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PRELIMINARY INVESTIGATION ON SAFETY PERFORMANCE OF CLT WALL PANELS UNDER IMPACT AND SUSPENSION TESTS

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ABSTRACT: Cross-Laminated Timber (CLT) panels are a relatively new construction element of the international construction industry. In Brazil, the manufacture of this technology started about ten years ago. The use of this innovative construction element in the country is still limited. For this reason, many of those who are first introduced to the material express several doubts regarding its applicability. Thus, this paper sought to analyse this type of panel in terms of safety performance, as this is the fundamental requirement of any building and one of the essential premises to guarantee its stability, as well as the safety of the user. The proposed verification was carried out according to the Brazilian technical standard ABNT NBR 15575:2013 – Residential Buildings – Performance. For this, the following laboratory tests were carried out in one specimen of CLT wall panel: soft body impact, hard body impact and determination of the resistance of the panel to the demands of suspended parts. At the end, it was found that the panels tested met the minimum requirements and criteria established by the studied standard.

KEYWORDS: Cross-Laminated Timber (CLT), safety performance, wooden structure, prefabricated structure, engineered wood.

1 INTRODUCTION

CLT panels are prefabricated structural timber panels, that can be used as floor or roof slabs, and internal or external walls, with or without structural function. As the name describes (Cross-Laminated Timber), they are composed of layers of solid wood glued perpendicularly to each other. Initially developed in the 1990s in Europe, they started to be manufactured in Brazil about ten years ago by a national manufacturer located in São Paulo state. The first Brazilian CLT structure was fabricated and assembled in 2012. Between this first example and 2018, as pointed by [1], more than 30 constructions were built in the country, most of them being single-family homes.

The use of this innovative construction element in Brazil is still limited. For this reason, many of those who are first introduced to the material express several doubts regarding its applicability. Thus, the study of the panels' performance is imperative. Additionally, considering the predominant residential use of CLT in Brazil, it is essential that the requirements established by the technical standard "ABNT NBR 15575:2013 – Residential Buildings – Performance" [2] are properly met by this new technology.

Therefore, this paper aims to analyse CLT wall panels in terms of safety performance, which is considered the fundamental requirement of any building as well as one of the essential premises to guarantee its stability and the safety of the user.

The basis for this study was the standard "ABNT NBR 15575: 2013 Part 2: Requirements" for structural systems, which presents the requirements that must be met by the construction to guarantee minimum building performance. Most of those presented requirements can be verified through the project's analysis, which varies according to each building. One of them, however, can be checked through laboratory tests, which is item 7.4 – Soft and hard body impacts.

In addition, since CLT panels may be applicable for structural walls, one must also verify its conformity with "ABNT NBR 15575:2013 Part 4: Requirements for internal and external vertical sealing systems – VVIE". In this part of the standard the item which can be verified through laboratory test was item 7.3 – Load requests from suspended parts acting on internal and external sealing systems.

Hence, for the proper determination of the safety performance of CLT buildings, the tests were carried out between September and October 2017 in one specimen of CLT wall panel. The results obtained were compared to the performance requirements established by the ABNT NBR 15575:2013, which are classified as minimum (M), intermediate (I) or superior (S).

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2 CONTEXT

As seen previously, CLT panels are of European origin. According to [3], this technology started to be developed in Switzerland, in the cities of Zurich and Lausanne, during the early 1990s. However, CLT, as it is currently known, is the result of a research that started in 1990 in Austria and involved a partnership between a wood-based systems' manufacturer and Graz University.

Since its development, the use of CLT panels has increased significantly, including the growth in the number of tall buildings that incorporate this innovative building technology along with other mass timber products, such as Glued-Laminated Timber (Glulam). As pointed by [4], almost 200 mass timber buildings with five storeys or more were developed between 2004 and 2019 around the globe. Over 80% of those are located in Europe. In North America, the implementation of CLT panels is still recent, although this is the region that concentrates most of mass timber tall buildings, after Europe [4] [5].

In Europe, the first standard that regulates CLT panels, EN 16351, was published in 2015. It addresses performance features, in addition to establishing minimum requirements for the manufacture of panels, whether straight or curved. It applies to panels made with at least three orthogonal layers, which can also have up to three successive layers glued in parallel, in the case of panels with at least four layers [6].

