CAN TIMBER HOUSES BE PRODUCTIVELY FASTER TO BUILD THAN OTHER BUILDINGS?

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ABSTRACT – To identify the time spent with the different construction techniques of timber houses, this study evaluates the execution time of different models available in Brazil. Using face-to-face interviews, semi-structured questionnaires were randomly applied to collect average time according to distinct production methods. The most efficient techniques were: 'clapboard and wainscot', 'post-and-beam', and 'log-home' using artisanal production; 'clapboard and wainscot', 'stick framing with masonry', and 'post-and-beam' in semi-industrial process; and, 'modular for building sites', 'modular in cross-laminated timber' and 'modular woodframe' in industrial production. Different industrial developers were not as agile as artisanal competitors due to production obstacles in customized projects. Timber construction offers lower execution time than masonry, representing an agile form to build a versatile sustainable dwelling.

Keywords: Building time; timber; construction sector.

AS CASAS DE MADEIRA PODEM SER PRODUTIVAMENTE MAIS RÁPIDAS DE CONSTRUIR QUE AS OUTRAS CONSTRUÇÕES?

RESUMO – Para identificar o tempo gasto com as diferentes técnicas de construção de casas de madeira, este estudo avalia o tempo de execução de diferentes modelos disponíveis no Brasil. Utilizando entrevistas face-a-face, formulários semiestruturados foram randomicamente aplicados para coletar o tempo médio de acordo com distintos métodos de produção. As técnicas mais eficientes foram: 'tábua e mata-junta', 'pilar-viga' e 'casa de toras' utilizando produção artesanal; 'tábua e mata-junta', 'paliteiro com alvenaria' e 'pilar-viga' em processo semi-industrial; e, 'modular para canteiros de obras', 'modular em madeira laminada colada-cruzada' e 'entramado leve modular' em produção industrial. Diferentes produtores industriais não foram tão ágeis como seus concorrentes artesanais devido aos obstáculos produtivos em projetos customizados. A construção em madeira oferece um tempo produtivo mais baixo que a alvenaria, representando uma forma ágil para construir uma moradia sustentável e versátil.

Palavras-Chave: Tempo de construção; madeira; setor construtivo.

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1. INTRODUCTION

Nations have tried to replace, partially or totally, the environmentally unfriendly mineral-based products for healthy timber building alternatives towards rationalized uses of renewable inputs, low waste generation, higher production standardization, and shorter production time.

In Brazil, timber construction has been more evident in regions with expressive forestry activities and cultures influenced by immigrants. But, Brazil does not have development plans and public policies to stimulate their consumptions and productions as evaluated by De Araujo et al. (2018c; 2019b). This national disarticulation was analyzed by Hersen et al. (2019), who found that there are no integrated actions to contribute to the sustainable development of the states and, above all, the whole country. Therefore, there is an urgency to review and acquire knowledge of innovative techniques in order to modernize the construction industry, affording good quality and facilitating housing acquisition (Vasques and Pizzo, 2014).

Timber concentrates decent attributes as material rationalization due to the prefabrication, water-free plant processing and rapid production, having a cleaner construction site (De Araujo et al., 2016a,b; De Araujo, 2021). Wood allows the assembly of prefabricated parts, with easy handling by workers, in less time than conventional building systems, reducing investments and costs, and intensifying labor use (Shimbo and Ino, 1997). For safe and useful uses in structures, wood may be strength graded and properties must be available for users, which satisfies different building codes and regulations (Moya et al., 2015; Görgün and Dündar, 2018). Aesthetically, wood offers multiple combinations of colors and designs for product finishing (Costa et al. 2021).

In Brazil, the timber housing market has presented a visible production volume, whose distribution permeates substantial trades towards domestic extensions (municipal to interstate regions) and moderate exportation for Africa, Europe, and other regions (De Araujo et al., 2020c). This domestic sector has a natural potential to contribute to foreign trade in the future.

But, for the admission and survival in competitive international markets, there are some requisites regarding increases of logistical support for production and utilization of wood-based materials, decreasing the time losses in the development of new products, and decreasing the time required for production of goods (Matičević and Lovrić, 2007). Globally, the timber housing industry needs to be prepared for fierce competition among many countries and competitors, especially large contractors from traditional markets.

Conclusion time, team coordination, technical quality of projects, changing costs, and building durability have emerged as the main factors that affect any construction project (Duarte and Cordeiro, 1999). Thereby, the deadline fulfillment is a constant concern for project managers and companies (Berssaneti et al., 2016), since time is closely related to size and cost of any building (Bromilow, 1969; Hegazy, 1999; El-Karim et al., 2017). In general, the conclusion time can be defined by that execution period from site preparation to building finalization, excluding non-integrated recreation areas, gardening, and other factors unrelated to this main building.

