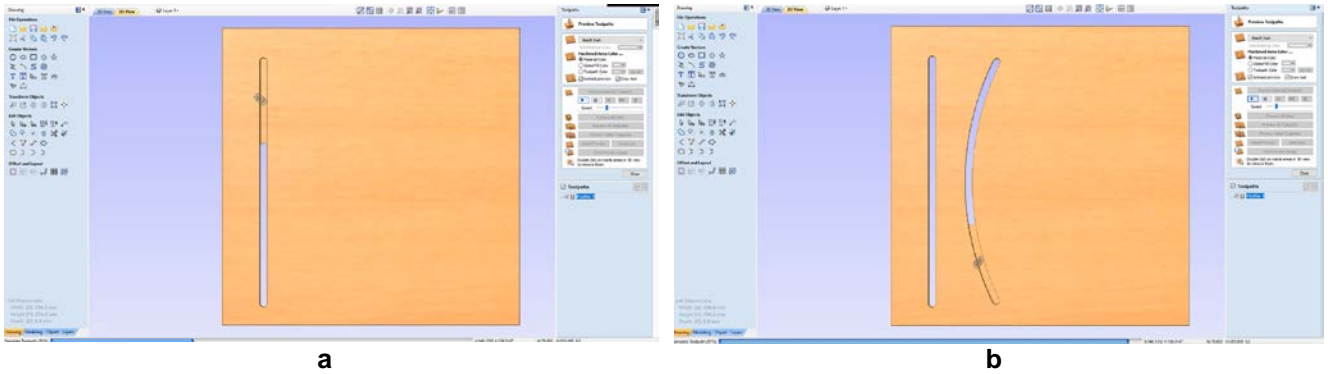


Fig. 3.
Generated tool path (a) and start of the simulation process (b).

The simulation process continues as indicated by the arrows on the generated trajectory, first with the straight line (Fig. 4a) and then with the curved one (Fig. 4b).



a

b

Fig. 4.
Toolpath simulation
a – straight line; b – curved line.

The tool selected for milling on CNC Router and the equipment are shown in Fig. 5.



a



b

Fig. 5.
Tool (a) and CNC Router (b).

Information related to tool path and milling parameters are transferred to CNC Router for the processing phase.

RESULTS AND DISCUSSIONS

The samples were CNC machined in order to obtain the designed tool path on the three materials selected for the investigation, namely spruce wood, poplar plywood and MDF (Fig. 6), using the tool presented in Fig. 5a and having the diameter of 6 mm.



a



b



c

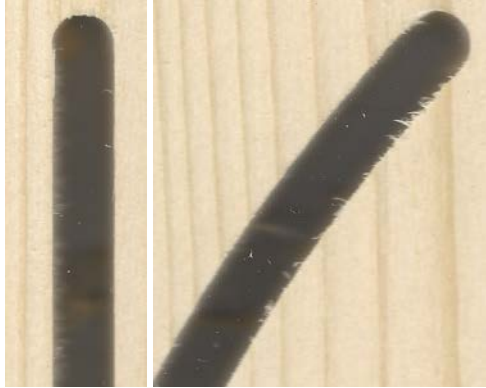
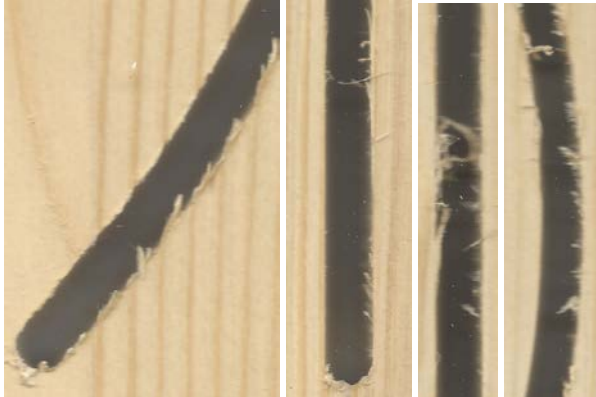
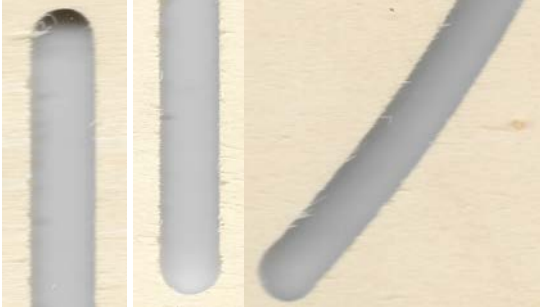
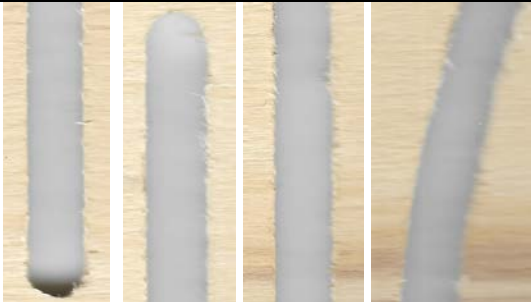
Fig. 6.
Samples processed on CNC Router.
a – spruce wood; b – poplar plywood; c – MDF.