The American standard ANSI/APA PRG 320, which establishes rules for the manufacture and characterization of the CLT produced in the United States and Canada defines Cross-Laminated Timber as a prefabricated engineered wood product consisting of at least three layers of solid sawn wood or Structural Composite Lumber (SCL), glued with structural adhesive. The thickness of each layer must be a minimum of 16 mm and a maximum of 51 mm, resulting in panels up to 508 mm thick [7].

As indicated by [4], the cross configuration of the layers enables the distribution of loads in a bidirectional way, allowing to achieve high strength and stiffness capacities. Thus, the main innovation is the production of panel elements, which function as self-supporting walls or slabs.

The sizes of CLT panels vary according to the manufacturer, reaching dimensions of up to 2.95 m x 24.00 m [3]. Transport regulations, however, can also impose dimensional limitations on these construction elements. As highlighted by [8], the common dimensions are lengths of up to 18.00 m, reaching 30.00 m, and maximum widths of 3.00 m, reaching up to 4.80 m, with maximum thicknesses between 300 and 400 mm.

In national production, according to [1], the panels are manufactured with maximum dimensions of 12.00 x 3.00 m, with thicknesses varying between 60 mm and 250 mm. The author also mentions that the Brazilian construction process can be divided into three parts: raw material, manufacture of panels and assembly of the building. Each has its own internal phases. The raw material, after extraction, may or may not receive preservative treatment to prevent the attack of deteriorating organisms, such as fungi or insects. The manufacture, in turn, begins with visual screening of the lamellas, passing through the splicing of these, the assembly and pressing of the panel and the cutting and machining of the pressed panel. The assembly of the building includes logistics, that is, the transportation of the construction elements to the construction site, as well as the movement and connection of the parts, the execution of the building installation and facade [1].

Regarding the assembly of CLT buildings in Brazil, [1] reports that the panels are fixed together, or in other building systems, such as concrete slabs, metal beams, among others, by means of self-tapping screws or metal connectors. In the joints formed between two CLT elements, being parallel or perpendicular to each other, a line of weather-resistant silicone sealant is applied. The screws used in Brazil are manufactured by an Italian company specialized in connectors for wooden structures, the Rothoblaas®. They are used both in simple connections, as well as in more complex ones, that is, when the fixation occurs by means of metallic connectors.

In Brazil, as beforementioned, the production of CLT panels is even more recent than in North America, dating back to 2012. There are no multi storey buildings in the country yet.

However, the use of CLT panels is expected to increase soon. One of the reasons for that is the recent publication of the reviewed national standard for timber structures, that occurred in the second semester of 2022. This document, which regulates wood structures in Brazil, was going through a revision process since 2002. Among many important changes that were incorporated in its latest version was the mention of CLT panels and the introduction of five tests methods for panels that are produced in the country [9].

Even though, as any other construction technology, when used for residential purposes, CLT panels must also meet the criteria established by the technical standard "ABNT NBR 15575:2013 – Residential Buildings – Performance", which is also known by the denomination of "Performance Standard".

3 MATERIALS AND METHODS

To verify the safety performance of a CLT wall panel produced by the first Brazilian Manufacturer, the following laboratory tests were carried out: Soft body impacts, Hard body impacts, and Load requests from suspended parts acting on internal and external sealing systems.

For the three tests mentioned, a single sample was used, which was 80 mm thick (three layers panel, with 20 mm thick external layers and 40 mm thick internal layer), 4000 mm wide and 2700 mm height. It consisted of two CLT panels: the first one measuring 3000 mm wide and the second one 1000 mm wide (Figure 1). Such thickness is the most commonly used in CLT panels to build walls in Brazil.

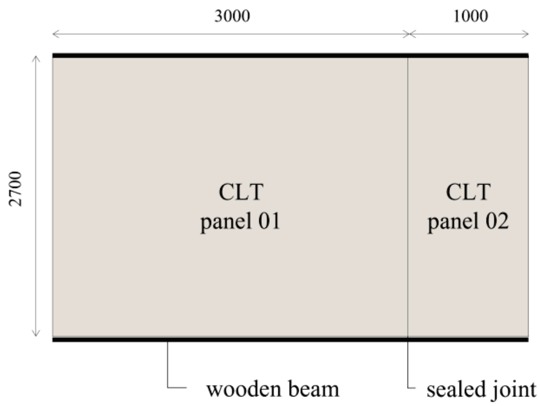

Figure 1: *Design of the specimen carried out to verify the safety performance of the CLT panel. Measures in millimetres (without scale)*

The panels were produced using a vacuum press, with lamellas of *Pinus taeda* wood that were glued with polyurethane structural adhesive. The grade and strength class of each layer was not provided. For more information about the production process of this manufacturer see [1], that describes the production process in detail.