In construction, time is the amount required to complete the works within the stipulated period, from the feasibility study and project to the final conclusion, which is directly influenced by expenses with building inputs, services and financial transactions (Andrade and Souza, 2003).

The construction time can be well-established by the reduction of workflow variation, or even by a sequence of predictable workflow (Howell and Koskela, 2000). Thus, industrialization levels could directly influence the global execution time of housing construction. Therefore, the conclusion time is very important as a construction variable for measurement and control, since higher costs are caused by delays resulting from project and production errors – these facts were confirmed in different studies such as Olawale and Sun (2010), Singh (2010), Polat et al. (2014), Larsen et al. (2016), Samarghandi et al. (2016), Senouci et al. (2016), Adam et al. (2017), Aljohani et al. (2017), Bauer et al. (2017), Raman et al. (2019), Ilyas and Ullah (2020), Carvalho et al. (2021), Chandragiri et al. (2021), Sharma et al. (2021), Gashaw and Jilcha (2022), and other numerous publications. Regardless of construction raw materials and techniques, the production and assembly temporal values are essential factors for the efficiency and feasibility of building processes, which can affect global costs, positively or negatively.

Timber houses can be obtained from different production systems, which differ in work volume performed on industrial plant and/or on construction site (Piqué Del Pozo, 1984). Regarding possible groups, three production systems of timber construction could be assumed, for example, artisanal, with part manufacturing made solely on construction site; semi-industrial, which involves mixture of parts production in plant and on site; and industrial, with all processing operations on industrial plants (De Araujo et al., 2016c). From these production types, the verification of execution time of timber techniques can typify the most efficient houses under temporal perspectives.

This study aims to compile total execution time values of houses produced by the Brazilian timber housing sector in order to delimit, according to typical production system of each developer (artisanal, semi-industrial or industrial), the interval spent on each available construction technique. The following hypotheses were analyzed: in the production perspective, timber houses can be more efficient in the execution time than traditional techniques for housing; and, regardless the production, timber houses are more efficient than masonry houses.

2. METHODOLOGY

2.1. Literature prospection about execution time for construction techniques

The previous identification of execution time was driven by literature prospections. Initial process was carried out using randomized searches on the ‘Google’ engine.

Further prospections were performed using other two alternative search engines, ‘Google Scholar’ and ‘Portal Periodicos’ by CAPES (Coordination for the Improvement of Higher Education Personnel) – the latter is a scientific database from this Brazilian educational agency, which include journals of the main publishing companies such as Springer-Nature, de Gruyter, Taylor & Francis, Elsevier, Wiley, Oxford, Emerald, Sage, Maney, and others. These secondary searches regarded specific keywords. First, the ‘house execution time’ expression was inserted initially. Jointly, seven single strings were utilized along with two Boolean operators (AND/OR): ‘execution time’, ‘house’, ‘housing’, ‘building’, ‘construction’, ‘month’ and/or ‘day’. This procedure was repeated for the Portuguese terms, which included: ‘*tempo de execução*’, ‘*casa*’, ‘*habitação*’, ‘*edificação*’, ‘*construção*’, ‘*mês*’ and/or ‘*dia*’. From this dual language consideration, documents from all over the world were considered.

2.2. Company prospection

Timber housing developers were considered as the main research material to collect data about the execution time of each construction technique available in Brazil. Initially, a sectoral listing was created using internet-based prospections to search the official websites for each timber housing developer.

There are corporate representatives of the timber housing sector in all macro-regions of the Brazilian territory – as De Araujo et al. (2019a) identify 64 companies in the Santa Catarina state, 49 in Rio Grande do Sul, 37 in São Paulo, 29 in Paraná, 13 in Minas Gerais, 8 in Rio de Janeiro, 4 in Espírito Santo, 2 in Distrito Federal, 2 in Rondônia, 1 in Amazonas, and 1 in Ceará. In fact, this sector is perceptibly distributed in the South and Southeast macro-regions, since just over 97% of all Brazilian developers are located in the seven states from these macro-regions.

For reasons of insignificance of sectoral representativeness and economic infeasibility for the road displacements to the North and Northeast regions, the survey prioritized those federative states with intense corporate representations, which were marked by states located in the southern cone of the Brazilian territory. Thus, only a sparse portion of 2.9% of the sector was not regarded.

2.3. Company participation

All entrepreneurs had the formal opportunity to participate in the interview process, as the interviewer actively participated in several sectoral events that would allow data collection from companies in more distant regions. This alternative route for interviews allowed, for example, the formal participation of a company located in the Distrito Federal in the Midwest region.

Every company located in the South and Southeast macro-regions was initially contacted and invited by phone to participate in this survey. Face-to-face interviews were represented by a randomized sampling, whereas each process of data collection strictly depended on the effective motivation and availability of each entrepreneur.

