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THE ROLE OF THE INCREASING GEOMETRY PRECISION FOR SAWLOG QUALITY GRADING

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ABSTRACT

This paper is focused on the possibilities of using geometry obtained by CT scanning to improve the quality assessment of sawlogs. This study is the initial part of the author's research in qualitative log sorting. The selected 60 Norway spruce sawlogs were measured manually according to the valid standards in the Czech Republic and then scanned using a CT LOG X-ray computed tomography scanner (MiCROTEC, Bressanone, Italy). Based on CT scan reconstruction, the average wood density was determined to be 687.9 kg/m^3 at a moisture content of 60.6%. When comparing methods of manual measurement and computed tomography, a slightly stronger relationship was found between density based on computed tomography and wood moisture content, with a Pearson correlation coefficient of $r = 0.7195$. The tests performed confirmed a statistically significant difference between the volume determined by manual measurement and by computed tomography. Obtained volumes are input in follow-up studies when correcting the parameters received from acoustic nondestructive testing. The results proved the high accuracy of the CT scans, which enables an improvement in the sawlog quality assessment.

Keywords: CT scanning, nondestructive techniques, acoustic methods, volume reconstruction.

1. INTRODUCTION

Nondestructive methods are an essential tool that allows the prediction of the actual properties of a material without the need to damage its structure. When using wood for construction purposes, it is necessary to know its mechanical properties, which are usually predicted by a number of nondestructive methods, such as visual assessment (Takahashi et al. 2022), acoustic methods (Uzcategui et al. 2023), methods based on computed tomography (Rais et al. 2017), fiber orientation measurements (Olsson et al. 2018), or simulations using the finite element method (Weidenhiller et al. 2023). Each of these options has its advantages and disadvantages, but they all share the principle of indirect measurement of mechanical properties, which are significantly influenced by several factors and the surrounding environment. The properties of final sawn timber can be predicted before processing at the sawlog stage or later during industrial processing at the sawmill. Since the 20th century, industrial prediction of the mechanical properties of sawn timber has been used primarily before or, more often, after drying, whereby we distinguish between visual and machine grading (Ridley-Ellis et al. 2016). However, since the aforementioned nondestructive techniques have advanced technologically in recent years, efforts to forecast the characteristics of sawn timber at the sawlog stage have started to emerge. (Fischer et al. 2015; Krajnc et al. 2019; Simic et al. 2019).

In both cases, information about the geometric properties of wood can play a crucial role in predicting other properties. The geometric model can be used in computer simulations, but it can also refine the calculation of the density of logs, which often have a highly irregular shape. Wood moisture content significantly affects the physical and mechanical properties of wood. In general, the density of

wood increases with increasing moisture content (Ross, 2010). A number of studies have also demonstrated the significant influence of moisture content on acoustic properties such as natural frequency or sound velocity (Unterwieser and Schickhofer, 2011). On the contrary, for wood with moisture content above fiber saturation, no significant effect of moisture on the dynamic modulus of elasticity was found when calculations are based on natural frequency (Rais et al. 2020). Determining the moisture content of a log for calculation correction can be technically challenging, as it is often impossible to take the necessary samples from the log for the kiln-dry moisture determination method. There is a strong correlation between the density and moisture content of wood, so it can be used to predict real values. Accurate determination of this density is offered by new technologies, where calculations can be based on knowledge of the weight and volume of the trunk, with the volume of the trunk obtained using optical scans or scans taken by computed tomography.

This study is part of a larger project focused on designing models for predicting the mechanical properties of sawn timber based on nondestructive measurements of roundwood. The main objective is to assess the suitability of geometric reconstruction of logs using computed tomography to determine log moisture content. A secondary objective is to compare the results of geometric reconstruction obtained using computed tomography and standard manual measurement.

