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Evaluation of the surface quality of reused woods from Maçaranduba (Manilkara sp.) and Sucupira (Pterodon sp.)

Avaliação da qualidade superficial de madeiras de reuso de Maçaranduba (Manilkara sp.) e Sucupira (Pterodon sp.)

Evaluación de la calidad superficial de maderas reutilizadas de Maçaranduba (Manilkara sp.) y Sucupira (Pterodon sp.)

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Abstract
The present study aimed to evaluate the surface quality of reused wood, analyzing whether the behavior and characteristics indicated in the production of furniture are still maintained after use, in order to indicate appropriate uses and applications. In the furniture sector, the better the machined surface, the better the quality of the product. Two wood boards of Maçaranduba (*Manilkara* sp.) and Sucupira (*Pterodon* sp.) were then manually planed longitudinally and tangentially, considering the slow and fast machining speeds for each face, and the evaluation of the feed and speed speeds advancement per tooth. The relationship between feed speed and surface finish quality was observed, since faces machined at high speed presented a thick finish, obtaining 11.10 m.min^{-1} and 7.09 m.min^{-1} in feed speed for, respectively, Maçaranduba and Sucupira. The faces machined at slow speed showed medium quality of finish, less roughness and better quality of the planed surface according to the ASTM D 1666-22 standard when presenting 3.17 m.min^{-1} and 2.79 m.min^{-1} at speed of advance to, respectively, Maçaranduba and Sucupira. It was also noted that the faces that have a thick finish and, consequently, a higher feed speed per tooth, are subject to rework in order to achieve the necessary quality for furniture manufacturing. In view of this, it was verified that Maçaranduba machined slowly presented excellent surface quality, responding positively to the objective of the exposed work.
Keywords: Advance speed; Quality; Wood machining.

Resumo
O presente trabalho objetivou avaliar a qualidade superficial de madeiras reaproveitadas, analisando se o comportamento e características indicadas na produção de móveis ainda se mantém após o uso, a fim de indicar usos e aplicações adequadas. No setor moveleiro, quanto melhor a superfície usinada melhor é a qualidade do produto.

Realizou-se então o aplainamento manual longitudinal tangencial de duas tábuas de madeira de Maçaranduba (*Manilkara* sp.) e Sucupira (*Pterodon* sp.), considerando as velocidades de usinagem lento e rápido para cada face, e a avaliação quanto às velocidades de avanço e avanço por dente. Observou-se a relação entre velocidade de avanço e qualidade do acabamento superficial uma vez que faces usinadas em rápida velocidade apresentaram grosso acabamento, obtendo 11,10 m.min^{-1} e 7,09 m.min^{-1} em velocidade de avanço para, respectivamente, Maçaranduba e Sucupira. As faces usinadas em lenta velocidade apresentaram média qualidade de acabamento, menor rugosidade e melhor qualidade da superfície aplainada conforme a norma ASTM D 1666-22 ao apresentarem 3,17 m.min^{-1} e 2,79 m.min^{-1} em velocidade de avanço para, respectivamente, Maçaranduba e Sucupira. Notou-se ainda que as faces que apresentam grosso acabamento e, consequentemente maior velocidade de avanço por dente, estão sujeitas ao retrabalho a fim de alcançar a qualidade necessária para fabricação de móveis. Diante disto, verificou-se que a Maçaranduba usinada de forma lenta apresentou excelente qualidade da superfície, respondendo positivamente ao objetivo do trabalho exposto.
Palavras-chave: Velocidade de avanço; Reciclagem; Usinagem da madeira.

