Machinery from Brazilian Wooden Housing Production: Size and Overall Obsolescence

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In the current competitive market, production efficiency and product quality are prioritized by the whole industry. Machinery characterization is an understudied topic, particularly in those sectors focused on basic raw material production, processing, and/or heavy industrialization. For this reason, the wooden housing sector requires evaluation to identify its mechanical potential and support future policies dealing with industrial development. This study aimed to identify the equipment and machinery from Brazilian timber housing producers. Such a sectoral study involved individual personal data collection by way of face-to-face interviews. Sampled producers were asked about equipment/machinery size, drying process availability, and the range of overall obsolescence from these devices. Thus, tools, portable machines, and medium-sized machinery exhibited the highest popularities, revealing a lower industrial level. Most of these producers do not have machined drying processes because of the demand for static infrastructures. The low obsolescence was a result of the greater utilization of compact equipment, which is easier to replace because of its low cost. Lower-cost machinery could also stimulate in the creation of new businesses for this sector.

Keywords: Machine; Equipment; Wooden construction; Sectoral research; Personal interview

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INTRODUCTION

Masonry construction is an important part of the architectural heritage of many nations (Sacco *et al.* 2018), but wood-based construction was also part of the progress of humanity, and wood is considered one of the oldest and most consistently applied materials (Swoboda 1975; Calil and Dias 1997; Rampazzo and Sponchiado 2000; Pfeil and Pfeil 2003; Radkau 2011; Klein and Grubner 2015; Gosselin *et al.* 2017), providing various shapes and carpentry techniques in the form of palaces, simple barns, religious buildings, and houses (Wibowo 2015). Timber structures enable wide variations in shape, assembly, and manufacture techniques (Wraber 2009; Gonçalves *et al.* 2014). But, timber construction has been undervalued if compared to traditional houses made with minerals and metals, whereas Pandey *et al.* (2011) stated that wood is the most versatile material.

Machinery for Wood Processing and Transformation

Knowledge of a wood's properties and behavior during machining operations is important for proper utilization, optimum species selection, and dimensioning of machines and tools for manufacturing (Lucas Filho 2004). Timber has been produced along the advance of industrialization, because initially, hand tools were used to carve the most rudimentary shapes on wood, using coarse procedures (De Araujo *et al.* 2016b). It was only after the transition from the 19th to the 20th century, when the timber industry underwent a mechanization period from axe-cut wooden logs to sawmilling, that wooden architecture was able to spread throughout the southern Brazilian states (Berriel 2011). Through investments in innovative technologies, the wood-based products industry could evolve from laboratories to new markets and their distinct segments, offering additional benefits to society (IBÁ 2017). There is a need to understand the relationships between wood properties, and to provide advances in the machining methods for such material (Lucas Filho 2004). Such technological improvement in the production techniques and machinery is another component that contributes to this advance (De Araujo *et al.* 2015).

Sawn wood production is directly related to the number and characteristics of the machines, as well as their yield, focusing on log utilization according to tree diameter (Zenid 2009). Wood processing can be ordered into three stages (system, process, and operation), and its respective operations could be stratified into: harvesting, debarking, cutting, lamination, particle production, machining, drying, and preservation (Kollmann and Côté 1968; Gonçalves 2000; Iwakiri *et al.* 2005; Keinert and Iwakiri 2005).

The operations used in wooden housing production are essentially based on machining and/or processing of structural parts from sawn wood and/or wooden composites (De Araujo *et al.* 2016a). Technological aspects are often unknown or neglected during wood processing, which results in poor utilization of this raw material and/or poor quality of final products (Gatto 2002). As a result, there is a need to identify the main characteristics of the machinery used in the production of higher added-value manufactured goods such as wooden houses. For this reason, factors such as size or obsolescence (service life) of wood processing equipment may be mechanisms to identify their status. This machinery could be classified into size categories (Table 1).