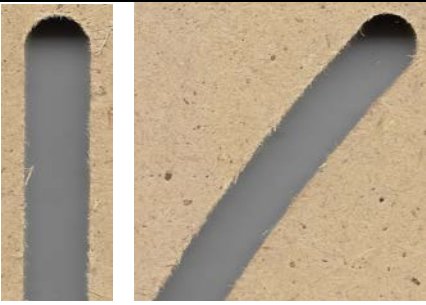
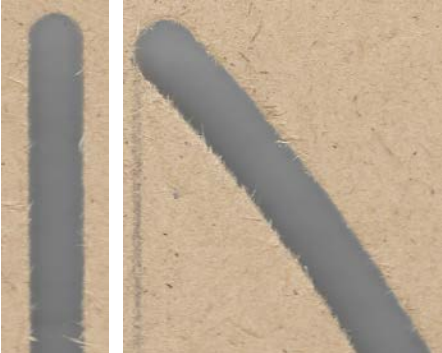
The samples were tested on two spindle speeds, namely 12000 rot/min for spruce wood and poplar plywood and 18000 rot/min for MDF, with higher feed speed for MDF, which has higher density than the other materials.

The processed samples were scanned with high resolution both on top face and bottom face, and the defects in terms of grain tearing were visually analyzed. The results are presented in Table 2.

Table 2

The results of sculptured surfaces after CNC machining

Material and scanned face		Image	Work Time, h:min:s	Defects
Spruce wood	Top		0:02:41	Few small grain tearing on the curved tool path
	Bottom			Lot of big grain tearing, both on the straight and on the curved tool path
Poplar plywood	Top		0:00:18	Few grain tearing, both on the curved and straight tool path
	Bottom			Lot of small grain tearing, both on the straight and on the curved tool path, irregular contour

MDF	Top		0:01:01	Few small grain tearing, both on the curved and straight tool path
	Bottom			Few small grain tearing, both on the straight and on the curved tool path

As seen in Table 2, the smallest grain tearing, both on top face and bottom face were obtained for MDF sample, which had the more homogeneous structure. Low quality of the perforated surface was obtained for spruce wood sample, on the bottom face, both for straight and curved trajectories. The poplar plywood resulted also with a low quality surface on the bottom face after milling in depth on the entire thickness of the sample (3 mm). In this case irregularities of the contour were also observed.