2.4. Interviews about execution time for timber construction techniques

Using the survey strategy performed by De Araujo et al. (2018a; 2018b; 2018c; 2019a; 2019b; 2020a; 2020b; 2020c), the methodological route included the application of face-to-face interviews driven by a semi-structured questionnaire for dozens of major topics, including this unprecedented approach to identify execution time of timber housing construction techniques.

To develop a query to identify execution time per technique, some considerations were done. The Brazilian standard document ABNT NBR 12721:2006 establishes an equivalent area of 99.47 m^2 and a real area of 106.44 m^2 for medium-sized houses.

Thus, the questionnaire considered the evaluation of a medium-sized single-family house with 100m^2 of built area as a standardized parameter. All evaluated developers were required to share an average value per technique, which includes the total production of a timber house in this conditioned built area. Temporal values on project drawings, permissions, gardening, recreation areas, and other factors unrelated to housing production were not considered due to regional peculiarities and lacks.

The questionnaire was formed by the following question: '*what is the execution time of your company for a single-story housing unit of 100m² for each timber construction technique?*'. Objective responses were numerically shared by the sampled companies. All responses were openly collected using the variable of the period measured in days to obtain a finished housing unit. The construction system indicated by production method was obtained by the interviewer (general manager) as a main factor to organize average time values declared by the respondents.

2.4.1. Statistical analyses

The margin of error regarding the sampling process was thereupon estimated using the online software Raosoft (2004) and its calculation prescriptions. Numerical results were statistically analyzed through t-test by two-to-two verification. Sampling and normality were randomly admitted with the independence of samples. The evaluation still admitted two hypotheses of equivalent means (H_0: $\mu_1 = \mu_2$) and not equivalent means (H_1: $\mu_1 \neq \mu_2$). The P-value of each analysis rejected each hypothesis for

Table 1 – Execution time of main housing examples.
***Tabela 1** – Tempos de execução dos principais exemplos habitacionais.*

Housing Technique	Production System	Built Area (m^2)	Average Time (day)	Country	Source
Conventional Masonry	Artisanal production from a single builder	100	200*	Brazil	Lima et al. (2015)
Conventional Masonry	Artisanal production of a small company	–	151	Mexico	Solís-Carcaño et al. (2017)
Structural Masonry	Artisanal production of small company	100	152	Brazil	Bianchi et al. (2021)
Concrete-stabilized Rammed-earth	Artisanal production of small company	91 / 100*	274 / 301*	Portugal	Marques et al. (2021)
Precast Concrete	Artisanal production	100	115	Peru	Aquise et al. (2021)
Steelframe	Industrial prefabrication	100	134	Brazil	Bianchi et al. (2021)
Timber Post-and-beam	Industrial prefabrication	100	60	Brazil	Antunes (2003)
Platform-type Woodframe	Industrial prefabrication	200 / 100*	60 / 30*	Brazil	Molina and Calil Jr (2010)
Glulam-based Modular	Industrial modulation	130 / 100*	135 / 104*	Portugal	Torres (2010)

* estimated times from literature for the consideration of a 100m^2 single-story house.
** tempos estimados a partir da literatura para a consideração de uma casa térrea de 100m².*

mean equality, which did not reach 5% significance ($P < 0.05$).

3. RESULTS

3.1. Outcomes of literature prospection about execution time for construction techniques

This initial part refers to a compilation of the available literature on the amount of time it took to execute different construction techniques as a strategy to elucidate and contradistinguish this topic. The use of three search engines and the verification by dual language prospections were utilized to prospect technical and scientific data about execution time of timber buildings.

From random searches on the 'Google' engine, some information about execution time for housing production was identified for the raised perspective, although those searches of this initial prospection were disregarded in line with the suggestions of a blind-evaluator of this study due to the unscientific nature of the data found. In view of this, the prospection procedures were restarted using other two scientific databases, 'Google Scholar' and 'Portal Periodicos'. Several studies were delivered in both engines, but little information was found to be related to execution