Table 1. Machinery for Wood Processing and Transformation According to Size

Category*	Example*
Hand Tool	Hand saws, pointers, jacks, hammers, axes, clamps, *etc.*
Portable Equipment	Pneumatic nailers, drillers, routers, circular saws, jigsaws, *etc.*
Machinery	Table routers and saws, millers, thickness planers, sanders, *etc.*
Heavy Machinery	Driers, hydraulic presses, turning lathes, cranes, bandsaws, *etc.*
Automated/Robotic Machinery	Molders, feeders, robotic tables, computer controlled router, *etc.*
* Adapted from De Araujo *et al.* (2015; 2016a)	

Wood Driers

Drying is an important stage in wood processing. Jankowsky (1990) detailed that drying is a possible and viable method for the protection, against microorganism decay, of woods for construction and joinery. Jankowsky and Silva (1985) stated that rational drying of the basic material is an essential operation in the wood transformation industry, where moisture removal to a suitable content will improve dimensional stability.

Wood driers can be categorized in different ways, for example, by heating types, operation techniques, operation temperatures, energy sources, *etc.* (Simpson 1991). There is a wide range of driers with specific models for each purpose (De Araujo *et al.* 2011).

In short, wood dryer models can primarily be categorized as follows:

- Open air: drying in a dry space (Santini 1983) at a low temperature (< 50 °C) of weather exposition, whose variables are not controlled (Vital and Collom 1974). It requires good stacking for air circulation and efficient drying (Kettula 2015);
- Solar kiln: thin wooden structure with walls and roofing covered with transparent material to allow solar incidence (Santini 1981), characterized as an inexpensive way for a not controlled process based on simple operation (Bond *et al.* 2011);
- Confined within shed: weather-protected and uncontrolled wood drying, only at internal room temperature in large structures, *e.g.*, sheds, storehouses, barns, *etc.*;
- Hot air: steam-less system whose heated air is generated from burning (gas, oil, wood, *etc.*), under variable control (Simpson 1991);
- Vacuum: chamber with pressure cycles that reduce boiling water, allowing rapid wood drying at less than <100 °C (Jankowsky *et al.* 2003);
- Conventional kiln: variable-controlled drier powered by artificial heating, from 40 °C to 90 °C (Vital and Collom 1974) with or without top baffles (Bedelean 2014), which has been usually applied for hardwoods and softwoods (Wengert 2006);
- High temperature: kiln operated between 110 °C and 140°C, which results in a lumber subject to defects, but with shorter drying times (Simpson 1991), and mass losses caused by thermal degradation of cell walls (Bond and Espinoza 2016);
- Microwave: process from inside out, which produces centered heat (McLoughlin *et al.* 2003) using free water in wood. Harris *et al.* (2008) stated it reduces checks;
- High frequency: kiln with devices based on circuits up to 100 MHz of frequency band in electric current, which transfer energy to inserted material (Resch 2006);
- Dehumidification: in this process, moisture is removed by its condensing on cold coils (Wengert 2006), which is limited to 50 °C, resulting in longer drying times below fiber saturation point (Simpson 1991);
- Lamina or lamella dryer: continuous drying process on heated conveyors.

Machinery Service Life

Obsolescence of the production process is an important component of operational risk for companies (Wendling 2012). Although the business strategy of product service life is an unfair practice, since in a short time such goods will not have functionality or will become obsolete (Vieira and Rezende 2015), industrial machines are more robust, and thus, have longer service lives. De Araujo *et al.* (2016a) concluded that machine service life varies according to its size, performed activity, and operation location. According to the United States Department of Commerce (2003), the typical service lives related to housing construction are 10 years of durability for electric equipment/tools, and 16 years for hand tools/equipment, as well as industrial and heavy machinery.

Sectoral Studies on Timber Housing Construction

Sectoral surveys are important ways to identify aspects and characterize them for a complete industrial view. Before the wide research of De Araujo (2017) that generated this present article, only three studies showed reports regarding to timber housing sector.

Firstly, Sobral *et al.* (2002) presented first insights about timber housing industry from the Brazilian state of São Paulo, revealing little information about its basic aspects and focusing precisely on its wood consumption. Morgado and Pedro (2011) possibly did the first study about timber housing sector characterization, which included some details from Portuguese industrial scenario concerning to techniques, woods, costs, production, etc. Next, in a thesis about the reduction of carbon dioxide emissions in timber houses, Punhagui (2014) slightly described some impressions of this respective sector in Brazil, which detailed company profiles, raw materials, techniques, market, logistics, and clients. However, these authors did not evaluate and/or share data about machinery from timber housing sector, whose importance is strictly related to knowledge of production aspects.