The results show that the processing parameters selected for the milling process applied to the three materials in order to obtain perforated simple ornaments are not the most appropriate ones, so an experimental design has to be set up in order to consider the three variables influencing the quality of the processed surface, namely spindle speed, feed rate and pass (or cut) depth. These factors have influence both on the quality of the processed surface and on the productivity of the machine. The quality of the surface is quantitative assessed by two accepted roughness parameters, namely average roughness (R_a) and mean peak to valley height (R_z). In most cases R_a is used to evaluate the surface quality of the samples. The productivity is linked to the processing time and it depends on the thickness of the sample, as seen in Fig. 7.

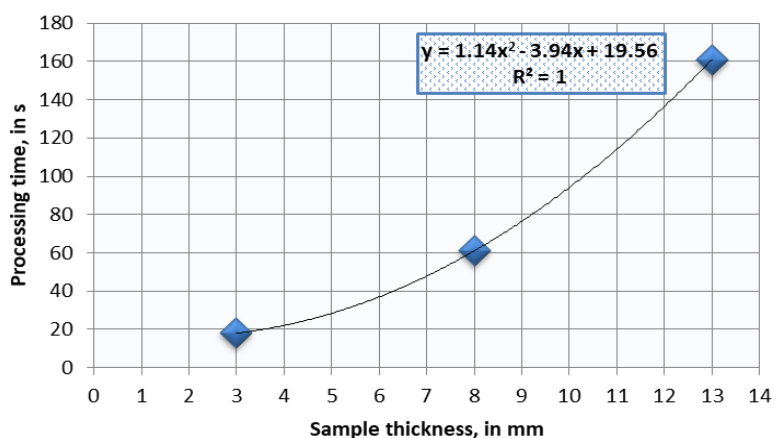


Fig. 7.
Equation of processing time depending on the sample thickness.

The following step in the research work is to evaluate the optimal result for the selection of spindle speed, feed rate and depth of cut in order to achieve good surface average roughness (R_a) during the CNC milling process of perforated ornaments. Thus, a 3^k full factorial design of experiments will be carried out, where 3 is the treatment levels figure and k is the number a variables (in our case three variables). The

treatment levels and the variables taken into consideration in the next experimental design are shown in Table 3.

Table 3

Levels and variables used in 3^k full factorial design

Parameters (Variables)	Unit	Level (-1)	Level (0)	Level (+1)
Spindle speed (S)	rpm	10000	14000	18000
Feed rate (F)	m/min	2	5	8
Depth of cut (D)	mm	2	3.5	5

The levels from Table 3 are established according to the results obtained by other researchers for similar materials (Hazir and HüseyinKoc 2016, Çakiroğlu et al. 2019, İşleyen and Karamanoğlu 2019).

There are 27 treatment combinations (runs) for a full factorial design with three variables at three levels (-1, 0, and 1) per variable, as seen in Table 4.

Table 4

Treatment combinations of the planned experiment

Combinations (Runs)	Variables (Factors)			Interactions			
	S	F	D	SF	FD	SD	SFD
1	-1	-1	-1	+1	+1	+1	-1
2	-1	-1	0	+1	0	0	0
3	-1	-1	+1	+1	-1	-1	+1
4	-1	0	-1	0	0	+1	0
5	-1	0	0	0	0	0	0
6	-1	0	+1	0	0	-1	0
7	-1	+1	-1	-1	-1	+1	+1
8	-1	+1	0	-1	0	0	0
9	-1	+1	+1	-1	+1	-1	-1
10	0	-1	-1	0	+1	0	0
11	0	-1	0	0	0	0	0
12	0	-1	+1	0	-1	0	0
13	0	0	-1	0	0	0	0
14	0	0	0	0	0	0	0
15	0	0	+1	0	0	0	0
16	0	+1	-1	0	-1	0	0
17	0	+1	0	0	0	0	0
18	0	+1	+1	0	+1	0	0
19	+1	-1	-1	-1	+1	-1	+1
20	+1	-1	0	-1	0	0	0
21	+1	-1	+1	-1	-1	+1	-1
22	+1	0	-1	0	0	-1	0
23	+1	0	0	0	0	0	0
24	+1	0	+1	0	0	+1	0
25	+1	+1	-1	+1	-1	-1	-1
26	+1	+1	0	+1	0	0	0
27	+1	+1	+1	+1	+1	+1	+1

