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Sound Transmission Loss in Light Steel Framing Walls With Vermiculite and Recycled-pet Fiber

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Abstract

Due to the demand for multifamily constructions, there is an increasing need for buildings with enhanced acoustic comfort. This study evaluated the acoustic performance of facade walls in the Light Steel Framing (LSF) construction system, using recycled-PET (Polyethylene Terephthalate) fiber and vermiculite board according to ISO 10140:2021 (Acoustics – Laboratory measurement of sound insulation of building elements). Experimental tests on sound transmission loss (STL) were conducted on LSF walls, comprised of two plates (a fiber cement board and an OSB (Oriented Strand Board) separated by an air gap. Four different internal cavity configurations were considered herein: a prototype without any material inside the wall; the second configuration with only recycled-PET fiber inside; the third configuration with solely vermiculite board inside; and the last model with both recycled-PET fiber and vermiculite board inside the wall. The ‘composite’LSF wall with two sound absorbing materials inside, achieved the value of STL equal to 37 dB. It complies with the minimum requirements of the Brazilian Standard NBR 15575-4 (ABNT, 2021) for facades. Furthermore, this study introduces a new approach for LSF walls which considers the introduction of vermiculite boardin between the external boards.

Keywords: light steel framing. acoustic performance. sound transmission loss

1. Introduction

Light steel framing (LSF) is a construction system composed of structured panels of cold-formed galvanized steel profiles. Its design is done in a rational way, allowing a dry construction system, with little waste and a more sustainable approach. The system assembly can be executed faster than the one in comparison to conventional masonry constructions (Rodrigues and Caldas, 2016). According to Olivieri *et al.* (2017), the rationalization of the system not only reduces the construction costs on sites but also provides better performance for the construction management and work activities.

LSF systems began to be adopted in Brazil in early 1990's. At that time, its use was aimed at high social classes (Malta, Arcipreste and Aguiar, 2021). According to Duarte and Daltro (2018), nowadays, large-scale of LSF constructions are still growing in Brazil. According to the authors, LSF housing in the country, especially those of social interest, needs improvements in terms of design, comfort, energy efficiency, and preservation of material resources. Although this type of construction is still not popular in Brazil in comparison with the traditional masonry walls, LSF systems have the potential to contribute to reduce the Brazilian housing deficit. This is mainly due to the minimum waste generated by the system assembly in a optimized short period. (Angelis and Serra, 2014). In addition to the benefit of reducing structure weight, the use of a LSF system also guarantees a stiffer structure in comparison to the conventional masonry. Furthermore, it also has shape stability in the presence of moisture. On top of that, the LSF system might also be reused whether necessary (Santos, Martins and Silva, 2014).

Brazil ranks ninth in the world among the ten largest steel producers in the world (Gandra, 2019). However, there is a lack of specialized labor and high-tech machinery to boost the development of LSF systems. Thus, this is why the LSF system is still not much popular in the country (Gonçalves and Bode, 2015; Malta, Arcipreste and Aguiar, 2021). Despite this, the use of steel in civil constructions has considerably increased in recent years. Nowadays, Brazil has developed housing policies, technology and national standards that have contributed substantially to the adoption of LSF systemsas a powerful alternative (Gomes, Souza and Tribess, 2013; Malta, Arcipreste and Aguiar, 2021). As the number of multifamily dwellings using steel-framed partition walls increases, architects and engineers are facing a urgent need to prioritize adequate acoustic performance for thoseLSF buildings. According to Cohen *et al.* (2019), the acoustic quality of a building is the result of the influence of the characteristics of the built environment and particular factors such as size, volume, coating and materials used in the construction.

Traffic noise must also be considered for the design of quiet buildings ifone wishes to achieve the best acoustic performance and human comfort. The increase in the fleet of vehicles and the lack of territorial planning have contributed to worsening the problemin large cities. Besides, noise emitted by industries, civil construction work and general commerce are also potential sources of urban noise. Frequent exposure to high noise levels has negative effects on health, such as cardiovascular diseases which can impact an individual's quality of life (Botteldooren, Dekoninck and Gillis, 2011; Suriano, Souza and Silva, 2015).

It is evident that there is a need to prioritize the acoustic performance of buildings in general. It is a fact that the choice of appropriate construction materials in terms of sound isolation may contribute to the overall noise control of buildings.

