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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 inside and vermiculite board, in accordance with 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 fiber cement board on the external side and OSB (Oriented Strand Board) and drywall on the internal side, with four different internal cavity configurations as follow: a model without any material inside the wall; the second with only recycled-PET fiber; the third with solely vermiculite board; and the last model with both recycled-PET fiber and vermiculite board. The composite with the two investigated materials achieved the value of 37 dB and can be applied in external facades of buildings according to the Brazilian Standard NBR 15575-4 (ABNT, 2021). Furthermore, this study introduces the STL of a previously unexplored product in the LSF system, the vermiculite board.).

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

I. 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 is made faster compared to masonry constructions (Rodrigues and Caldas, 2016). According to Olivieri et al. (2017), the rationalization of the system also favors the reduction of costs on sites and provides better conditions for construction management and workflow due to organized work activities.

LSF began to be used in Brazil in the early 1990s and its use was aimed at the higher social classes (Malta, Arcipreste and Aguiar, 2021). According to Duarte and Daltro (2018), today, large-scale LSF constructions in Brazil are still growing. According to the authors, LSF housing in the country, especially those of social interest, needs improvements in terms of their design, comfort, energy efficiency, and conservation of material resources. Although it is still little used in Brazil, LSF has the potential to become widely used, contributing to the Brazilian housing deficit. This is due to its rationality, which allows a dry construction with little construction waste and faster execution, compared for instance to masonry buildings (Angelis and Serra, 2014). In addition to the benefit of reduced weight, the LSF system has significant stiffness in comparison to its actual weight. It also has shape stability in the presence of moisture. On top of that, the LSF system is practical in terms of prefabricationassembly and might still 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 little access to specialized labor and high-tech machinery for the development of the LSF system compared to masonry constructions. Thus, it makes the LSF system a difficult one to execute and maintain (Gonçalves and Bode, 2015; Malta, Arcipreste and Aguiar, 2021). Despite this, the use of steel in civil construction has considerably increased in recent years. Nowadays, Brazil has developed housing policies, technology and national standards that have much contributed to theadoption of LSF systemsas an powerful alternative to traditional building constructions (Gomes, Souza and Tribess, 2013; Malta, Arcipreste and Aguiar, 2021). On the other hand, as the number of multifamily dwellings with steel-framed partition walls increases, architects and engineers are increasingly confronted with the need to prioritize adequate acoustic performance for the LSF buildings, either through appropriate design solutions or mitigation procedures for noise control. 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.

Noise from urban traffic must also be consideredon noise control designs in order to one achieve the best acoustic performance of a building. The increase in the fleet of vehicles and the lack of territorial planning have contributed to worsening the of noise level in 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 a possible increase in cardiovascular diseases which can impact an individual's quality of life (Botteldooren, Dekoninck and Gillis, 2011; Suriano, Souza and Silva, 2015).

Thus, it is evident that there is some need related to the acoustic performance of buildings tha should be prioritized. It is a fact that choosing the right construction materials may or not contribute to the acoustic insulation.

A material that has recently been used inside LSF wallsto provide an overall better acoustic system performance is the PET wool blanket, which can be recycled. Due to the concern with the production of solid waste in the environment, 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, 12% above the amount recycled PET in 2018. It generated 3.6 billion in revenue (Abipet, 2019). PET recycling promotes social benefits, guaranteeing 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, and also may contribute to the cleanliness of cities. It is possible to recycle 35 PET bottles per m2 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 theirfeatures 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 could be used in LSF that can boost the acoustic performance of the system, is vermiculite. It is a recyclable material, not harmful to the environment neither to humans. Vermiculite is insoluble in water and other organic solventsand 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 acoustic 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 construction, chemical industries, agriculture, among other applications, ensuring its commercial value. In addition, it is flame retardant and hydrophobic (Anm, 2018; França et al., 2016). The mineral has affordable price and also can have commercial advantages in comparison to other materials, such as glass wool and rock wool. Not only the vermiculite but also the PET wool are not yet popular materials used inside LSF walls in Brazil.

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 (Carbajo et al., 2015), not yet used in the LSF systems in Brazil, has physical characteristics to collaborate with the acoustic performance of the systems; second, that the use of both vermiculite board and recycled PET wool blanket (sustainable material already used in LSF) can improve the overall acoustic performance in LSF system housing.

II. THEORETICAL BACKGROUND

LSF constructions can provide acoustic performance to buildingsas quality and properties of the materials used on them are proper considered. When buildings are treated adequately, the acoustic quality of them contributes to the well-being of the user (Roque, Santos and Pereira, 2019).