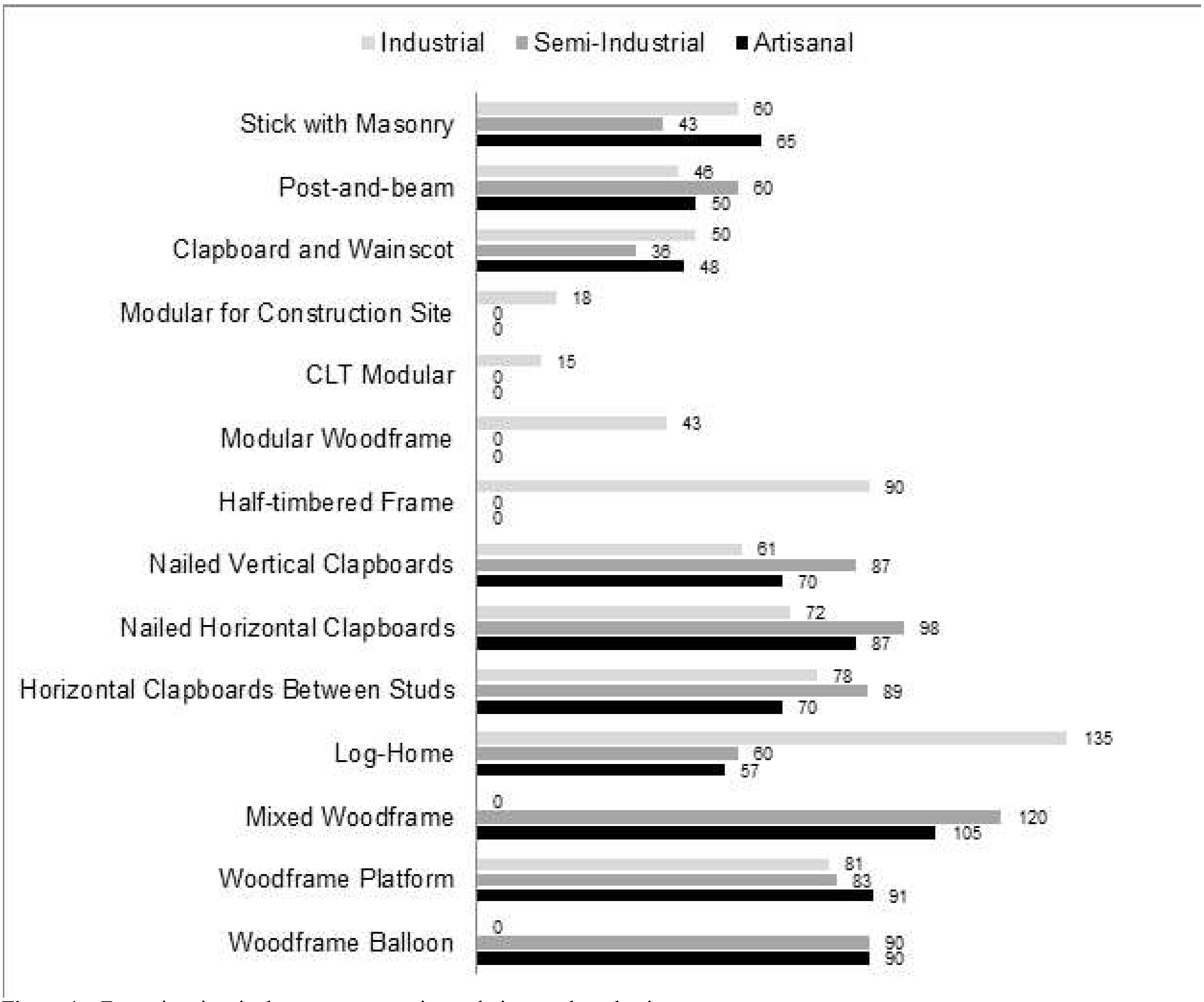

Figure 1 – Execution time in days per construction technique and production system.
Figura 1 – *Tempos de execução em dias por técnica construtiva e sistema produtivo.*

time of timber housing construction. These rare studies prospected are identified in the Table 1.

Execution time is a very important subject for buildings. Each construction technique has a singular time and demand, which depends on its production system. Silva (2013) remarked that mechanization directly influences the factors of construction production. In this sense, building speed is a relevant attribute of houses with engineered wood products (Cvetković et al., 2015).

As masonry is the most popular construction technique in Brazil as cited by Sabbatini (2003), this study regarded it as the main parameter to compare with timber techniques (Table 1).

3.2. Outcomes of company prospection and participation

From a sector formed by 210 companies, 107 developers were successfully interviewed with a 50.95% response rate. Considering the 205 companies contacted by phone, a 52.20% response rate was obtained for a macro-region formed by the South, Southeast and Midwest states. From the Raosoft (2004) statistical software, the sampling reached a ±3.325% margin of error for the studied sector – this sampling error satisfies the acceptable condition of ±5.00% (10%) and is close to the ideal condition of ±2.50% (5%) prescribed by Pinheiro et al. (2014).

Our sample outperformed the precepts of Dworkin (2012) practically four times over, since 25 to 30 participants are recommended for a minimum sample size to meet redundancy and saturation in scientific studies by in-depth interviews. Compared to other serious sectoral surveys with face-to-face interviews for timber and forestry sectors (Toppinen et al. 2011; Holopainen et al. 2015; Wan et al., 2015; Giesekam et al., 2016; Wan et al., 2017; Hurmekoski et al., 2018; Toppinen et al., 2018, Arvola et al., 2019; Toppinen et al., 2019; D'Amato et al., 2020; Karjalainen et al., 2021; Niu et al., 2021; Viholainen et al., 2021, and Zhu and Lo, 2021), our sampling was satisfied and results were validated due to a notable participation of respondents.