PET wool blanket is a material that has recently been used inside LSF wallsto provide a better acoustic system. However, the production of solid waste in the environment has become another nuisance. PET containers have increasingly been used in recycling processes around the world.

In 2019, Brazil recycled 55% of the PET waste produced in the country, which represented 311 thousand tons of the material. It represents a percentage of 12% above the amount recycled PET in 2018. It generated 3.6 billion in revenue (Abipet, 2019). PET recycling promotes social benefits, ensuring work for professional collectors. This is not only an economic benefit but also a way of providing job creation. Recycling material saves natural resources, such as water and energy. Besides, it may contribute to the cleanliness of cities. It is possible to recycle 35 PET bottles per m^2 of 50 mm thick PET wool roll. In addition, the use of PET wool, which is a hypoallergenic material, can eliminate the risk of human contamination during the handwork. Another important characteristic, which needs to be guaranteed by the companies that manufacture it, is their features of being self-extinguishing material (Trisoft, 2020). The amount of PET material needed to make an acoustic treatment is incredibly lower than the one necessary to provide the same level of noise insulation (Buzatu *et al*., 2020).

Another material that is recommended to be used is 'vermiculite'. It is believed that it can boost the acoustic performance of the system. It is a recyclable material, not harmful to the environment and neither to humans. Vermiculite is insoluble in water and other organic solvents. It also has chemical stability over time (Carbajo *et al.*, 2015). Vermiculite expands when heated, increasing its volume by up to 30 times its original size. In this way, the dense mineral is transformed into porous and light particles. In its expanded form, it has low density, ease of handling and high thermal insulation and sound absorption capacity. Vermiculite is odorless, non-toxic, does not decompose over time and absorbs up to five times its weight in water. It has commonly been used in civil constructions, chemical industries, agriculture, among other applications. In addition, vermiculite is flame retardant and hydrophobic (Anm, 2018; França *et al*., 2016). The mineral has an affordable price and has commercial advantages in comparison to other materials, such as glass wool and rock wool. Both vermiculite and PET wool are not yet popular materials used inside LSF walls.

In this context, the development of this work is based on the following hypotheses: first, that vermiculite board (a material with low environmental impact since it can be recycled and does not generate hazardous waste for the environment)has the potential to improve the sound insulation performance of LSF walls (Carbajo *et al*., 2015). Second, the use of both vermiculite board and recycled PET wool blanket (sustainable material already used in LSF) can also improve the overall acoustic performance of the whole LSF system housing.

2. Theoretical Background

When buildings are treated adequately, their acoustic quality contributes not only to the well-being of the user (Roque, Santos and Pereira, 2019) but also to the building market value.

The sound insulation capacity of a particular wall varies according to the sound frequency. Low-frequency sounds are harder to attenuate than high-frequency sounds. In addition, in a building, two types of noise must be considered, airborne and structure-borne type of noise. Airborne type of sound is transmitted through the air and both walls and floors must be treated for correct insulation (Way and Couchman, 2008).

In acoustic insulation, sound transmission loss (STL) is measured in decibels (dB). It represents the reduction of a sound that is being propagated from one environment to another one.
The parameter 'Weighted Sound Reduction Index' $R_w$is a single number (in dB), which represents the performance of a particular partition in terms of its sound insulation 'capacity'.
Table 1 shows the Weighted Sound Reduction Index $R_w$for the facades, according to the NBR 15575-4 standard (ABNT, 2021). The parameter *Linc* represents the level of sound that reaches the façade of the building, thus allowing the expected noise class to be evaluated in the area in which the building is located.

Table 1**.** Reference values of R_w(Weighted Sound Reduction Index)Source: NBR 15575-4 (ABNT, 2021).

Noise Class	***Linc*** **dB**	R_w**(dormitory) dB**	R_w**(living room) dB**
I	≤ 60	25-29	Not applicable
II	61-65	30-34	Not applicable
II	66-70	35-39	30-34

According to Way and Couchman (2008), sound insulation of double wallsis much better than single ones. It is due to the presence of an air layer between the wall leaves. It contributes to the overall increase in the Sound Reduction Index. It is recommended an air layer thickness of at least 40mm. If a sound absorption material is placed in the air space, the overall performance is still better than that without any material. Finally, sealing around the edges of floors and walls is another important measure for the complete sealing of the LSF system, especially at the joints among walls, ceilings and floors. Acoustic sealants or mineral wools are usually used for this purpose.