The sound insulation capacity of a particular wall varies according to the sound frequency. Low-frequency sounds are harder to attenuate while high-frequency sounds are easier. 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), that is, the reduction of a sound that is being propagated from one environment to another is measured considering a wall barrier in between them. R_w the measure of the amount of sound insulation that a partition can provide, being a single classification value.

The Table 1 shows the default sound insulation values $R_w$for the facades, according to the NBR 15575-4 standard (ABNT, 2021). The parameter Lincrepresents 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 Rw airborne noise insulation on (bedrooms and living rooms) – Minimum performance level.Source: NBR 15575-4 (ABNT, 2021).

Noise Class	**Linc Db**	**Rw (dormitory) Db**	**Rw (living room) Db**
I	≤ 60	25 to 29	Not applicable
II	61 a 65	30 a 34	Not applicable
II	66 a 70	35 a 39	30 a 34

According to Way and Couchman (2008), the insulation between wall layers with the presence of air contributes to the increase in the Sound Reduction Index, as occurs in the walls of the LSF system, in which the distance between the layers should be at least 40 mm. In addition, the presence of an absorbent material between the layers of the wall also contributes to insulation.Finally, sealing around floors and walls is important for the complete sealing of the system, especially at the joints between walls and between ceiling and walls. Acoustic sealants or mineral wools are usually used for this purpose.

According to Bies and Hansen (2017) and Bistafa (2018), in a double wall, such as those of LSF, the theoretical curve of the typical STL is presented according to Figure 1. The graph shows the lowest structural resonance frequency (f_0) (Equation 1), which is the lowest of the panel-spacing-panel set (when the natural frequencies of the system are excited by the incident sound) natural frequency. The limiting frequency (f_L) (Equation 2), related to the spacing between the panels. In addition, the critical frequency (Equation 3), (f_{c1}), corresponds to the lowest coincidence frequency of the LSF system, and the critical frequency (f_{c2}) corresponds to the highest critical frequency. Critical frequencies occur when the sound wavelength in the air equal the length of the sound wave propagating in the panel. Furthermore, in some regions of the graph there is a decrease in STL (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.

$$f_L = \frac{55}{d}\,\mathrm{Hz} \qquad (2)$$

Where d is the measure of the cavity spacing between the closing panels, in meters.

$$f_c = \frac{c^2}{2\pi}\sqrt{\frac{M}{B}} \qquad (3)$$

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.

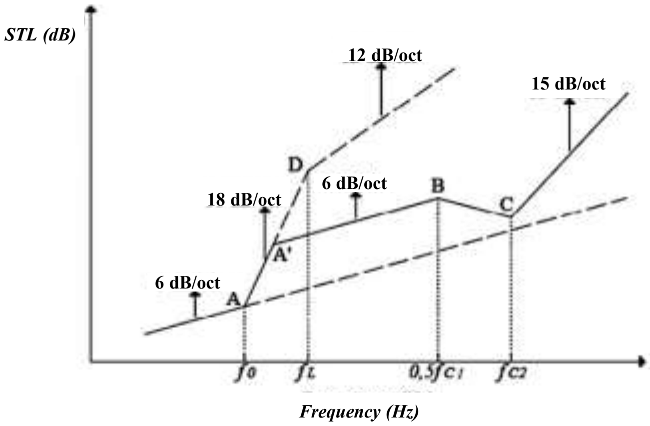


Figure 1. Graph for estimating the STL as a function of the frequency for double walls.Source: Adapted from Bies and Hansen (2017).

Although not present in the STL curve of the double walls, the resonant frequency of the air cavity (f_{air}) also occurs in different vibration modes. It is also responsible for the loss of transmission STL of the wall system (Bies And Hansen, 2017; Gerges, 2000) (Equation 4).

$$f_{air} = \frac{cn}{2d} \qquad (4)$$

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 external seals of the LSF. According to the author, the panel contained only glass wool and an air chamber in the center of the wall. In addition, external coating with synthetic stucco and PVA latex putty on the inside presented a level difference of 39 dB. On the other hand, the wall with no acoustic treatment presented a value of 36 dB. The author concluded that the glass wool contributed to the decrease in the sound transmission at very low frequencies contributing to the overall acoustic insulation.

In the research carried out by Radavelli (2018), typical LSF walls, i.e. walls with resilient bars and walls with acoustic bands were compared. Walls with resilient bars and acoustic bands had a higher $R_w$of more than 3 dB compared to the typical LSF wall. The author suggested that acoustic bands should be used in LSF constructions in Brazil.