Resumen
El presente trabajo tuvo como objetivo evaluar la calidad superficial de la madera reutilizada, analizando si el comportamiento y las características indicadas en la producción de muebles se mantienen después de su uso, con el fin de indicar usos y aplicaciones adecuadas. En el sector del mueble, cuanto mejor es la superficie mecanizada, mejor es la calidad del producto. Dos tableros de madera de Maçaranduba (*Manilkara* sp.) y Sucupira (*Pterodon* sp.) fueron luego cepillados manualmente longitudinal y tangencialmente, considerando las velocidades de mecanizado lenta y rápida para cada cara, y la evaluación de las velocidades de avance y velocidad de avance por diente. Se observó la relación entre la velocidad de avance y la calidad del acabado superficial, ya que las caras maquinadas a alta velocidad presentaron un acabado grueso, obteniendo 11,10 m.min^{-1} y 7,09 m.min^{-1} en velocidad de avance para Maçaranduba y Sucupira, respectivamente. Las caras maquinadas a baja velocidad mostraron calidad de acabado media, menor rugosidad y mejor calidad de la superficie cepillada según norma ASTM D 1666-22 al presentar 3.17 m.min^{-1} y 2.79 m.min^{-1} a velocidad de avance a, respectivamente, Maçaranduba y Sucupira. También se observó que las caras que tienen un acabado grueso y, en consecuencia, una mayor velocidad de avance por diente, son objeto de retrabajo para lograr la calidad necesaria para la fabricación de muebles. En vista de eso, se verificó que Maçaranduba maquinado lentamente presentó excelente calidad superficial, respondiendo positivamente al objetivo del trabajo expuesto.
Palabras clave: Velocidade de avance; Calidad; Mecanizado de madeira.

1. Introduction

Understanding the legal and environmental parameters surrounding the use of native wood is relevant. According to Veríssimo (2006), the exploitation of native forests in the Amazon, Caatinga, and Cerrado biomes has historically been marked by widespread predatory actions, driven by the timber and non-timber forest products sectors. Both the Brazilian Amazon and the Cerrado suffer from the extraction of wood for industrial processing, as well as for firewood and charcoal production. Due to legislation and enforcement measures, there has been a reduction in the exploitation of native species in the Amazon, but illegal exploitation cannot be ignored. Furthermore, the continuous exploitation has led to a decrease in the frequency of species and a reduction in the annual growth rate, especially when considering their behavior within ecological groups (Oliveira, 1997; Lopes et al., 2011). Given the aforementioned, there is a clear need for alternative approaches to witness the decrease in the exploitation of native forests in all sectors.

Some of the natural woods in Brazil, such as Sucupira and Maçaranduba, due to their good mechanical strength, are commonly used in the construction industry as beams, columns, and even for roofing. Their durability is equally undeniable, reaching up to 10 years. Their chemical and anatomical composition provides them with low permeability and, consequently, greater resistance to attacks by wood-boring insects and decaying organisms. However, it is evident that this resistance tends to decrease over the years, leading to the loss of their structural functionality and requiring their replacement, ultimately leading to their disposal.

The technique of reusing wood subjected to machining processes is based on treating the pieces that would otherwise be discarded, making use of their remaining lifespan. This technique offers the wood the possibility of a new use after being exposed to the process of longitudinal tangential hand planing, acquiring the final finish accepted for furniture production. This emphasizes the intense need for the exploitation of new logs to serve the furniture sector.

According to Latorraca and Albuquerque (2012), machining can be described as the ease of processing wood using tools, aiming not only for sawing but also for achieving surface quality and economic satisfaction in relation to the produced form (Marchesan et al., 2013). Considering this, Silva et al. (2005) emphasize the need to understand the structure of processed wood and its machining parameters in order to achieve better relationships between its properties and quality (Da Silva et al., 2009). These concepts indicate that well-executed machining directly affects the performance and quality of the machined material. Therefore, according to the same author, the properties of the wood, machining parameters, and their interactions should be considered, especially when thinking of wood as a biological and anisotropic material. In this regard, Stemmer (1993) highlighted tool life and the forces acting on it, machine power, and the quality of the surface finish as parameters for evaluating the machinability of a material. Consequently, Coletti et al. (2010) emphasize that the quality of wood can be influenced not only by parameters associated with machines but also by a lack of instruction and training of machine operators (Marchesan et al., 2013).

