ISOLATION CALCULATION FOR A CHURCH USING THE SAVIOLI METHOD.

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This report presents the calculation of the insulation according to Savioli's method for a 14882 m3 church. This method is compared with the one proposed by Sharp for double panels and conclusions are drawn on the advantages and disadvantages of using one method or the other. The facing is proposed so that the church can perform night concerts in a residential area as stipulated by the Argentinean law 1540.

Keywords: STC, church, design, Savioli, Sharp.

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1. Introduction

When the sound wave hits an obstacle, a vibration is generated in the obstacle. Part of the energy of the wave will be dissipated by the obstacle, part will be reflected, and part will be transmitted to the adjacent room, so that the wall acts as a source of noise in the other room. The transmission loss indicates the capacity of a facing not to transmit the incident sound wave. This loss depends mainly on its mass per unit area, its stiffness (Young's modulus) and the damping in the material (Poisson's modulus). The transmission loss parameter is the ratio between the energy of the incident sound wave and that which is transmitted through the designed facing. There are different types of movement in a facing when impacted by the sound wave. Compression waves, torsion waves and bending waves.

There are authors who each present their own prediction method to estimate the transmission loss of a facing, and these methods are only useful for certain types of facing. This paper compares Sharp's method (5) for double cavity panels with the method proposed by Savioli (1).

2. Theoretical framework and model comparison

Two different methods for the design of double air cavity walls will be compared. Sharp's proposal takes into account three working zones of double walls:

$$R_{f<f_0} = 20 * \log_{10}(m_1 + m_2) - 48\, dB \qquad (1)$$

$$R_{f_0<f<f_l}=R_{m(1)}+R_{m2}+20*\log(10)\,(m_1+m_2) \tag{2}$$

$$R_{f_l<f}=R_{m_1}+R_{m_2}+6 \tag{3}$$

These three regions are separated at the frequency f_0 of resonance of the mass-spring-mass system, and f_l is the limiting frequency, at which the cavity effects do not influence the isolation.
The terms R_{m_1} and R_{m_2} are the insulation of each of the two layers that make up the wall.
facing. This insulation will be calculated by the single panel method with corrected mass.

$$R_{f<f_0}=20*\log_{10}(m_1+m_2)-47\,dB \tag{4}$$

$$R_{f_c<f}=20*\log(10)\,(m\,(1)+m\,(2))-47dB-10*\log(10)\,(\frac{\pi}{4\eta})-10*\log_{10}(\frac{f_c}{f-f_c}) \tag{5}$$

With η the damping factor of the material.
According to the mass law (equation 1 and 4), the theoretical sound insulation of the enclosure increases by 6 dB each time the mass doubles. In turn, it also increases by 6 dB each time the frequency or surface mass doubles.
When the frequency of the incident wave coincides with the natural frequency of the material, the insulation drops to its minimum level, and can mean a loss of up to 10 dB depending on the material. This frequency is called the critical frequency.
For the single panel method, the critical frequency is calculated as:

$$f_c=\frac{c^2_{(0)}}{2\pi}\sqrt{\frac{m}{B}} \tag{6}$$

Where c_0 is the air velocity, m is the surface mass of the building material, and B is the stiffness of the material, which can be calculated as:

$$B=\frac{E}{1-\theta}\frac{h(3)}{12} \tag{7}$$

With h the material thickness, and θ the Poisson's modulus.
Although all these parameters are known, in general, for common materials in construction, it is to be expected that some kind of error is being made in these calculations, since there may be coefficients that are affected by issues that cannot be controlled, such as climate, taking into account humidity and temperature, these parameters may be modified. Therefore, by trying to increase the accuracy of these models, we are falling into another type of problem that prevents the model from being more accurate.
On the other hand, Savioli proposes a much simpler method, where it is not necessary to have knowledge of all the parameters seen in the previous methods. He proposes that the isolation depends on:

$$R=20*\log_{10}(\frac{m*2*\pi*f*\cos\alpha}{2*D*c_0}) \tag{8}$$

With D the density of the air, and α the angle of incidence of the wave on the surface of the material, for our case this parameter will always be 90º.
And the critical frequency proposed is:

$$f_{critica} = 60 * \sqrt{\frac{1}{d} * \left(\frac{1}{m_1} + \frac{1}{m_2}\right)} \qquad (9)$$