CONCLUSIONS

The present paper is a case study of CAD-CAM-CAE tool applied in wood industry for CNC milling of perforated ornaments. A first advantage of CNC processing using advanced software is the whole control over the tool and parameters selection and processing time estimation. The experiment in this paper was carried out on three materials, namely spruce wood (*Picea Abies*), poplar (*Populus Alba*) plywood and MDF. Simple perforated ornament composed of straight line and an arc of circle was CNC milled on the three materials, using tapered ball nose tool with a diameter of 6 mm. The selected processed parameters were as follows: spindle speed of 12000 rpm for spruce wood and poplar plywood and of 18000 rpm for MDF; feed rate of 2 m/min for spruce wood, 3 m/min for plywood and 3.5 m/min for MDF. A constant depth of cut of 3 mm was selected for all materials. The visual assessment of the processed surfaces showed that the selected

parameters were not the optimum one, especially for spruce wood and poplar plywood. Considering the results as a first step of research, the authors of this paper plan the further experiment design using 3^K full factorial design of experiments and setting minimum, average and maximum values of the parameters, which are considered variables in the future experiment. The limits are set according to the results of the research works found in the literature and the values are 10000 rpm and 18000 rpm for the spindle speed, 2 m/min and 8 m/min for the feed rate and 2 mm to 5 mm for depth of cut. The results of the planned experiments will be presented on a future paper.

REFERENCES

Çakiroğlu EO, Demir A, Aydın I (2019) Determination of the Optimum Feed Rate and Spindle Speed Depending on the Surface Roughness of Some Wood Species Processed with CNC Machine. *J. Anatolian Env. and Anim. Sciences* 4(4):598-601. DOI:10.35229/jaes.635310

Finzer T (1999) High Speed Machining (HSC) of Sculptured Surfaces in Die and Mold Manufacturing. In: Olling G.J., Choi B.K., Jerard R.B. (eds) *Machining Impossible Shapes*. IFIP — The International Federation for Information Processing 18: 333-341. Springer, Boston, MA. https://doi.org/10.1007/978-0-387-35392-0_34 333-341.

Gawronski T (2013) Optimisation of CNC Routing operations of wooden furniture parts. *International Journal of Advanced Manufacturing Technology* 67:2259–2267, DOI 10.1007/s00170-012-4647-5.

Hazir E, HüseyinKoc K (2016) Optimization of wood surface machining parameters in CNC routers: Response surface methodology (RSM) approach. *International Journal of Scientific Research Engineering & Technology* 5(10):494-501.

Işleyen UK, Karamanoglu M (2019) The Influence of Machining Parameters on Surface Roughness of MDF in Milling Operation. *BioResources* 14(2):3266-3277. DOI:10.15376/biores.14.2.3266-3277

Koc KH, Erdinler ES, Öztürk E (2017) Effect of CNC application parameters on wooden surface quality. *Measurement* 107:12-18. DOI:10.1016/J.MEASUREMENT.2017.05.001

Michigan State University (2020) What is the Difference between CAD, CAE and CAM? Engineering articles. Available on <https://online.egr.msu.edu/articles/>. Accessed on 30 August 2020.

Nagy J, Oláh J, Erdei E, Máté D, Popp J (2018) The Role and Impact of Industry 4.0 and the Internet of Things on the Business Strategy of the Value Chain-The Case of Hungary. *Sustainability* 10, 3491. Doi:10.3390/su10103491.

Sütçü A, Karagöz Ü (2012) Effect Of Machining Parameters on Surface Quality after Face Milling of MDF. *Wood Research* 57(2):231-240.