In order to verify the performance of the system also at the point of attachment between the two panels, a joint in the panel was made. The fixation between the two panels occurred through Rothoblaas® VGZ7140 screws fastened with an angle of 45° in relation to the faces of the panels. The joint between the two panels received an application of silicone sealant weather resistant.

The specimen was fixed at its lower and upper edges in a pre-existing porch, composed of two metal beams filled with concrete (Figure 2). For this fixation, in order to replicate a real connection between CLT elements and concrete foundations, a wooden beam was adopted, which was fixed to the concrete sleeper by means of anchor bolts. An EPDM tape was positioned above the beam. The panels were fixed to the beam using Rothoblaas® VGZ7140 screws fastened with an angle of 45° in relation to the faces of the panels.

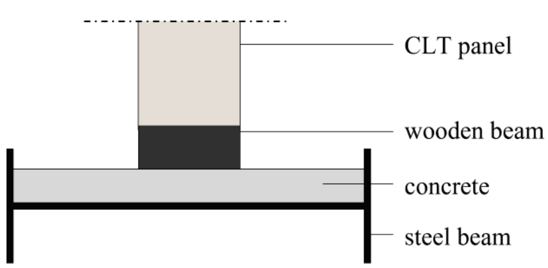

Figure 2: *Schematic detail of the lower fixation of the specimen carried out to verify the safety performance of the CLT panel. Measures in millimetres (without scale)*

3.1 SUSPENDED PARTS TEST

The first test carried out was the requirement Load requests from suspended parts acting on internal and external sealing systems. The method adopted for this test is set out in Annex A of the ABNT NBR 15575:2013 Part 4 [2]. The purpose of this test is to analyse the resistance of CLT panels to the demands caused by fixing suspended parts, such as cabinets, shelves, washbasins, hydrants, pictures and others. The application of the load on the panel, to verify its resistance, is carried out by means of a standardized shelving bracket.

Two tests of this type were performed, each one using different screws for fixing the shelving bracket. In the first, Rothoblaas® HBS 660 screws and, in the second, conventional screws for MDF in size 4.5 x 60 mm were used. The first screw is not produced in Brazil and, therefore, it is more difficult and expensive to acquire. That was the reason for conducting this test with a second screw, which is considerably more common and can be found in all regions of the country.

The load was applied to the shelving bracket at 50 N levels and without blows, according to the standard, with an interval of 3 minutes between the positioning of each level (Figure 3). The maximum load considered in the test had to be maintained after a period of 24 hours.

Figure 3: *Suspended parts test in progress*

3.2 HARD BODY IMPACT TEST

For the second test, which consisted of verifying the resistance of wall panels to hard body impacts, the method adopted is set out in Annex B of the ABNT NBR 15575:2013 Part 4 [2]. In this test, structural components under hard body impacts must not be broken or pierced under any impact energy, but the occurrence of cracks, chipping and other damages (impacts of use) can be tolerated. The test was carried out with the pendular release, at rest, of a body of known mass, at a specified height. The body consisted of steel balls of two types: a small hard body of 0.5 kg and a big hard body of 1 kg.

These bodies were suspended by a cable and released in a pendular motion, generating impact energies that are

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indicated in the standard, until reaching the specimen (Figure 4). The impacts were applied at different random points, that is, each impact had to occur at a different point, without repeating. The standard in question establishes as impact energy 10 J and 20 J, for the big body, and 2.5 J and 3.75 J for the small body. To mark the point of impact on the panel, a carbon paper was used and fixed with self-adhesive tape on the specimen.