Being d the cavity that separates both faces of the facing, and m_1 and m_2 the resulting surface mass of all the materials that compose each face of the facing. The simplification of
The simplification of this method lies in the fact that it is not necessary to know the Poisson's modulus, Young's modulus, or the loss factor of the materials. In addition, this method assumes that the worst insulation level is the one corresponding to the critical frequency, and from this frequency it calculates the insulation, which according to the author increases 8 dB for each frequency doubling. Therefore, in this method the calculation is made from the critical frequency of the facing, and not at lower frequencies.
There are clear advantages to using one method or the other. The results of comparing different faces of different materials, where the dimensions were kept fixed, are attached in the appendix. Two faces of 12.5 mm section, separated by a 10 cm cavity. As a general rule, it is observed that the Savioli method is a straight line that always results in an insulation index lower than that indicated by Sharp. This is probably related to the fact that Savioli's text is called 'Practical Acoustics', in which he does not want to delve into theoretical facts, but into results. For this reason, the increase of the isolation as a function of frequency is a value that, besides being a result of his personal experience, is related to constructive and assembly issues of the materials.
On the other hand, when having a double enclosure, resonances arise inside the chamber, so it is recommended to fill between 50% and 75% of this cavity with filling materials. A smaller amount of absorbent would imply a decrease in insulation, and a filling greater than 75% implies an increase in cost without improving the results.

3. Location

The design of the church is presented in Figure 1.

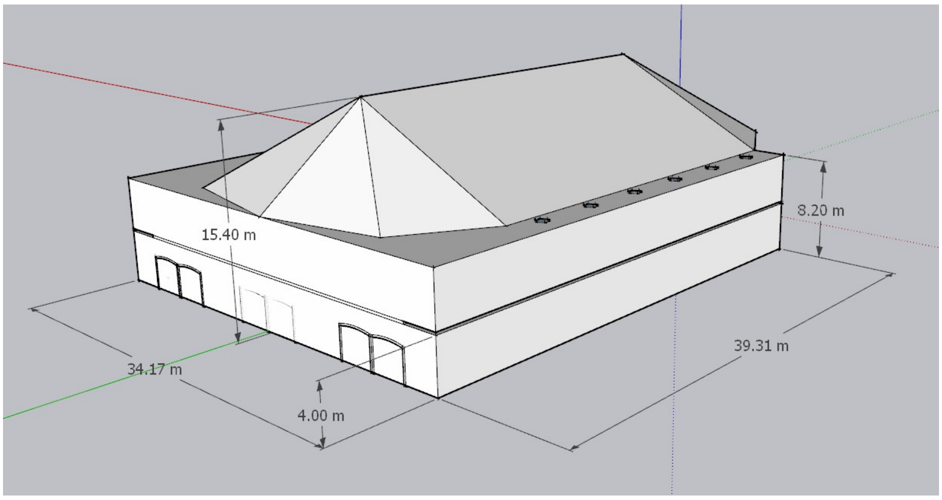

Figure 1. Exterior view and detail of dimensions of the church design (2).

A building is assumed next to the church and joined by an area of 82 m^2. The enclosure is evaluated for organ concerts with an SPL level of 100 dB for the octave bands of 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz, totaling 107 dB SPL, which is a higher level than that proposed in previous investigations (6)(7).
The necessary isolation is proposed according to the Argentinean law 1540 (3), which aims to prevent, control and correct noise pollution that affects people, the environment and buildings, protecting them against noise and vibration. Assuming that the church is located in a type VII zone, housing area in a type IV or V noise sensitivity zone, the maximum permissible limit of noise immission from fixed sources in an indoor environment in a habitable area is 60 dBA in the daytime period and 50 dBA in the nighttime period.