3.3. Outcomes of interviews about execution time for timber construction techniques

Figure 1 shows multiple results for 100m^2 single-story houses, whose total time values were grouped by timber-based construction technique and production system. In general terms, 'cross-laminated timber modular' was the fastest technique, which is featured by a high industrialization. Technologically simpler, 'clapboard and wainscot' was the fastest technique in other production types.

Due to the stratification of execution time per technique and production type (Figure 1), this study

Table 2 – Execution time of main construction technique examples for housing.
Tabela 2 *– Tempos de execução dos principais exemplos de técnicas construtivas para a habitação.*

Timber-based Housing Technique	Global Time (day)	Standard Deviation
Balloon Woodframe	90.00	0.0000
Platform Woodframe	85.26	57.7945
Mixed Woodframe	110.00	17.3205
Modular Woodframe	43.33	20.8167
Log-Home	83.33	49.2612
Horizontal Clapboards Between Studs	84.18	38.1460
Nailed Horizontal Clapboards	85.80	35.0039
Nailed Vertical Clapboards	74.90	29.7492
Half-timbered Frame	90.00	*
CLT-based Modular	15.00	*
Modular for Construction Site	18.40	4.2190
Clapboard and Wainscot	44.55	14.7402
Post-and-beam	51.36	30.7482
Stick with Masonry	58.13	53.9800

* did not share standard deviation values due to sampling of a single company per technique.
** não compartilharam valores de desvios padrões devido a amostragem de uma única empresa por técnica.*

showed different scenarios available in Brazil. Data organized by production system limited a sampling by construction model, as repetitions per technique were reduced in this wider approach. In response to this limitation, the study exhibits a scenario about global execution time per technique without the representation by production type. From average total values, this strategy supported the statistical analysis by t-test at two-to-two trials. The missing values of standard deviation do not represent a weak sampling, as they refer to a very limited number of producers in operation. 'Cross-laminated timber modular' was the fastest technique (Table 2).

4. DISCUSSIONS

4.1. Discussions of interviews about execution time for timber construction techniques

In theory, and especially in practice, the mechanization contributes to shorter production time for construction (Silva, 2013). But this condition was not properly satisfied in this sectoral survey. Some unexpected facts are identified by Figure 1, because only 'platform woodframe' exhibits shorter time according to the increased mechanization of its production system. For situations in which the artisanal production was similar or faster than semi-industrial variant of the same technique, there is an evident justification by the mixed existence of two or more processes, and possibly different work teams, in operation to produce buildings under the responsibility of only a single company.

Therefore, production delays and management flaws between distinct teams allowed unexpected execution time for semi-industrial systems. Three techniques surprisingly registered longer time for the industrialization compared to artisanal production. This fact was marked by companies focused on high-class custom projects, whose development process is slow due to owners' diverse demands and wishes to add new insertions.

In another observation, the 'stick with masonry' and 'half-timbered frame' techniques have similarities to conventional masonry houses, since their walls are produced, partially or almost integrally, with bricks and cement. The perceptible contrast is confirmed by framing structures, because timbered examples utilize timber parts as structural frames and masonry uses a concrete-metal frame. From this conceptualization, 'stick frame with masonry' technique was more agile than masonry in each production system under analysis (Figure 1, Table 1); specifically, this comparison was established under different construction examples cited by literature (Table 1), which included techniques from different materials, productions and national origins.

On proportional terms relative to artisanal production, the 'stick with masonry' technique was more efficient than masonry examples, because this timber-based technique consumes only 33% of total execution time of a conventional masonry house required by a single builder in Brazil and 43% of period spent by a small-sized company in Mexico – that is, 67% and 57% more rapid. Still, stick with masonry is 57% and 44% faster than structural masonry produced in Brazil and precast concrete produced in Peru, respectively. In the specific stratum of timber techniques (Figure 1), 'stick frame with masonry' is among the most efficient examples. 'Half-timbered frame' technique is also more productively faster than conventional masonry (Table 1, Figure 1), since this timbered example utilizes only 45% and 60% of total time spent for the completion of masonry houses in Brazil and Mexico, respectively. Also, the 'half-timbered frame' technique requires 41% and 22% less execution time than Brazilian structural masonry and Peruvian precast concrete.

A very efficient execution time was obtained in this comparison – because Weimer (2005) determined that the 'half-timbered frame' is among the oldest housing techniques, which is known by a high complexity of assembly and the presence of woodworking joints without screws absence. This literature statement was also confirmed by Figure 1, due to the long period of time demanded for a more complex production.