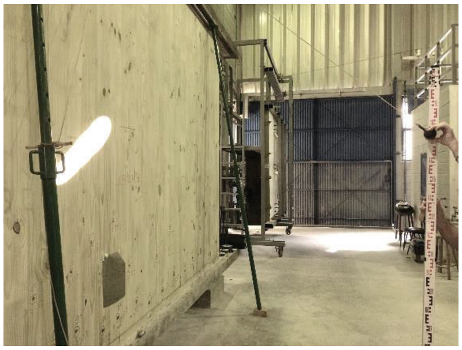

Figure 4: *Hard body impact test in progress. The picture shows the moment before the hard body is abandoned.*

3.3 SOFT BODY IMPACT TEST

The last test consisted of measuring the resistance of the panels to soft body impacts, according to the test method which is indicated in the ABNT NBR 11675:2016 Modulated internal light partitions – Verification of resistance to impacts [10]. For this purpose, a cylindrical leather bag was used as a soft body. It measured approximately 350 mm in diameter and 900 mm high and contained dry sand and sawdust inside, with a total weight of (400 ± 4) N (equivalent to about 40 kg). In addition, the measurement of the horizontal displacement of the panel was carried out by means of a depth calliper with a resolution equal to or less than 0.1 mm.

As the standard describes, the test begins with the suspension of the leather bag, through a steel wire, so that the projection of its centre of mass on the surface of the specimen coincides with the point where the impact must be applied. The device for the graphic record of the displacements of the panel must be installed in a position coincident with the centre of mass of the leather bag, on the face of the specimen opposite to that which will suffer the direct impact. The cylindrical leather bag is then abandoned in a pendular motion and must reach the specimen with the energies that are specified in the standard: 120 J, 180 J, 240 J, 360 J, 480 J, 720 J and 960 J (Figure 5).

After each impact, the specimen undergoes visual inspection. The instantaneous horizontal displacement (dh) and the residual horizontal displacement (dhr) of the panel are determined for each impact using the depth calliper. Five minutes after the application of each impact, one can register the residual displacement of the panel and, then, the device's graph paper is moved to record the displacements graphically in order to apply the following impact [10].

Figure 5: *Soft body impact test in progress. The picture shows the moment after the leather bag is abandoned.*

The test performed on the CLT panels followed the procedures described above and provided for the mentioned standard. Two points were determined where the impact was applied, the first being in the centre of the CLT Panel 01, with a width of 3000 mm and the second located at the joint between the two panels. For each point, an impact was made for every energy specified in the standard, registering the horizontal displacement by means of the depth calliper (Figure 6).

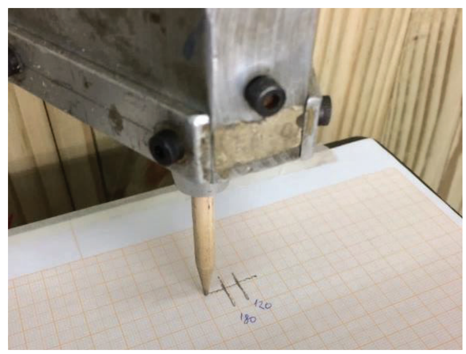

Figure 6: *Soft body impact test in progress. The picture shows the measurement of the instantaneous horizontal displacement (dh) and the residual horizontal displacement (dhr) of the panel by the depth calliper.*

4 RESULTS

4.1 SUSPENDED PARTS TEST

The first test aimed to verify the resistance of the panel to load requests from suspended parts acting on internal and external sealing systems. As a result, loads of 80 kgf and 100 kgf were kept in the shelving bracket for 24 hours, for both screws that were tested, without any kind of damage or instantaneous or residual horizontal displacements in the panel.

4.2 HARD BODY IMPACT TEST

When verifying the resistance of the wall panel to hard body impacts, the panel was tested only with energy of 3.75 J, for the small body, and 20 J, for the big body. It was decided not to test the lowest energies, for, since the panel did not suffer damage with the highest energies, neither would it suffer with lower energies. Due to the impacts made, dents with small depths were observed. However, there was no rupture, piercing, and occurrence of cracks, chipping or other damages. The dents' depths verified in each impact are shown in Table 1.