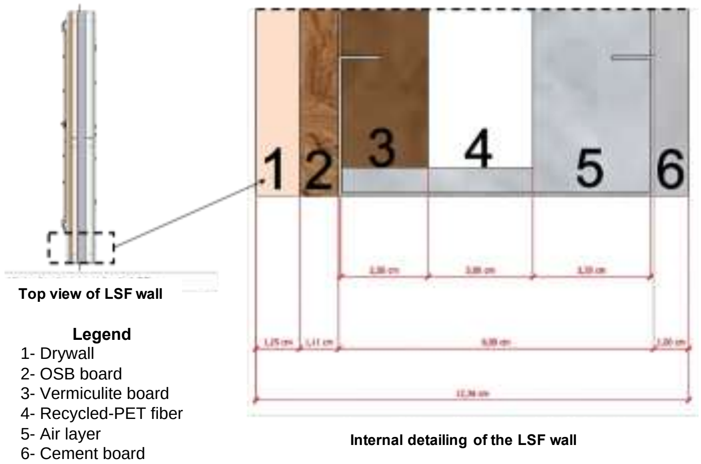
Way and Couchman (2008) presented some construction options to increase the acoustic performance of LSF systems, such as double walls with mineral wool between them. The authors concluded that the double walls presented a sound reduction index (R_w) between 56 dB and 66 dB and walls with resilient barsa value between 59 dB and 62 dB.

III. MATERIALS AND METHOD

To perform the experimental tests of TST on LSF walls, 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 a 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/m²). Their yield strength was equal to 230 MPa. The screws for fixing the plates were drill-point screws and needle-point screws.

The wall was inserted in a gap with dimensions of 110 cm by 235 cm, because of 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 plates were inserted: the OSB and the plasterboard, 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.



Top view of LSF wall

Internal detailing of the LSF wall

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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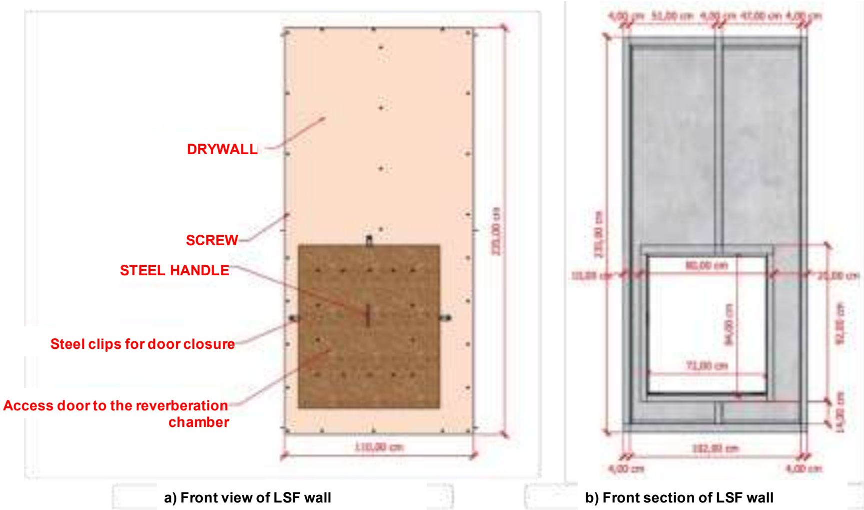

a) Front view of LSF wall

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 using sound pressure, the noise reduction index is given by the Equation (5) below:

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

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 source 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 source used was a balloon, responsible for providing the excitation of the field for measuring the decay of the sound pressure level as a function of time. Due to the background noise, the decay analyzed in the receiving room was 20 dB (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 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 it was possible to determine the Schroeder Frequency (Schroeder, 1987).

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 for all of the four LSF system configurations. 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 ( ).