According to Bies and Hansen (2017) and Bistafa (2018), in a double wall partition, such as those of LSF, the theoretical curve of the typical STLcan be presented as the one shown on Figure 1. The graph shows the lowest structural resonance frequency (f_0), obtained from Equation (1), and the lowest natural frequency peak of the panel-spacing-panel system(Bies and Hansen, 2017). Critical frequencies occur when the sound wavelength in the air equals the length of the sound wave propagating in the panel. In some regions of the graphit is observed that there is a decrease in the STLvalues (Bies and Hansen, 2017; Bistafa, 2018).

$$f_0 = 80\sqrt{\frac{(M_1+M_2)}{dM_1M_2}} \qquad (1)$$

M_1 and M_2 *are* the surface densities in kg/m^2 of panels 1 (panel with the lowest critical frequency) and 2 (panel with the highest critical frequency) respectively; *d* is the spacing between the panels in meters (Bies and Hansen, 2017).

Equation (2) presents the limiting frequency f_L, which is related to the spacing between the panels (Bies and Hansen, 2017).

$$f_L = \frac{55}{d} Hz \tag{2}$$

where d is the measure of the cavity spacing between the closing panels, in meters.
From Equation (3) below, the critical frequency of the system can be determined (Bies and Hansen, 2017).

$$f_c = \frac{c^2}{2\pi}\sqrt{\frac{M}{B}} \tag{3}$$

where, c is the velocity of the acoustic wave propagating in the air m/s; M is the surface density in kg/m² and B is the flexural stiffness of the wall in N.m.

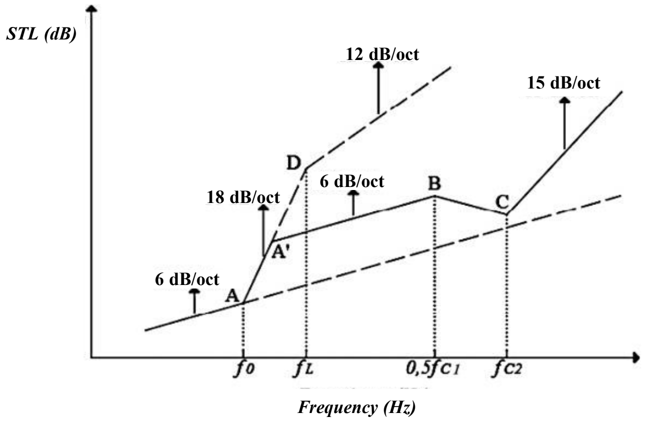

Figure 1. Prediction of the variation of STL with frequency for double walls.Source: Adapted from Bies and Hansen (2017).

Equation (4) can be used to calculate the resonance frequency of the air cavity (f_{air}). (Bies And Hansen, 2017; Gerges, 2000). This resonance frequency is given by

$$f_{air} = \frac{cn}{2d} \tag{4}$$

Where, c is the velocity of the acoustic wave propagating in the air m/s; n is the acoustic vibration mode of the wave (n=1; n=2; ...) and d is the distance of the spacing between the panels, in m.

Franzen (2015) carried out tests to evaluate the acoustic performance of LSF external seals. According to the author, the panel contained glass wool and an air cavity in the center of the wall. External coating with synthetic stucco and PVA latex put inside LSF walls can complement the sound insulation and provide a sound reduction index improvement of about 3 dB. The author concluded that the glass wool contributed to the decrease in the sound transmission at very low frequencies. In other words, it contributed to the overall acoustic insulation at low frequencies.

In the research carried out by Radavelli (2018), typical LSF walls were considered. The walls had resilient bars and acoustic bands in order to improve their performance. Walls treated with resilient bars and acoustic bands had the $R_w$value about 3 dB higher than walls without any treatment. In this research acoustic bands were used on the prototypes.
Way and Couchman (2008) presented some construction options to increase the acoustic performance of LSF systems, such as double walls with mineral wool in between. As a result, a slightly better sound reduction index was obtained. The double walls presented a sound reduction index (R_w) value in the range 56-66 dB and for walls with resilient bars, values ranging from 59 dB to 62 dB.