Table 1: *Depth of the dents verified in each hard body impact.*

Impact nº.	Depth of dent (mm)	
	Impact of 3.75 J	Impact of 20 J
1	0.6	1.3
2	0.6	1.7
3	1.0	1.1
4	0.7	1.6
5	0.2	1.2
6	0.3	2.5
7	0.7	2.1
8	1.4	1.6
9	0.6	0.8
10	0.2	0.6

4.3 SOFT BODY IMPACT TEST

In the last test (soft body impacts) at the two points of impact and for all energies tested, there was no occurrence of ruin and piercing or surface flaws, such as dents, cracks, chipping, detachments and breakdowns. However, there was a small instantaneous horizontal displacement in the panels, which was recorded by the depth calliper. This displacement, for each point and impact energy, is shown in Table 2.

Table 2: *Displacements verified in each soft body impact.*

Energy (J)	Impact on the joint		Impact at the center of the specimen	
	Instantaneous displacement – dh (mm)	Residual displacement – dhr (mm)	Instantaneous displacement – dh (mm)	Residual displacement – dhr (mm)
120	8	0	6	0
180	9	0	7	0
240	11	0	9	0
360	13	0	12	0
480	14	1	13	1
720	18	0	16	0
960	22	1	18	1

5 DISCUSSION

5.1 SUSPENDED PARTS TEST

Regarding load requests from suspended parts acting on the CLT panel, the test was paused when the tested screws reached the load limit established by the ABNT NBR 15575:2013 for intermediate performance level (Annex F of the ABNT NBR 15575-4:2013) [2], that is 1.0 kN (equivalent to 100 kgf). In both cases, no cracks, detachments or instantaneous or residual horizontal displacements were identified. However, it is possible that the screws could withstand a load even greater than the value reached. Thus, it is not possible to say whether they would achieve intermediate or higher performance in this regard.

5.2 HARD BODY IMPACT TEST

In order to verify the wall panel's resistance to hard body impacts, as established by the ABNT NBR 15575:2013 [2], the minimum performance level for energies of 2.5 J and 10 J requires no failure in the structural element, although dents with any depth are allowed. For energies of 3.75 J and 20 J, surface flaws such as dents, cracks, chipping and disintegration are allowed. Ruins and piercing cannot occur. For 3.75 J energy, to reach the intermediate or higher performance level, the standard determines as the maximum depth allowed for the dent 5 mm and 2 mm, respectively.

In this test, as mentioned above, there was no rupture, piercing, cracking, chipping or other damage in any of the cases. While for dents, as seen in Table 1, the maximum depth obtained in the energy impact of 3.75 J was 1.4 mm. Consequently, regarding the panel's resistance to hard body impacts the higher performance level was reached, according to the criteria established in the ABNT NBR 15575: 2013 [2].

5.3 SOFT BODY IMPACT TEST

The analysis of the results obtained with soft body tests applied the performance criteria presented in Annex F of the ABNT NBR 15575:2013 Part 4 [2] for all CLT possible uses, which are: internal walls with and without structural function, external walls (facades) of single-story houses with structural function and external walls of single-story houses without structural function. In the last case, only the criteria for light seals were analysed, that is, with a density less than 60 kg/m², considering that the tested panel (80 mm thick and an average density of 550 kg/m³), by having a mass of approximately 44 kg/m², falls into this category.

Whereas the absence of ruins, piercing or any other failure, it is necessary to check the horizontal displacements caused by the impacts. The method that must be used to calculate the displacements, as presented by the mentioned criteria, are presented in Table 3.

Thus, it was calculated the maximum instantaneous and residual displacements that were allowed in each situation. These displacements were compared to the maximum values established by the Performance Standard, which determines three performance levels: minimum (M), intermediate (I) and superior (S).

Table 4 shows the calculated values and the actual values that were measured during the test for each impact point. It can be seen from the results presented in Table 4, that practically all the actual displacements measured, whether

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instantaneous or residual, were lower than the values that were calculated with the equations presented by the ABNT NBR 15575-4:2013 [2] and in Table 3.

It is also interesting to analyse the use of "external walls of single-story houses with a structural function – external impact (external public access)". For this use and for the impact energy of the soft body of 240 J, the instantaneous displacement limit must be less than or equal to h/250. As mentioned, the specimen was 2700 mm high and, therefore, according to the equation, the dh limit is 10.8 mm. In this case, the 11 mm value measured for the instantaneous displacement would be higher than the calculated limit of 10.8 mm. However, considering the accuracy of the 1 mm depth calliper, and not 0.1 mm, as provided by the standard, it is not possible to say, for sure, that the actual displacement was, in fact, below the established limit. Thus, it was considered that the measured value would be equivalent to the one calculated, rounding the limit from 10.8 mm to 11 mm, by proximity.