In this same concept of freestanding framing, the 'post-and-beam' technique formed by timber-based structural parts and walls with intense mixed uses of wood and glass materials. 'Post-and-beam' is among the most efficient timbered techniques in the artisanal process, since this technique is 75% and 67% faster than conventional masonry houses in Brazil and Mexico, respectively. Still, 'post-and-beam' utilizes only 67% and 57% of the artisanal-based productions required by structural masonry and precast concrete construction techniques (Table 1, Figure 1). The industrialized 'post-and-beam' requires (Figure 1), in practice, only 77% of the complete period to build this technique in Brazil according to the expectation described by the literature (Table 1). Also, the 'post-and-beam' technique needs only 66% of the time required to build a light-steelframe in Brazil.

For the 'clapboard and wainscot' technique, the shortest execution time was observed in the semi-industrial production. Also, this wood-based technique demonstrates a similarity of the values obtained for industrial and artisanal systems (Figure 1), although the artisanal production of this technique is 4% faster than industrialized manufacture – despite the apparent contradiction, this fact may be justified by the evident technological simplicity as suggested by Hoffmann and Pelegrini (2009), whose technique requires simpler productions towards the utilization of lumber parts and metal nails for walls and frames. Without respect to a specific type of production (Figure 1), its three production types are efficiently rapid compared to most other timbered techniques. More compact companies with leaner productions possibly influenced this greater efficiency in the face of other construction examples. In terms of artisanal production, the execution time verified for 'clapboard and wainscot' technique is more temporally agile than artisanal productions of conventional and structural masonry in Brazil (76% and 68%), conventional masonry in Mexico (68%), and precast concrete in Peru (58%). The industrialized version of 'clapboard and wainscot' requires only 63% of this temporal parameter in relation to the Brazilian light-steelframe (Figure 1, Table 1).

The 'double walls of nailed clapboards' construction technique is available both in vertical and horizontal orientations of external walls, represented by purely aesthetic reasons. In general terms, vertical style took less execution time than horizontal variant (Figure 1). This efficiency is justified by the greater demand of shorter pieces for vertical-oriented variety, since smaller and lighter lumber parts are quickly handled by workers. Both 'nailed clapboard' techniques were in the group of the slowest productions (Figure 1), since these examples demand more time to be customized and developed. This fact was justified by De Araujo et al. (2019a), since both construction varieties have been directed to finer chalets and vacation cottages. In the scope of artisanal production (Table 1), both horizontal- and vertical-oriented versions are, respectively, 57% and 65% more temporally rapid than Brazilian conventional masonry, or even, 42% and 54% more than Brazilian structural masonry and Mexican conventional masonry, and 24% and 39% more than Peruvian precast concrete. From the industrial point of view, horizontal and vertical versions are, respectively, 46% and 55% faster than Brazilian light-steelframe (Figure 1).

The 'horizontal clapboards between studs' construction technique is formed by clapboards joined together with tongue-and-groove joints and stabilized laterally by notched studs (De Araujo et al. (2016c). Robust parts are the main lumber inputs, requiring intense handling and greater infrastructure to prefabricate parts – which are no existent in nail-featured houses. As expected (Figure 1), it needs more time than other techniques based on light-weight lumber such as 'clapboard and wainscot' or 'nailed vertical clapboards'. Thus, the 'horizontal clapboards between studs' technique is, respectively, 23% and 62% slower than 'post-and-beam' and 'platform woodframe', and 42% faster than light-steelframe under a Brazilian perspective of the industrial production. But, its artisanal variation is faster than conventional masonry examples from Brazil (65%) and Mexico (54%), structural masonry from Brazil (54%), and precast concrete from Peru (39%) (Table 1, Figure 1).

An exceptional situation was noted in 'log-home' technique, whose industrial production requires more execution time than semi-industrial and artisanal models (Figure 1). This reverse situation was attributed to two factors. Initially, few producers have been directed to industrial production in plants, since Brazil does not present machinery suppliers effectively specialized to subsidize technology for 'log-home' developers. This contrast is also linked to different aesthetic ends; for example, there is a common practice where 'log-homes' can be intensively customized in relation to exceptional projects for higher-class clients as cited by De Araujo et al. (2016c). Thus, a slower process was expected to get a 'log-home' construction in Brazil due to the processing and assembly of robust parts. Industrial-based manufacture of the 'log-home' technique is more rapid than conventional masonry

(33% in Brazil and 10% in Mexico), requires a similar period to light-steelframe, and yet, it is 23% and 56% slower than Portuguese 'glulam-based modular house' and Brazilian 'post-and-beam' as mentioned by the literature, respectively. Its artisanal variation is perceptibly faster than all examples from literature, as this variety requires only 29% and 38% of execution time needed to produce conventional and structural masonry models in Brazil, respectively (Figure 1, Table 1).