3. Materials and Method

To perform the experimental tests for STL, PET wool blankets with a density of 7 kg/m3 and thickness of 3.0 cm were used. The roll of this material was 120 cm wide and 1000 cm long. The vermiculite plate had a density of 420 kg/m^3, a thickness of 2.4 cm and dimensions of 30 cm by 60 cm. The coating boards used were 1 cm thick cementitious boards. A OSB plate 1.11 cm thick plus a white standard plasterboard with a thickness of 1.25 cm were also considered in the LSF system. The dimensions of the guides and uprights used were 9 cm wide and the thickness of the steel bars was 0.95 mm. The steel bars were made of cold-formed galvanized steel and coated with aluminum and zinc (275g/m^2). Their yield strength was equal to 230 MPa. The screws for fixing the plates were drill-point and needle-point screw types.

The wall was inserted into a gap with dimensions of 110 cm by 235 cm. It was the available set-up aperture between the rooms. On one side, the cement plate was placed, facing the sound emission room. On the other side of the wall, two connected plates were inserted: the OSB and the plasterboard, with the latter one facing the source room. The platehad a surface density of approximately 41 kg/m^2. Inside the wall, a PET wool blanket and a vermiculite board (Figure 2) were inserted.

PET wool blankets and vermiculite plates were inserted according to Figure 3. The tests were performed with four different configurations: the first test was done without material inside the test element; in the second test, the panel was composed only with PET wool inside the space between the board plates; in the third test, the LSF system presented only vermiculite plates inside the space between the board plates; in the last test, the LSF systemwas composed of vermiculite boards and a PET wool blanket inside the space in between the external boards.

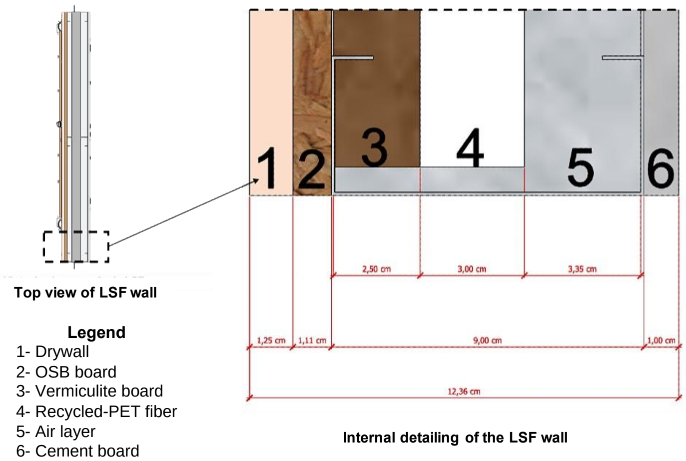

Figure 2. Internal detailing of the test wall (view from above).Source: Prepared by the authors, 2024.

a) Insertion of Recycled-PET fiber insulation in the LSF wall

b) Insertion of vermiculite boards in the LSF wall

Figure 3. Different configurations of the test wall. a) Wall with PET wool blanket; b) wall with vermiculite boards.Source: Prepared by the authors, 2024.

The LSF wall was built in the Laboratory of Dynamics and Structural Acoustics (LADAE) of the School of Engineering of UFMG and inserted between two reverberation chambers with volumes equal to 70.65 m^3 and 71.90 m^3 respectively.

To access the reverberant chamber, it was necessary to make an opening in the test wall with dimensions of 72 cm by 84 cm. To close this space, a small removable panel was made with proper dimensions (in order to one access the source room). This removable panel was builtwith the same material considered in the experimental tests in order to ensure the complete sealing of the gap during the acoustic tests (see