Then, De Araujo (2017) developed a wide research about timber housing industry in Brazil to characterize several aspects from products, companies, and respective sector. From this observation, many approaches were possible such as the presented here and those sectoral difficulties reported by De Araujo *et al.* (2018). Thus, this present article aimed to identify the machine sizes and drying processes used by Brazilian producers of wooden housing, and their overall obsolescence throughout the 2015 yearly period.

EXPERIMENTAL

Survey Method

This study was derived from broad and unprecedented research about the wooden housing sector in Brazil. From this research, a machinery evaluation of this sector was conducted, particularly focused on machine size category and overall obsolescence.

Because of a lack of information about the wooden housing sector and different populations revealed by Sobral *et al.* (2002) and Punhagui (2014) in Brazil, a wide search started from corporate websites to prospective producers, revealing the local panorama.

Face-to-face interviews were carried out by the first author to characterize this industry through a semi-structured questionnaire, which was prepared by the first author and his advisors, and refined by sector/academic professionals. Such personal interviews were performed in face-to-face way with entrepreneurs from timber housing production sector in Brazil (De Araujo *et al.* 2018). Machinery identification and characterization according to size category (type) and overall obsolescence were the main topics studied here. To accomplish this purpose, four queries were applied to this sampling (Table 2).

Table 2. Questionnaire Queries Applied in Personal Face-to-Face Interviews

Query	Alternative
* What are the sizes of your machines applied for house production?	Hand tool; portable equipment; machinery; heavy machinery; automated/robotic machinery
* What is the overall obsolescence of these machines?	Less than a year; 1 to 3 years; 4 to 6 years; 7 to 10 years; 11 to 20 years; 21 to 30 years; more than 30 years
Does your company use any wood drying process on plant?	Yes; no; not informed
If yes in last question, what are the drying processes used on plant?	Open answers
* Based on former brief studies from De Araujo *et al.* (2015; 2016a) tested in small populations.	

Result Analyses

The production sector of wood-based housing was evaluated using simple random sampling, and the responses were converted to percentage. In this evaluation, analyses by triangulation and margin of error were used to check and statistically validate the results. Because face-to-face interviewing required time and cost for the whole personal-based survey, the inability to collect data using simultaneous interviewer(s) and different times were some limitations. Therefore, from Miles and Huberman (1994) prescriptions for data triangulation, three methods were considered here: data source from distinct people, data source from different places, and data type between comparison with qualitative and quantitative information. Next, the margin of error was estimated for this survey by the statistical software Raosoft Sample Size Calculator (Raosoft Inc., Seattle, WA, USA). Raosoft (2004) prescribed the response distribution of 50% and confidence level of 95%. If the margin is within acceptable level, the sampling is validated (De Araujo *et al.* 2018).

RESULTS AND DISCUSSION

This research reached a relevant number of the overall estimation (Table 3), with about four times more producers than the 50 companies estimated by Punhagui (2014). However, the Brazilian wooden housing sector has notably more companies than this first pertinent verification of the local scenario, which according to De Araujo *et al.* (2018) refuted Punhagui's listing. Then, 107 interviews were completely returned here, reaching a respondent rate of 93%, considering that five entrepreneurs did not want to respond this query, and three producers were not found. The margin of error of 6.65% (or ± 3.325%) (Table 3) was below the acceptable level of 10%, and almost reached the ideal level of 5%, as prescribed by Pinheiro *et al.* (2011), which statistically validated the survey.

Table 3. Evaluated Population and Survey Sampling

Result	Value (Producer)	Margin of Error (%)
Population Size (Estimated Companies)	210	–
Interviewed Sample Amount	107	6.65
Adapted from De Araujo *et al.* (2018)		

Machinery Size Categories

In the identification of best practices for wood industrialization, there is the need to comprehend the interaction between timber properties, as well as resources for their transformations into manufactured products (Lucas Filho 2004). Characterization of the tools and machines used for wood processing is an important stage for forest-timber industries, because such verification is fundamental to exploring strategies to encourage technological expansion of this chain, including whole related manufacturing sectors.

Machinery size in the wooden housing production sector was evaluated using five categories, from the most simplified of hand tools to the most complex automated and robotic machinery. Thus, this categorization allowed simplification and grouping of data collection, where a large number of machines and tools could be presented as different wood processing methods, whereas Brazilian wooden housing companies can concentrate artisanal, semi-industrial, and fully industrial processes. This strategy was also efficiently used by De Araujo *et al.* (2015; 2016a) in previous studies applied in small populations.