Despite promising markets, three modular techniques integrally produced on industrial plants are already available in Brazil: 'modular for construction sites', 'modular woodframe' and 'CLT-based modular'. As predicted, they were confirmed as the faster solutions for timber houses (Figure 1). In the comparison with the literature (Table 1), the production of 'CLT-based modular' construction technique is 86% and 75% faster than its similar Portuguese version and Brazilian timbered 'post-and-beam', respectively. The 'modular woodframe' technique is 30% slower than 'platform woodframe' and this same modular variety is 59% faster than the 'glulam modular' technique from Portugal. Due to a less definitive feature and intense utilization of lighter and shorter parts, the 'modular on construction site' is faster than all literature examples, specifically, with time efficiencies about 40% ('platform-type woodframe'), 70% timbered 'post-and-beam', and 83% (Portuguese 'glulam modular'). Compared to light-steelframe (Table 1), three modular techniques are visibly more rapid, specifically, in 68% (woodframe variety), 87% (construction site variety), and 88% (CLT-based variety). Despite the contrasting production features, three modular-based techniques are evidently much faster than all artisanal-based masonry types, whether from Brazil or Mexico (Figure 1, Table 1). In regards to the 'glulam modular', it achieves greater efficiency than application in large buildings – since Wells (2011) cited that this technique typically reduced 30% of execution time in relation to other construction examples; its high efficiency is ensured by modulation operations for assembly, storage and transport (Estévez Cimadevila et al., 2013).

The 'light-woodframe' technique was a relevant wooden construction in evaluation, since its popularity was represented by four varieties. The modularized example is at the top of the industrialization scale – this range is given by the volumetric prefabrication of modules, prefabrication of engineered parts and machined standardized timber as mentioned by De Araujo et al. (2016c). Using this consideration, the industrialization scale of 'light-woodframe' technique is decreasingly formed by the following varieties: 'modular', 'platform', 'balloon', and 'mixed'. Outcomes confirm the main expectation, because 'modular' was the fastest technique. Also, 'platform-based' example is more rapid than 'balloon' (8%) and 'mixed' versions (30%) in the semi-industrial production as well as it was 1% slower than 'balloon' and 13% faster than 'mixed' in artisanal process (Figure 1). As 'platform technique' is the streamlined and rationalized version of original type of 'balloon', this former example did not present an industrial production. 'Mixed' variety blends processes and technologies, although it presents a lower industrialization. In addition, the execution time of industrial-based 'platform woodframe' was 63% slower than this version cited by the literature – with a time allotted for a modern production. Despite their similar features on the industrialization process, 'platform woodframe' technique is 40% faster than light-steelframe. All 'light-woodframe' varieties in their different production types are more temporally agile than Brazilian and Mexican masonry houses – specifically, 'platform' variety, which is popular in Brazil, requires only 46%, 42% and 41% of the execution periods for masonry houses nationally produced (Figure 1, Table 1).

Lastly, all timber-based techniques are productively more rapid than concrete-stabilized rammed-earth produced in Portugal using artisanal processes (Figure 1, Table 1). This slowness is the result of the mud curing required after the building completion. According to Gupta (2014), this curing process needs an additional month to dry soil-based walls stabilized with cement.

In the case of timber-based techniques, some aspects may have contributed to slowness beyond expectations. Several developers reported to the interviewer some delays attributed to, for example, processes and techniques with dissimilar execution time due to distinct technology and flexibility levels, procurements from multiple material suppliers marked by different logistics and deadlines (and why not delays?), and dependence on different partners and operation teams with complex strategies and inexorable routines. For luxury construction developers, there is still the possibility of delays about timber procurement, since these buildings usually require native wood species from remote regions in northern Brazil. This process time is influenced by rainy seasons in the log extraction, slow legalization bureaucracies, and inefficient logistical operations limited by road transport and poor infrastructure (mud and bumpy roads). Simultaneously, the requests for larger logs and rare woods also contribute to longer time in the finest construction solutions such as the 'post-and-beam', 'nailed clapboards' (horizontal and vertical styles), 'horizontal clapboards between studs', 'half-timbered frame', and 'log-home' techniques. As a result, some developers took longer than expected to complete houses despite their higher industrialization levels. In terms of production, the findings may be regarded by all global developers, as the execution time showed by the Figure 1 may serve as a strategic factor to improve performance through time reduction.

From global averages (Table 2), t-test identified rejection of hypothesis of equality H_0 between means for the following comparisons: 'balloon woodframe' in relation to 'modular woodframe', 'modular for construction site', and 'clapboard and wainscot'; 'platform woodframe' with respect to 'modular for construction site', and 'clapboard and wainscot'; 'mixed woodframe' ('modular woodframe', 'modular for construction site', 'clapboard and wainscot', and 'post-and-beam'); 'horizontal clapboard between studs' ('modular for construction site', 'clapboard and wainscot', and 'post-and-beam'); 'log-home' ('modular for construction site', and 'clapboard and wainscot'); 'nailed horizontal clapboards' ('modular woodframe', 'modular for construction site', 'clapboard and wainscot', and 'post-and-beam'); 'nailed vertical clapboards' ('modular for construction site', 'clapboard and wainscot', and 'post-and-beam'); 'modular woodframe' ('modular for construction site'); and, 'modular for construction site' ('clapboard and wainscot', and 'post-and-beam'). Other two-to-two tests showed similarities in their means, that is, the P-value of each analysis was greater than 5%. It was justified by the existence of a single producer of 'half-timbered frame' and 'CLT-based modular' techniques.