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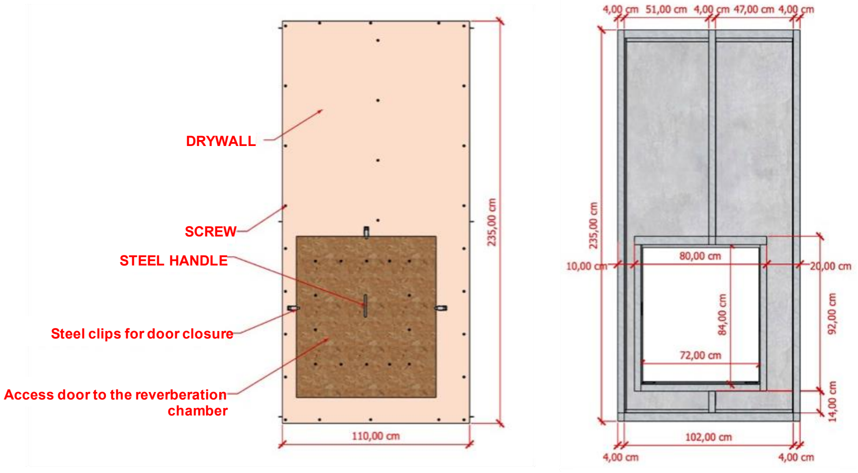

a) Front view of LSF wall

b) Front section of LSF wall

Figure 4. Front view schematic drawing of the test wall. a) frontal view; b) front cut.
Source: Prepared by the authors, 2024.

The experimental tests of STL were performed following the procedures describedon ISO 10140-2 (ISO, 2021) standards – *Acoustics: Laboratory measurement of sound insulation of building elements - Part 2: Measurement of airborne sound insulation*, NBR ISO 717-1 (ABNT, 2021) - Classification of acoustic insulation in buildings and building elements - Part 1: Airborne noise insulation and NBR 15575-4 (ABNT, 2021). According to ISO 10140-2 (ISO, 2021), for laboratory measurements the noise reduction index is given by:

$$R = L_1 - L_2 + 10log\frac{S}{A} \tag{5}$$

where, $L_1$is the average sound pressure level in the source room, in dB; L_2 is the average sound pressure level in the receiving room, in dB; S is the area of the tested wall, in m^2 e; A is the equivalent sound absorption area in the reception room, in m^2.

To determine the A value (total absorption in the receiving room), the test was carried out to calculate the reverberation time of the receiving room, according to ISO 10140-4 (ISO, 2021) *Acoustics: Laboratory measurement of sound insulation of building elements - Part 4: Measurement procedures and requirements*) and NBR ISO 3382-2 (ABNT, 2017) – Acoustics: Measurement of room acoustics parameters - Part 2: Reverberation time in common rooms. For this, the Impulsive Response Method was used, which consists of emitting an impulsive sound at a particular location in the source room (such as a balloon burst or a shot, capable of producing a sound pressure level sufficient to generate a decay curve of 60 dB, according to NBR ISO 3382-2). During the test, a sound pressure level meter was used, consisting of an omnidirectional microphone configured to measure the reverberation time. The sound sources of excitation used were the burst of balloons. The corresponding decay curves were then measured as a function of time. Due to the background noise, the decay analyzed in the receiving room was in the 20 dB range (T_{20}), where there was at least 35 dB, generated by the sound source, above the background noise level in each frequency band, as recommended by the Brazilian standard NBR ISO 3382-2 (ABNT, 2017). The frequency bands analyzed were between 100 Hz and 5000 Hz. The distribution of microphones was determined according to the Engineering Method, as indicated by the ISO 10140-4:2021 (ISO, 2021) and NBR ISO 3382-2 (ABNT, 2017) standards. According to ISO 10140-4 (ISO, 2021) it is advisable that the reverberation time be between 1 s and 2 s. For frequency bands between 100 Hz and 630 Hz, the T_{20} was between 1 s and 2 s, and for frequency bands above 800 Hz, the reverberation time result was below 1 s.

From the reverberation time data information, the Schroeder Frequency (Schroeder, 1987) was determined.

For each type of wall composition used on the experimental tests, three fixed microphone positions in each room were used. Thus, a total of six measurement mic positions for each wall and 24 positions for all of the four LSF system configurations were considered herein. Although the standard recommends at least 10 measurements for fixed microphones, six measurements were taken. Initially, 10 measurements were performed for the STL tests. However, it was observed that 6 measurements were sufficient due to the small dimension of the receiving room (