2. MATERIAL AND METHODS

In total 60 Norway spruce (*Picea abies* L.) sawlogs were processed. Logs came from the University Forest Enterprise Masaryk Forest in Křtiny. After transporting the sawlogs to the measuring area, samples were immediately taken to determine moisture content (Figure 1a). For each sawlog, a piece approximately 5 cm long was taken from the large diameter side of the log to determine the moisture content (Figure 1b). After that, all samples were packed and transported to the Josef Ressel Research Centre in Útěchov to determine their moisture content. The weight of the samples was measured with an accuracy of 0.1 g using a laboratory scale. The samples were then placed in a drying oven at a drying temperature of (103 ± 2)˚C. The weight of the samples was measured during drying, with the drying process considered complete when the differences in weight between two consecutive weightings at 2-hour intervals did not differ by more than 0.1%. The moisture content of the sample was calculated using equation (1). After sampling, all logs were weighed using a BAXTRAN STE 500 kg (Giropès SL, Girona, Spain) scale (Figure 1c). The total weight of the sawlog was expressed with an accuracy of 0.1 kg.

$$w = \frac{m_1 - m_0}{m_0} \times 100 \qquad [1]$$

where w is moisture content (%); m_1 is weight of test specimen before drying (g); m_0 is weight of test specimen after drying (g).

After sampling and weighing the sawlogs, manual measurements were performed in accordance with the Recommended Rules for Measuring and Grading of Roundwood in the Czech Republic 2008 (Recommended Rules 2007). A calibrated tree caliper and tape measure were used for these measurements. The diameter was measured in the middle of the trunk in two perpendicular directions, with the final thickness expressed as the arithmetic mean of these two measurements. Most of the logs were measured with bark. If bark was missing at the measurement point for a particular log, equation (2) was used to calculate the bark thickness based on the measurement closest to the mid-diameter. The bark thickness was then added to the mid-diameter for the purpose of calculating the volume of roundwood. The nominal length of all logs was 3 m, and the mid-diameter varied between 26.82 and 32.95 cm. Information on the dimensions of the logs based on manual measurements is provided in Table 1.

$$2k = p_0 + p_1 \times d_{sk}^{p_2} \qquad [2]$$

where k is bark thickness (cm); p_0 is 0.57723; p_1 is 0.006897; p_2 is 1.3123; d_{sk} is diameter of the log with bark (cm).



Figure 1. *Measuring area at the Sawmill Olomučany (a); Sample for the determination of the moisture content (b); Weighing of logs (c).*

Table 1. *Basic data of sawlogs according to manual measurement*

	Mean	Minimum	Maximum	St. dev.	CV (%)
Total length (cm)	300.88	299.80	302.30	0.46	0.15
Mid-diameter (cm)	29.30	26.82	32.95	1.57	5.36

St. dev. is Standard Deviation; CV is Coefficient of Variation

The volume of each log was calculated based on manual measurements using the Recommended Rules (2007) and equation (3). All resulting log volumes are based on the average value, including bark thickness.

$$V_{man} = \frac{\pi}{4} \times d_{sk}^2 \times l \quad [3]$$

where V_{man} is log volume calculated based on the manual measurements (cm^3); l is total length of the log (cm).

After manual measurement was completed, all logs were transported to the National Forest Centre, Zvolen area, where they were scanned using a CT LOG X-ray computed tomography scanner (MICROTEC, Bressanone, Italy). The CT scanner generated cross-sectional CT images composed of voxels with an in-plane resolution of 1x1 mm, while the images were acquired in the longitudinal direction at 10 mm intervals. Results were exported to an image file in TIFF format after scanning. For each scan, TIFF format was transferred by palette for grayscale images in IrfanView (Irfan Skiljan, Jajce, Bosnia and Herzegovina). All scans were then uploaded to the program 3D Slicer (Brigham Women's Hospital, Boston, USA). Subsequently, image spacing was adjusted according to real conditions. For the purpose of volume reconstruction, segmentation was performed using a manually set threshold range. After segmentation was completed, the total volume was exported from all images in cm^3 units (Figure 2). The density of sawlogs based on manual measurement was calculated according to equation (4), while the density of sawlogs based on CT scanning was calculated according to equation (5).

$$\rho_{man} = \frac{m}{V_{man}} \times 10^{-6} \quad [4]$$

where ρ_{man} is density based on the manual measurements (kg/m^3); m is total mass of the log (kg).

$$\rho_{CT} = \frac{m}{V_{\mathrm{CT}}} \times 10^{-6} \quad [5]$$

where ρ_{CT} is density based on the computed tomography (kg/m^3);V_{CT} is total volume of the log based on the computed tomography (cm^3).