However, among the five categories, the hand tools and portable equipment were the most popular solutions for wood industrialization for housing, reaching presences of almost 100% (± 3.325%) in sampled companies (Fig. 1). The high popularities were explained by the light weight and compact characteristics of these industrial devices, which favor production, both on industrial manufacture plants and/or construction sites. Despite the lower robustness of portable equipment compared to larger machines, these agile solutions allow adjustments and simplified production of timber parts and elements, as well as easy transportation from a particular construction site to another one, without the need for installation of specific anchorages and/or reinforced floors.

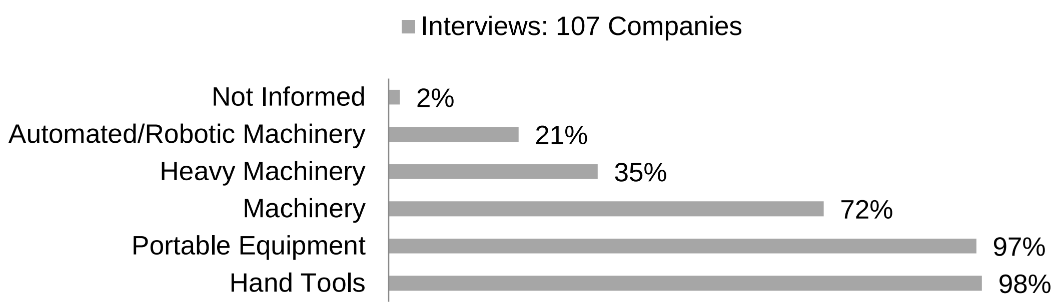

Fig. 1. Machinery size category popularity from Brazilian wooden housing producers

The machinery category – that is, those devices with a certain weight and volume, but still compact – was the third most popular solution, observed in 70% of the sector (Fig. 1). Despite the near impossibility of their transportation, which requires crane lifting and fixation on industrial flooring, such medium-sized machines were the most simplified and least costly alternatives for large-scale and serial production of prefabricated wood-based parts and elements for housing. Portable equipment is simpler and more limited in functionality compared to the machinery categories. Machinery generally has higher cost and low mobility, despite higher productivity and robustness. Companies with industrial plants – even based on simplified processes and/or activities –, manufacture houses with machinery in most cases.

Heavy machinery also demonstrated considerable popularity, with approximately 35% of the evaluated samples demonstrating its utilization and possession in their wooden housing productions (Fig. 1). This scenario indicated that more than 1/3 of the sampling studied have industrial plants to condition this option, that is, a relevant consolidated participation. This population has heavy machinery to process from compact parts to longer and massive elements for wooden housing.

In spite of the higher added technology, more than 20% of companies indicated possession of modern machinery, that is, machinery with cutting-edge technology based on any automation and/or robotics tasks. This favorable scenario already verifies that at least 1/5 of the sampling has invested in modern devices, allowing large-scale production through efficient manufacture processes (Fig. 1). This situation is diametrically different from that observed by Murara *et al.* (2013), which indicated that Brazilian sawmills still applied outdated technologies and low-yield machines. Around 2% of the sampling did not report their machinery size categories (Fig. 1), because of uncertainties or the silence option by interviewees. While log conversion into sawn wood is usual in sawmills (slats, blocks, boards, *etc*.), the most common wood processing stages for housing production are machining, cutting, drilling, finishing, as well as drying and chemical preservation.

Wood-Drying Categories

Wood drying has been largely neglected and underutilized in Brazil, and thus, this study obtained an overview about the existence and types of wood drying in the studied sector. Figure 2 shows that almost 2/3 of the companies from the wooden housing sector did not have any drying process in their plants. This situation could be explained by the need of wide physical permanent infrastructures, with hard removal for house production on building site, as well as the possible costs implied to maintain such static installations. Other justification is attributed to the fact that only few housing techniques really require dried wood such as woodframe, modular in cross-laminated timber, post-and-beam, *etc*. Traditional techniques (half-timbered frame, log-home, etc.) usually employ green wood. In contrast, about 36% (± 3.325%) of this sampling reported the existence of some drying process in their activities. No information was reported by 1% of sampling in this query.