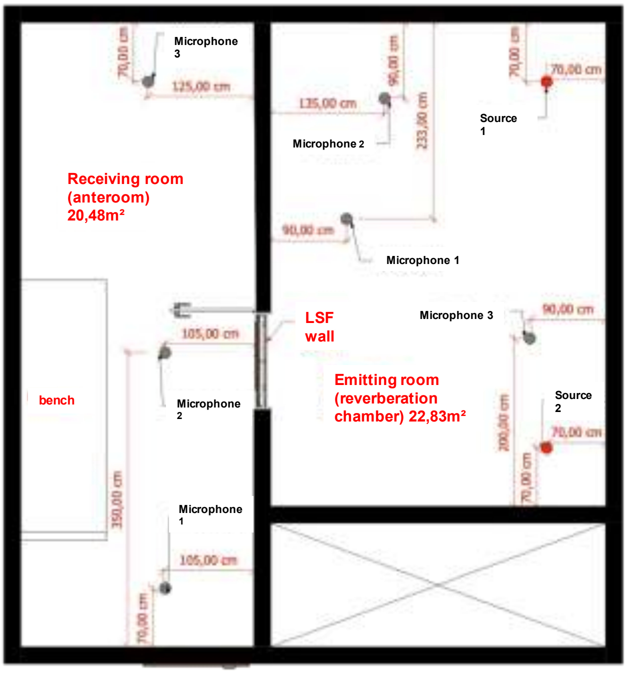

Figure 5. Floor plan: positions of the sound source and microphone during the STL test at LADAE/UFMG.Source: Prepared by the authors, 2024.

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

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

where $L_1, L_2, \ldots, L_n$ 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, according to NBR ISO 717-1 (ABNT, 2021). In this way, it was possible to make comparisons with the minimum sound insulation performance, required by ABNT NBR 15575-4:2021.

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.

IV. RESULTS AND DISCUSSION

After the experimental tests, a comparison chart was prepared comparing the variation of STF with frequency for the four LSF wall configurations. This is show in Figure (6). The coefficient of variation determined in the measurements ranged from 0.40% at the highest frequencies to 5.03% at the lowest frequencies. In all curves, it was possible to notice that from the 500 Hz frequency bands on there was a sharp drop in sound insulation on each wall, as well as a growing increase in sound insulation from the 2000 Hz frequency.

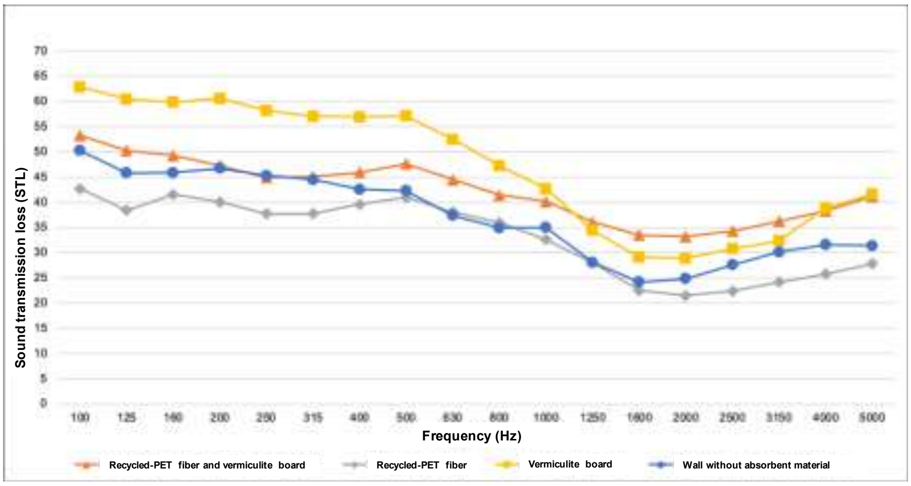

Figure 6. PT Chart: comparison between the four wall configurations.
Source: Prepared by the authors, 2024.

In the frequency bands between 100 Hz and 500 Hz, the wall consisting of only vermiculite board presented the highest insulation with values varying between 62 dB and 56 dB. For the ‘complete’ wall system, (with vermiculite board and PET wool blanket inside it) lower insulation for this frequency range for obtained, with values between 53 dB and 44 dB. In addition, the wall with only the PET wool blanket presented the lowest sound insulation between the 100 Hz and 500 Hz frequency band, with values between 42 dB and 37 dB. For the wall system without absorbent material theSTL results were in the range 50-42 dB in the same frequency range.

From above” 500 Hz frequency bands, the wall with vermiculite board 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)	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 Rwclassification values of different walls. From theRw 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.

V. CONCLUSIONS

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

However, the effects of resonant frequencies and critical frequencies cannot be eliminated and certainly may influence the results. In addition, mechanical connections between the steel frames must be considered in order to ensure a viable solution for sound isolation.

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 all types of airborne noise incident on building facades. The results obtained in this might contribute to the development of buildings with greater acoustic comfort and spatial quality. In addition,the use of vermiculite board may collaborateto a more sustainable approach towards light building constructions.

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