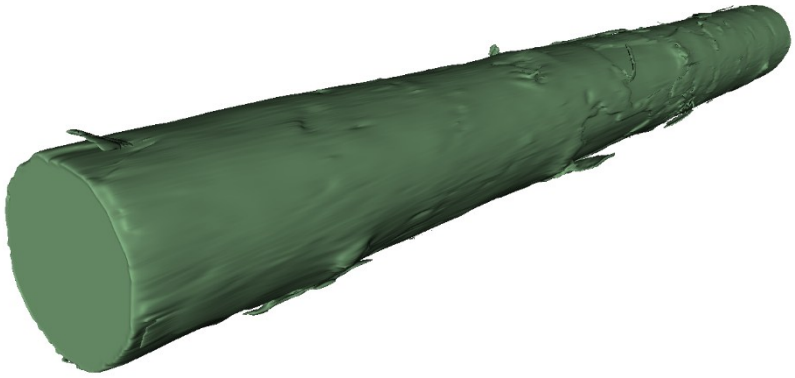


Figure 2. *Reconstructed volume of the log after the segmentation.*

3. RESULTS AND DISCUSSION

The results obtained are presented in Table 2. According to calculations, logs had significant moisture content variability, which can be considered as suitable conditions for assessing the relationship between density and moisture. Only two logs had moisture content lower than the fiber saturation point, with the lowest measured moisture content being nearly 25%. The average density achieved was 679.8-687.9 kg/m^3 at an average moisture content of 60.6%, which is similar to the findings reported by other authors, with Rais et al. (2014) reporting a spruce log density of 672 kg/m^3 at a moisture content of 58% and Unterwieser and Schickhofer (2011) reporting a density of 620 kg/m^3 at a moisture content of 65.7%. Edlund et al. (2006) generally state green spruce log density to be 700–1050 kg/m^3, so it can be concluded from these results that moisture content has a significant effect on wood density. The cause of lower density variability can be explained by the relatively similar dimensions of the logs, resulting in low variability in volume, which is included in the density calculation.

Table 2. *Basic descriptive statistics of the results obtained.*

	Mean	Minimum	Maximum	St. dev.	CV (%)
w (%)	60.6	24.9	115.7	17.9	29.5
m (kg)	138.3	94.5	199.0	22.6	16.3
V_{man} (cm^3)	203 411	169 597	256 410	22 000	10.8
V_{CT} (cm^3)	200 963	166 301	257 700	21 675	10.8
ρ_{man} (kg/m^3)	679.8	491.6	840.6	81.1	11.9
ρ_{CT} (kg/m^3)	687.9	511.4	866.0	80.7	11.7

The relationship between density according to both calculation methods and log moisture content is shown in Figure 3. Both methods of volume determination show a very similar relationship to moisture content, which is expressed by the Pearson correlation coefficient $r = 0.7166$ for manual measurement and $r = 0.7195$ for computed tomography. Unterwieser and Schickhofer (2011) reported a stronger correlation between density and moisture content, but it should be recognized that these experiments were conducted on sawn timber with a much more uniform structure and moisture distribution. Based on our results, it can be clearly confirmed that log density increases with increasing moisture content; however, this moisture content can only be predicted approximately based on density. The prediction can be further improved by including additional log parameters that directly affect wood density but do not significantly affect moisture content. Such parameters include, for example, the presence of compression wood, the proportion of latewood, or the average width of growth rings (Požgaj et al. 1993).