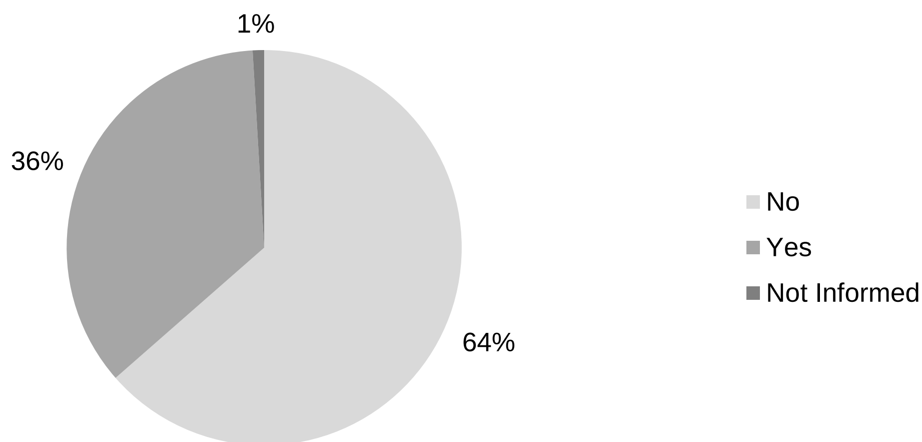

Fig. 2. Use of wood drying by Brazilian wooden housing producers

Here, 98 companies declared to dry wood exclusively by a single method (Fig. 3), whereas nine producers (about 8%) shared the utilization of two drying processes. These declarations only included the combinations of open-air with sheds or conventional kilns. In addition, from the drying processes described in the cited literature, these samples revealed that they did not have the following options (Fig. 3): solar, high-frequency, hot-air, high-temperature, microwave, and dehumidification.

Accordingly, in the companies that reported the existence of any wood drying process (Fig. 2), the open-air model was the most popular process, present in 1/4 of the samples (Fig. 3). Greater simplicity and lower cost have stimulated its greater utilization, despite this simple method, according to Susin *et al.* (2014), results in a product with higher moisture content, limiting to certain uses and requiring longer drying times.

The confined, within-shed process – without variable drying control – was the second-most common method used to dry lumber, reported by almost 1/6 of the evaluated population (Fig. 3). Because of the simple shed demand, this low-cost option has proven to be very present, particularly because of its simplicity and flexibility, since such a confined and weather-protected space could simultaneously be used both for natural wood drying and basic material storage.

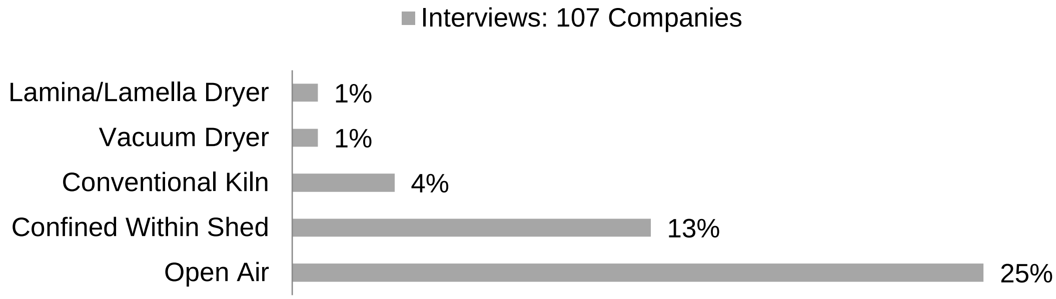

Fig. 3. Wood-drying process examples from Brazilian wooden housing producers

The primary controlled drying mode, by conventional kiln, was reported by about 4% of producers (Fig. 3). The greater economic output and the requirements for raw materials with greater mechanical strength were the main attributes used to justify its use. By rational drying under timber monitoring up to suitable moisture contents, according to Jankowsky and Silva (1985), this controlled operation offers a raw material with better dimensional stability, which, according to Zhou and Wang (2018) can provide better performance in respect to energy and saving water.

Such factors could be well-explored by this sector, introducing more processing efficiency and advantages for the final product, *e.g.*, houses. Even within controlled wood drying processes, vacuum and lamina/lamella driers were reported by nearly 1% of sampled producers (Fig. 3). The lamina/lamella process was particularly reported by a company that also manufactures plywood for its houses. According to Jankowsky (1995), the higher cost of vacuum drying has greatly restricted its industrial access.