In the observation of the standard deviations (Table 2), it is worth mentioning that:

- Missing values correspond to those techniques with a very limited volume of developers, for example, a single company, which restricts the sampling to two conditions: evaluation or no-evaluation of the rare availabilities ('half-timbered frame' and 'CLT modular');

- High values refer to those techniques with a small number of producers (modular and mixed woodframes) or contrasting conditions in relation to production technology and machinery ('platform woodframe', 'post-and-beam', 'horizontal clapboards between studs', 'nailed horizontal/vertical clapboards', 'stick with masonry', and 'log-homes');

- Mean and low values are formed by techniques with lower dispersions, that is, a greater homogeneity in the execution time measured for a same technique ('mixed woodframe', 'balloon woodframe', 'modular for construction site', and 'clapboard and wainscot').

Even with timely statistical orientation in the global view (Table 2), the perspective by production system enables a practical scenario (Figure 1), since it demonstrates the highest:

- Efficiencies in artisanal option: 'clapboard and wainscot', 'post-and-beam', and 'log-home';

- Efficiencies in semi-industrial option: 'clapboard and wainscot', and 'post-and-beam';

- Efficiencies in industrial option: all modular-based construction techniques;

- Inefficiencies in artisanal option: 'mixed', 'platform' and 'balloon' woodframe varieties;

- Inefficiencies in semi-industrial option: 'mixed woodframe', and 'nailed horizontal clapboards';

- Inefficiencies in industrial option: 'log-home' and half-timbered frame'.

In short, two perspectives are important to ensure detailed and reliable assays – that is, with data stratification to detail values per production system (Figure 1) and data grouping to allow the statistical analysis per average value of timber housing technique (Table 2).

Future directions may be followed in new research contributions as alternative strategies to develop the Brazilian market of timber houses – whose sector has the predominance of small- and medium-sized companies as ascertained by De Araujo et al. (2018b). A future continuation could be established by measuring *in loco* of execution time in a sequence of similar parameters to verify improvements over time as well as to check them in relation to the results reported here.

5. CONCLUSIONS

All timber construction techniques reached very efficient execution time compared to conventional and structural masonry examples made in Brazil and Mexico through artisanal processes. Regardless of production system (artisanal, semi-industrial and industrial), all timber techniques made in Brazil were faster than masonry varieties and rammed-earth technique. Due to significant sampling and a low margin of error, this finding minimizes speculative arguments related to worst execution time of timber housing techniques in relation to masonry examples. Yet, a considerable part of timber techniques are also more agile than other techniques cited by the literature. Given as rapid construction alternatives by the traditional mineral-oriented industry, precast concrete and light-steelframe are perceptibly slower than most of timber-based techniques. In practice, both hypotheses are satisfied and therefore confirmed.

Thus, the present analysis evinces a favorable perspective of domestic timber housing production relative to time execution, both in higher and lower industrialization levels. Positive outcomes of all timber housing techniques in their different types of production over traditional techniques, clearly supported by this representative sectoral survey, may be utilized to emphasize execution time as an advantageous feature of timber construction.

Henceforth, the time allotted to produce a timber house, regardless its construction technique and production type, may be mentioned as a positive attribute of timber buildings, since woods already surpass minerals in terms of resource renewability, carbon dioxide fixations, and production rationalization.

AUTHOR CONTRIBUTIONS

The manuscript is a complete chapter of the direct-doctorate thesis of the first author under the supervision of the last author. Victor Almeida De Araujo: Conceptualization, Methodology, Data collection and organization, Interviewing, Bibliographical research, Data analysis, Software, Investigation, Data processing, Visualization, Writing, Writing-Reviewing, Text organization and translation, and Editing. Juliano Souza Vasconcelos: Data analysis, Software, Data processing, and Statistical analysis. Juliana Cortez-Barbosa: Bibliographical research, Writing-Reviewing, and Editing. Elen Aparecida Martines Morales: Methodology, Software, Data processing, Statistical analysis, and Writing-Reviewing. Maristela Gava: Co-supervision, Conceptualization, Methodology, Data analysis, Visualization, Text organization, Writing-Reviewing, and Editing. José Nivaldo Garcia: Supervision, Conceptualization, Methodology, Visualization, Text organization, Writing-Reviewing, and Project management. All authors approved the final version of the manuscript.

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