This study was conducted with the aim of understanding the relationship between cutting speed, feed rate, and the surface quality of reused machined wood, as well as finding the optimal adjustment of cutting speed in a thickness planer for the machined woods of Maçaranduba and Sucupira. This research aims to identify suitable uses and applications, considering the anatomical, physical, and mechanical properties, as well as the machining parameters of these wood species, in order to promote the rational utilization of this resource.

2. Methodology

The present study was carried in 2022 and out through a systematic investigation (Pereira, et al., 2018; Koche, 2011) in which the focus was on understanding the behavior of reused wood for the production of furniture. In this way, two reclaimed wooden boards measuring 1m x 20cm x 3cm from the species *Manilkara* sp. (Maçaranduba) and *Pterodon* sp. (Sucupira) were used in this study. These boards were obtained from a roof renovation project at the Laboratory of Machining and Furniture Production (LUPM) of the Federal University of Sergipe. The machining test was performed using a thickness planer, which has only one active blade on its tool holder axis and rotates at 3460 min^{-1}. This machine was also acquired from the LUPM. The selected pieces were longitudinally tangentially planed using this equipment. Da Silva et al. (2016) explained in their study, according to Costes and Larricq (2002), that the relationship between cutting speed and feed rate directly influences the surface quality of machined wood. Therefore, for the test, it was considered that the machine operator would manually feed the pieces at slow and fast speeds. Consequently, the cutting speed and time varied throughout the evaluation, simulating the everyday practice in carpentry that often does not consider the anatomical, physical, and mechanical parameters of the wood, as well as characteristics of the cutting tool.

The machined surface of the pieces had its quality evaluated based on feed rate, feed per tooth (fz) calculated and average, roughness (Ra), and visual analysis (ASTM D 1666-22). The feed per tooth (average fz) was determined using a millimeter ruler scale, counting the number of ridges in a line measuring 30mm and 20mm in length for Maçaranduba and Sucupira, respectively. The determination of the calculated feed per tooth (calculated fz) was performed using Equation 1 (Braga et al., 2014).

$fz_{calculated} = \frac{Vf \times 1000}{n \times z}$, where:

$fz_{calculated}$ = calculated feed per tooth (mm);

Vf = workpiece feed rate (m.min-1);

n = tool-holding shaft rotation (min^{-1});

z = number of active cutting edges of the tool.

The obtained values for feed per tooth (fz) were classified according to the quality of the finish for milling cutters, jointers, and thickness planers, following a classification provided by SENAI (1995), as shown in Table 1. According to Braga et al. (2014), this classification methodology indicates that, in the relationship between fz and finish quality, the lower the value of feed per tooth (fz), the better the finish quality.

Table 1 - Classification of finish quality for milling, planing, and thicknessing, based on the values of feed per tooth (fz), in mm.

Feed per tooth (fz), in mm	Finish quality
0.3 to 0.8	Fine
0.8 to 2.5	Medium
2.5 to 5.0	Coarse

Source: SENAI (1995).

The roughness analysis was carried out using a profilometer of the Mitutoyo SJ-210 model. The roughness parameter Ra assisted in qualifying the machined surface of the pieces, following the Taylor Hobson methodology, considering the peaks and valleys and their variation on the surface through the horizontal displacement of the sensor. Braga et al. (2014) emphasize that the higher the values obtained, the rougher the surface of the pieces.

Finally, the visual analysis of the machined surface quality was evaluated according to ASTM D 1666-22 standard (Table 2), which assesses wood fibers for splintering and tearing at levels ranging from slight to severe, and assigns grades that classify the planed surface based on visible defects to the naked eye.

Table 2 - Assignment of grades regarding the quality of the machined surface considering visible defects to the naked eye.

Grades	Surface quality of machined wood	Classification of planed surface
1	free of any defects	Excellent (free of defects)
2	Presence of mild to medium splintering	Good
3	Presence of Surface strong roughness and slight tearing	Fair
4	Presence of strong splintering and light to medium tearing	Poor
5	Presence of strong tearing, regardless of splintering	Very Poor

Source: ASTM (2022).