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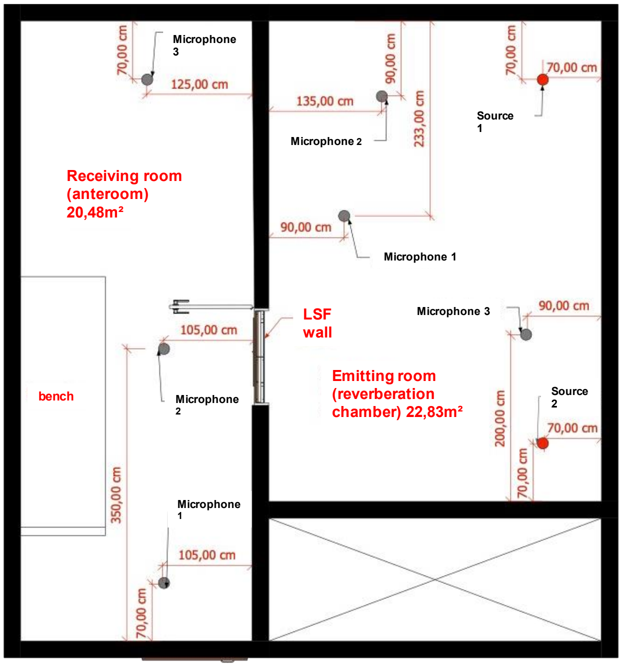

Figure 5. Floor plan: positions of the sound source and microphone during the STL test at LADAE/UFMG. Source: Prepared by the authors, 2024.

After carrying out the six tests for measuring the sound pressure level (SPL) in each room, the average sound pressure level of each room was performed according to Equation (6)below (ISO 10140, 2021):

$$SPL = 10\log\frac{1}{n}\sum_{j=1}^{n}10^{L_j/10} \qquad (6)$$

where L_1, L_2, ..., L_n are the sound pressure levels at n different microphone positions in the room, in dB.

From the results found, the single value classification of each LSF system was calculated. The results were based on the standard NBR ISO 717-1 (ABNT, 2021). Thu, it was possible to make assessments knowing the minimum sound insulation performance required by the standard ABNT NBR 15575-4:2021, which considers building acoustic performance indexes.

The wall area used for the test was 2.56 m^2. The transmission by the flanks, that is, the sound transmission that occurs by other paths rather than the test element, was not considered herein. Therefore, there was sound transmission through the combination of direct and flank path transmissions.

4. Results and Discussion

After the experimental tests, a comparison chart was prepared comparing the variation of STL with frequency for the four LSF wall configurations. This is shown in Figure (6). The coefficient of variation determined in the measurements ranged from 0.40% at high frequencies to 5.03% at the low frequencies. In all curves, it is possible to notice that from 500 Hz frequency bands on there is a sharp drop in sound insulation for each wall configuration. Nevertheless, from 2,000 Hz to 5,000 Hz, it is seen a slight increase in the STL values.

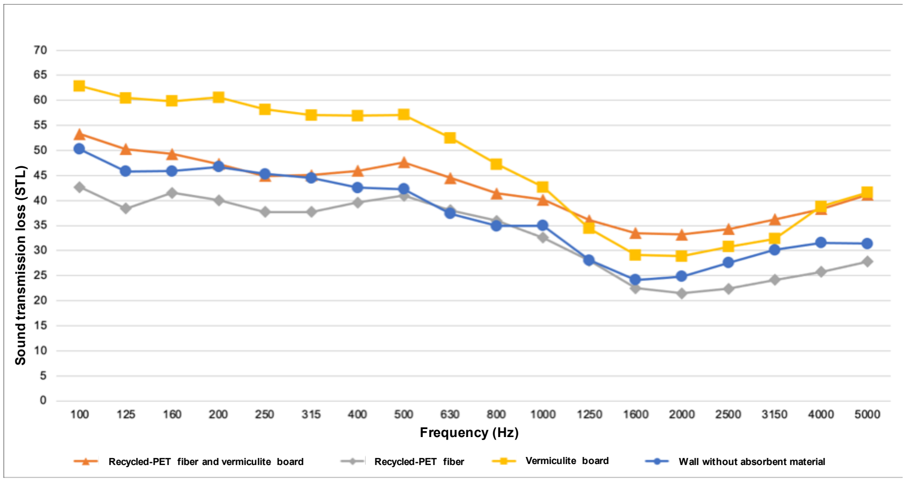

Figure 6. PT Chart: comparison between the four wall configurations. Source: Prepared by the authors, 2024.