Thereafter, it is possible to verify that, if used as an internal wall with or without structural function, CLT panels similar to the specimen from this study could reach the level of higher performance according to the resistance to soft body impacts. Also, as external structural walls of single-story houses, the level of performance that was achieved in this analysed requirement is also higher. Finally, CLT panels just like the one tested, when working as walls of a single-story house, without structural function, would also achieve the level of higher performance.

Table 3: *Compilation of the limitation of horizontal displacements presented in Annex F of the ABNT NBR 15575:2013 Part 4 for all possibilities of uses for CLT elements.*

Vertical seal type	Impact energy (J)	Limitation of horizontal displacements	Performance Level		
			M	**I**	**S**
Internal with structural function	**120**	d_h <= h/250; d_{hr} <= h/1250	X		
Internal without structural function	**120**	d_h <= h/125; d_{hr} <= h/625		X	X
	60	d_h <= h/125; d_{hr} <= h/625	X		
External of single-story houses, with structural function – External impact	**240**	d_h <= h/250; d_{hr} <= h/1250	X	X	X
External of single-story houses, with structural function – Internal impact	**120**	d_h <= h/250; d_{hr} <= h/1250	X	X	X
External of single-story houses, without structural function – External impact	**120**	d_h <= h/62.5; d_{hr} <= h/312.5	X		

Table 4: *Compilation of the results found for the horizontal displacements of the tested panel.*

Vertical seal type	Impact energy (J)	Calculate displacement (mm)	Actual displacement (mm)	
			Ponto A	**Ponto B**
Internal with structural function	**120**	d_h <= 10.8; d_{hr} <= 2.16	d_h = 8; d_{hr} = 0	d_h = 6; d_{hr} = 0
Internal without structural function	**120**	d_h <= 21.6; d_{hr} <= 4.32	d_h = 8; d_{hr} = 0	d_h = 6; d_{hr} = 0
	60	d_h <= 21.6; d_{hr} <= 4.32	- -	- -
External of single-story houses, with structural function – External impact	**240**	d_h <= 10.8; d_{hr} <= 2.16	d_h = 11; d_{hr} = 0	d_h = 9; d_{hr} = 0
External of single-story houses, with structural function – Internal impact	**120**	d_h <= 10.8; d_{hr} <= 2.16	d_h = 8; d_{hr} = 0	d_h = 6; d_{hr} = 0
External of single-story houses, without structural function – External impact	**120**	d_h <= 43.2; d_{hr} <= 8.64	d_h = 8; d_{hr} = 0	d_h = 6; d_{hr} = 0

6 CONCLUSIONS

The present work sought to verify the safety performance of CLT panels manufactured in Brazil according to the criteria established by the Performance Standard, ABNT NBR 15575:2013. To this end, the following laboratory tests were carried out: Hard body impacts and Load requests from suspended parts acting on internal and external sealing systems. The tests' results were compared with the minimum requirements and criteria established in the ABNT NBR 15575:2013, in order to verify their compliance.

The authors are aware that the study tested only one specimen of one producer. Therefore, the results cannot ensure that all Brazilian CLT panels have adequate performance according to national standards. There are a great number of other standards in Brazil and, also, other requirements in ABNT NBR 15575:2013 that must be achieved by this technology. It must be highlighted, further, that the performance analysis of the element in question should encompass other requirements not included by this study, such as thermal or acoustic comfort.

Moreover, since the latest publication of the reviewed Brazilian standard for timber structures and the introduction of tests methods for CLT panels that are produced in the country, it is also expected for the national production of CLT panels to meet those recent requirements. Therefore, it was not intended, in this work, to exhaust the studies on the use of CLT panels in Brazil.

Finally, it appears that CLT panels present themselves as an extremely promising option for the global and Brazilian construction industry. Certainly, as the demand to CLT panels in the national construction business increases, just like it has occurred in other countries, new challenges, and therefore new solutions, will be faced, and shall be overcome. Thus, the present study aims to be one unassuming step towards the actual and permanent implementation of this technology nationally.

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