2.1 Species Processed

Maçaranduba (*Manilkara* sp.)

Due to many years of indiscriminate exploitation, Maçaranduba species have irregular distribution throughout the Brazilian territory (Carvalho, 2010). It is referred to as a climax species by Barbosa (2002). Its commercial uses include latex production and sawn timber production. The wood of Maçaranduba has a variable density ranging from dense to very dense (Mainieri & Chimelo, 1989) and can be used for structural purposes and in the production of stakes used in construction (Rosa et al., 2014; Carvalho, 2010).

Gehring Junior (2011) pointed out an improvement in the surface finish of Maçaranduba pieces machined with a stellite tool, an alternative to the use of conventional tools.

Sucupira (*Pterodon* sp.)

Sucupira, a species distributed in Colombia, Venezuela, Bolivia, and several states in Brazil, including Sergipe, is classified as a pioneer to late secondary species by Ferretti et al., (1995). It has dense wood with a density ranging from 0.83 to 1.11 g/cm³ (Carvalho, 2006), reaching commercial thickness after 15 to 20 years (Tigre, 1970). Among its various uses, Sucupira is notable for its production of sawn timber and roundwood used in construction, furniture manufacturing, carpentry, and joinery (Carvalho, 2006). In their work, Marchesan et al. (2013) mention that Sucupira wood is difficult to work with due to the impermeability of the heartwood, which makes planing challenging.

3. Results and Discussion

The results obtained for feed speed are described in Table 3. It can be observed that higher values of feed speed were found for Maçaranduba compared to Sucupira, both for the slow (S) and fast (F) planing processes. This can be explained by the greater density of Maçaranduba wood, which is a typical characteristic of the species.

Table 3 - Feed speed of the machined wood for Maçaranduba and Sucupira, in the slow (S) and fast (F) processes.

Test specimen	Feed rate (Vf) (m/min)
Maçaranduba S	3.17
Maçaranduba F	11.10
Sucupira S	2.79
Sucupira F	7.09

Source: Own author (2023).

Considering that cutting speed and feed rate influence the quality of machined wood, Da Silva et al. (2007) concluded that low feed rates and high cutting speeds reduce the quality of machined wood by causing surface carbonization. On the other hand, high values of this relationship can result in fiber tearing, also leading to a reduction in the quality of machined wood (Da Silva et al., 2019).

The lower the feed rate, the better the quality of the wood, considering that these values are not too low, as already mentioned before. In this regard, Marchesan et al. (2013) observed that Sucupira had the highest frequency of lamellae within the standard, with 66.0%, ensuring a higher utilization of pieces within and above the standard for the production of engineered wood floors. Furthermore, in this study, it can be concluded that a feed rate of 8 m/min resulted in only 7.5% of rejected lamellae, suggesting that this feed rate should not be exceeded when evaluating the quality of the pieces. On the other hand, an increase in the feed rate caused variations in the thickness of the lamellae, which can be explained by the increased likelihood of tool burning due to the increase in feed rate. This result can be compared to the feed rate of Maçaranduba. The loss of quality may be associated with the handling of the pieces and the limited knowledge about the wood used, acknowledging that technical expertise is strongly associated with material quality (Coletti et al., 2010; Silva, 2002).

An increase in the feed rate directly affects the quality of machined wood, increasing the frequency of planer marks, as observed in the visual analysis of the surface quality of Maçaranduba in the fast process, which received a rating of 5 and was classified as "Very Poor".

It can be observed from Table 4 the strong relationship between feed rate per tooth and finish quality. In terms of rework, the higher the feed rate per tooth, the lower the finish quality, indicating a greater need for additional machining steps such as sanding.

Table 4 - Feed rate per tooth of machined wood from Maçaranduba and Sucupira, in slow and fast processes.

Test specimen	*fz* calculated (*cm*)	*fz* measured (*mm*)	Quality of finish
Maçaranduba S	0.09	2.14	Medium
Maçaranduba F	0.32	3.33	Coarse
Sucupira S	0.08	2.22	Medium
Sucupira F	0.2	4.00	Coarse

Source: Own author (2023).