In the frequency bands between 100 Hz and 500 Hz, the wall consisting of only vermiculite board presented the highest insulation performance. The STL values ranges from 62 dB to 56 dB. For the ‘complete’ wall system, (with vermiculite board and PET wool blanket inside it) the STL values decreased varying between 53 dB and 44 dB. Similarly, the wall with only PET wool blanket inside it presented also a decrease of their STL values (42-37 dB) in the frequency band 100-500 Hz. For the wall system without absorbent material the STLvalues varied from 50 dB to 42 dB in the same frequency range.

From above500 Hz, the acoustic performance of the wall with vermiculite board inside showed a more pronounced drop in sound insulation than the full wall system. In the LSF system wall with only vermiculite plate inside, a decrease from 57 dB to 28 dB in the 2000 Hz frequency band was observed. In the LSF system wall with only PET wool aSTL drop was also observed in the same frequency range.

In the frequency bands between 1250 Hz and 4000 Hz, the wall composed of vermiculite board and PET wool blanket presented the highest insulation among all experimental tests performed.
The STL curve corresponding to the test performed on the wall built with only vermiculite board showed the highest performance in the frequency bands between 100 Hz and 1000 H. The STL curve composed of the two materials inside showed greater insulation above the 1250 Hz frequency bands. The test performed on the wall performed with only the PET wool blanket showed the lowest PT in the entire frequency range analyzed, except between 630-800 Hz frequency bands.
According to the Table 2, at the critical (fc_1 and fc_2) and resonance frequencies (f_{air}) the STL presented the lowest values.

Table 2. Estimated frequencies of the theoretical curve of the typical STL.

Panels	Frequency band centres (Hz)
Outer panel (cement board) (fc_1)	3,142.42
Inner panel (OSB board and plasterboard) (fc_2) carton)	1,476.31
Natural Air Cavity Frequency (F_{air})	1,888.89
Structural Resonance Frequency (f_0)	93.03

Through this analysis, it was possible to realize that each absorbent material that makes up the LSF wall was responsible for an increase or decrease in the sound insulation. It should also be noted that the gap made in the wall to access the reverberation chamber, as well as the direct contact of the profiles of the movable panel with the steel structure of the wall, contributed to the reduction of STL values. This is due to the acoustic bridges, that is, structure-borne sound transmission due to the contact between metal profiles used in the LSF systems. In addition, the impossibility of sealing the wall at its full might have had some influence on deteriorating the STL performance.

From Table3, it was possible to make a comparison between the *Rw*classification values of different walls. From the *Rw* curve for two absorbing materials inside the LSF system (vermiculite board and PET wool blanket), it is possible to conclude that its performance was the highest one.

Table3. Summary table of R_w determined after the STLexperimental tests for LSF walls. Source: Prepared by the authors, 2024

Sound absorption materials placed in the air space between the boards.	*Rw* (dB)
No absorbing material	29
PET wool blanket	26
Vermiculite plaque	33
Vermiculite board and PET wool blanket	37

It is important to highlight that the classification values defined on the standards facilitate the comparison between LSF wall systems with different configurations. On the other hand, it is evident that they are not able to detail the sound reduction index curve behaviour in the entire frequency range. For a specific evaluation, it is recommended to analyze the sound insulation curve at high, low and medium frequency ranges.

5. Conclusions

This study contributed to the advance of scientific knowledge on the acoustic performance of LSF wall systems. It presented relevant information for professionals and researchers in the field of industrialized construction. As far as one is concerned, the vermiculite board has not been used in the fabrication of LSF systems yet. It is seen that this promising sound-absorbing material can be used inside LSF wall systems for improving their overall acoustic performance. The addition of PET wool blanket might be perhaps an alternative solution.

It is also important to consider the effects of resonant and critical frequencies which cannot be ignored in the evaluation of the LSF system once they can certainly have a significant influence on the results. The mechanical connections between the steel frames must also be considered in the analysis in order to ensure a ‘real’ viable solution for sound isolation in buildings.

The proposed system herein, with the two materials investigated, met the minimum recommendations determined by the Brazilian standard NBR 15575-4 (ABNT, 2021) which considers airborne noise incident on building facades. The results obtained in this research might contribute to the development of buildings with great sound insulation and human comfort. In general, it is believed that the use of vermiculite board may collaborate to a more sustainable approach towards light building constructions.

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