Machinery Overall Obsolescence

Based on many of the machines and tools declared in Figs. 1 and 3, seven ranges of obsolescence were selected to categorize, on average, the machinery ages (Fig. 4).

Nearly 60% (± 3.325%) of wooden housing producers reported an average obsolescence up to 6 years. Around 15% of this sampling stated that they still owned 7- to 10-year-old tools and/or machines (Fig. 4). This declaration revealed a relatively new mechanical condition of this sector, since the service life of construction equipment is, at worst scenario according to the United States Department of Commerce (2003), about 10 years or more. Only approximately 1/5 of sampled producers declared 11- to 20-year-old equipment (Fig. 4). Some companies still had production devices within the expected obsolescence, whereas the United States Department of Commerce (2003) determined 16-year service life for portable equipment and heavy- and medium-sized machinery.

In contrast, only 6% of the sampling had machines in fully obsolete conditions (Fig. 4), that is, above 20 years, respecting prescriptions of this aforementioned American agency. The recent condition of approximately 75% of studied sector with machinery under the prescribed minimum service lives (Fig. 4), revealed an opposite situation to the Brazilian sawing industry. Sawmills are the main force in wood machining and processing, and often use poorly maintained and obsolete equipment (Vital 2008). In short, the obsolescence scenario indicated that the wooden housing sector concentrates relatively recent machinery and equipment. Concomitantly, Frayet *et al.* (2007) stated that forest product companies need to re-engineer their organization processes and business practices with their partners to reach efficiency levels through new technologies.

From the foregoing, this study enabled recent information about the aspects and condition of machinery from wooden housing production sector in Brazil, which could identify that such sector has new equipment compared to local forestry and sawing industries.

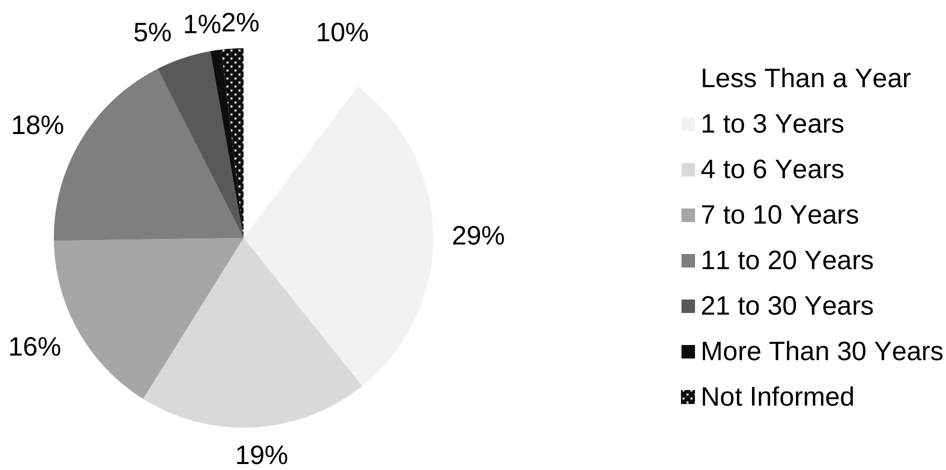

Fig. 4. Overall machinery obsolescence from Brazilian wooden housing producers

CONCLUSIONS

1. Brazilian wooden housing producers showed a near absolute positive attitude toward hand tools and portable equipment, whose presence reflects in production opportunity based on lower industrial levels. A visible sample reported the possession of robotic and automated machines, which are based on efficient technologies for prefabrication.
2. In contrast, most of the studied companies did not have any drying process at the plant. This was justified by the need of static physical infrastructure for large kilns, and respective installation and/or the demand of dried wood only by modern housing as woodframe, modular, *etc.* But, a considerable portion of the sector dried wood with simplified methods, that is, in open air and/or confined by sheds and raw material storages. Few producers reported drying wood using controlled processes (*e.g.*, kilns), which are important to offer more stable and durable parts/elements for construction.
3. The low overall obsolescence consonant with service life from most samples resulted in greater utilization of compact, portable and/or medium-sized equipment, which are smaller and less expensive than heavy machinery commonly found out in sawmills.
4. The favorable economic scenario of lower costs can encourage this sector to maintain recent equipment and, simultaneously, to stimulate the opening of new businesses.

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