It becomes evident the relationship between finish quality and roughness, as the specimens with coarse finish, specifically Maçaranduba F and Sucupira F, exhibited higher roughness (Table 5). In the case of Maçaranduba F, it even hindered the reading of the crest number. The importance of accurately defining the type of machining employed during wood processing is also associated with its anatomical structure. In their study, Martins et al. (2012) explain that the cell cavities composing the wood's anatomical structure influence surface roughness, thus affecting the quality of the final product (Taylor et al., 1999; Kilic et al., 2006).

Table 5 - Roughness of machined wood specimens of Maçaranduba and Sucupira, in slow and fast processes.

Test specimen	Roughness (Ra) (µm)
Maçaranduba S	1.955
Maçaranduba F	Reading error
Sucupira S	1.472
Sucupira F	2.700

Source: Own author (2023).

When analyzing the data, it is observed that the specimens subjected to slow machining exhibited lower roughness. This relationship can be explained by Braga (2008) and Silva et al. (2006), who concluded that lower feed rates and higher cutting speeds result in better surface quality due to reduced roughness values. The inverse relationship should be avoided as it reduces surface quality by causing scraping and darkening of the surface. Bonduelle (2001) emphasizes that excessive increase in cutting speed also affects the tool life by causing premature wear of its cutting edge (Braga et al., 2014).

The results expressed by Da Silva et al. (2016) in evaluating roughness show that the machined surface of denser woods exhibited shallower and smaller peaks and valleys, making the comparison inconclusive due to the reading error encountered with Maçaranduba F.

The ASTM D 1666 standard classifies and assigns grades to the planed surface of wood and wood-based materials based on the presence of defects. It can be observed in Table 6 that only one specimen (Maçaranduba S) was classified as excellent (grade 1), with a surface free of any defects. This demonstrates that rework with surface sanding steps can be reduced or even unnecessary, unlike the Sucupira specimens in both machining processes, which were classified as fair (grade 3), suggesting the need for rework to achieve the desired quality. In the latter case, the presence of strong tearout and light tearout was observed.

Table 6 - Classification of the planed surface of machined woods of Maçaranduba and Sucupira, in slow and fast processes.

Test specimen	Grades	Surface Planing Classification (ASTM D)
Maçaranduba S	1	Excellent
Maçaranduba F	5	Very poor
Sucupira S	3	Fair
Sucupira F	3	Fair

Source: Own author (2023).

According to Zamarian et al. (2012), higher feed rates result in a lower quality surface of the wood (Da Silva et al., 2016). Therefore, for the test specimens that underwent high-speed machining - processes with higher feed rates - classified as very poor (grade 5) and regular (grade 3), corresponding to Maçaranduba F and Sucupira F, respectively, it is strongly recommended to rework them in order to achieve a better surface quality of the piece.

Once again, the explanation provided by Da Silva et al. (2009) can clarify the results obtained in this study by stating that the quality relationship is related to the wood structure, as it is from it that the feed rates are defined, which can cause greater or lesser fiber pullout and thus alter the planed surface quality.

4. Conclusion

Based on the findings, it can be concluded that Maçaranduba wood achieved satisfactory results when machined at a slow feed rate, obtaining a rating of 1, "excellent," in terms of planed surface quality. Therefore, it can be reused for furniture production, as it requires a higher quality of surface finish, which is not achieved with Sucupira wood, at both machining speeds, as it did not yield satisfactory results. In theory, this would indicate a contraindication for the use of Maçaranduba wood in furniture production. However, Sucupira wood does possess good characteristics for furniture production, such as good mechanical strength and resistance to wood-boring organisms. Therefore, Sucupira wood requires more extensive rework to achieve better quality conditions for its use, with the possibility of investing resources and time, making it a viable alternative for reuse as well.

Based on this study, it is suggested that further studies involving the quality of wood for furniture production purposes be carried out in view of its relevance to society.

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