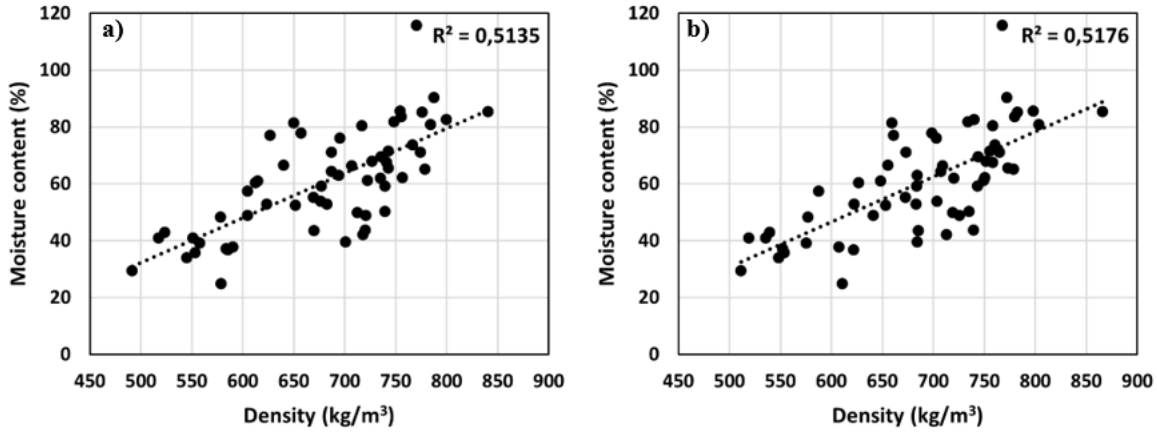


Figure 3. *Relationship between log moisture content and density determined by manual measurement (a); Relationship between log moisture content and density determined by computed tomography (b).*

The results of determining the volume of roundwood using both methods were compared with the box plot shown in Figure 4. Statistical tests were performed to compare these methods. First, the Shapiro-Wilk test was performed with a significance level of $\alpha = 0.05$. According to the test results, the p-value is 0.0933, which assumes that the data are normally distributed. Based on this, a paired T-Test was performed with a p-value of 0.0020. Since the p-value is below the set limit of the significance level $\alpha = 0.05$, the null hypothesis is rejected–the population means are considered unequal, and a statistically significant difference between the results of the two methods for determining volume was confirmed. The comparison clearly shows that the average log volume determined using computed tomography is higher than the results based on manual measurement. The advantage of computed

tomography is a more accurate reconstruction of the volume and bark over the entire length of the log, whereas manual measurement is based only on the value at a single middle point.

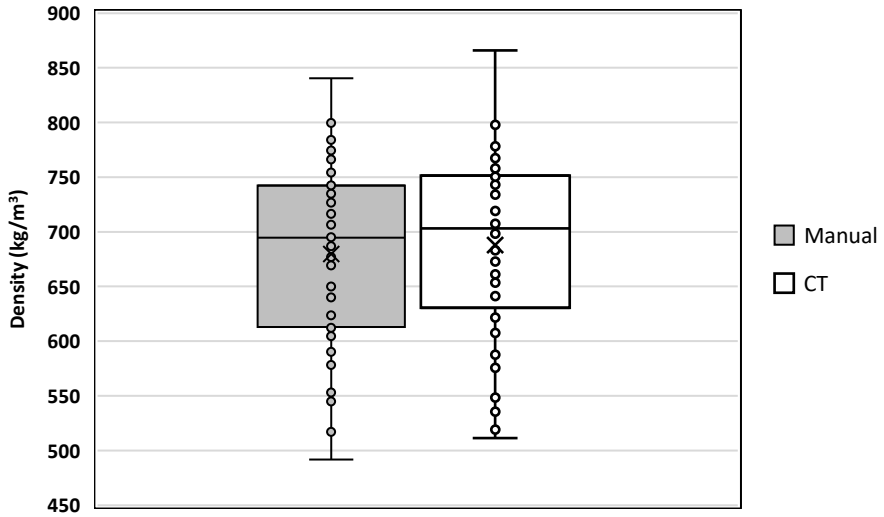


Figure 4. *Box plot for density determined by manual measurement and by computed tomography.*

CONCLUSIONS

Computed tomography can be used to easily and accurately reconstruct the volume and create a 3D model of the log, which can serve as input for subsequent analyses and quality assessments. The volume determined using computed tomography is statistically different from the volume determined by manual measurement, with the average log volume being larger according to the results obtained from the processed CT scans. Manual measurement is inaccurate mainly due to the calculation of volume based on thickness at a single point. However, in the case of high-quality roundwood with a uniform shape and surface, the results of manual measurement differ by only 2-3% compared to 3D reconstruction using computed tomography. When comparing the two volume measurement methods investigated, it can be stated that moisture content correlates slightly better with density determined based on CT scan processing ($r = 0.7195$ against $r = 0.7166$). Predicting log moisture content based on density alone is not very accurate, so it is advisable to include other parameters in the future, for example, average width of growth rings.

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