4. Results

The calculations performed result in a critical frequency of 44 Hz, with an isolation level of 33 dB at that frequency. Figure 2 shows the result of the design according to Savioli's method. For the proposed SPL levels inside the church, the levels in the adjoining room comply with Law 1540. Figure 2 shows the frequency isolation of the wall designed according to the Savioli method:

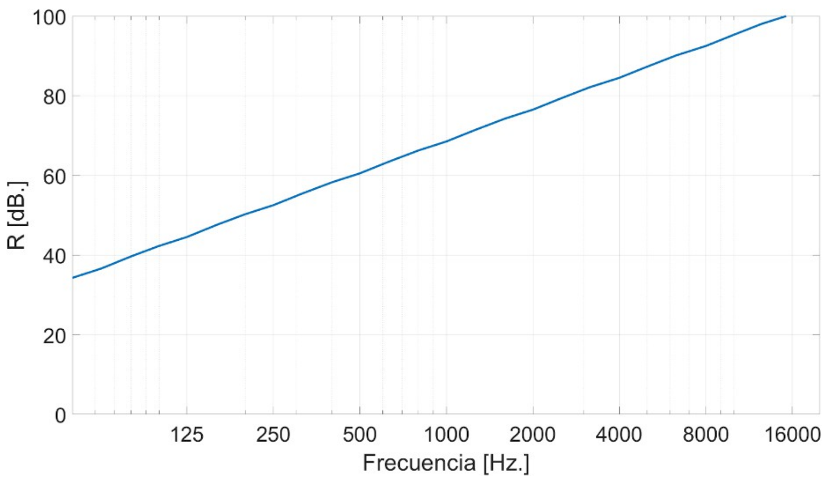

Figure 2. Insonority calculated by the Savioli method.

Table 1 shows the results and effectiveness of the facing, confirming that this design complies with the requirements of the current regulations. It should be noted that if it complies with this method, it also complies with the method proposed by Sharp.

Table 1. SPL level transmitted by the facing in dB....

	125	250	500	1000	2000	4000	Global dB
SOURCE	100	100	100	100	100	100	107.8
R	44	52	60	68	76	84	51.0
LEVEL	56	48	40	32	24	16	56.7

SPL level transmitted by the facing in dBA.

	125	250	500	1000	2000	4000	Global dBA
SOURCE	100	100	100	100	100	100	106.3

POND. A	-16.1	-8.6	-3.2	0	1.2	1	
SOURCE A.	83.9	91.4	96.8	100	101	101	
R	44	52	60	68	76	84	62.2
LEVEL	39.9	39.4	36.8	32	25.2	17	44

It can be observed that the overall level in dB in the church is 107 dB, and the insulation capacity of the walls reduces the level to 56.7 dB or 44 dBA. This exceeds by 6 dB the level proposed by law 1540.

5. Conclusions

The conclusion is that a facing designed by the Savioli method, although it is a simplified method, generally yields a lower isolation result than the Sharp method, so it can be stated that, if a design is made with this method, the facing will meet the requirements needed by the Sharp model, thus avoiding the use of models that require greater complexity.
In spite of this clear advantage of Savioli's method over Sharp's, due to its easy and fast implementation, it is always necessary to keep in mind that the critical frequency obtained implies that this frequency must be one octave below the frequency of interest to be isolated.
Another point to take into account is the legal and economic issue. Regarding the economic aspect, it is to be expected that a facing calculated using the Savioli method will be more expensive, at least from the point of view of materials, since the insulation index obtained with this method is lower compared to the Sharp method. From the legal point of view, as observed in this work, it is to be expected that the designed and calculated facing complies with current regulations, since, if the facing is calculated through the Savioli method and complies with the necessary requirements, it also complies with other methods. This has already been clarified, it is probably linked to the experience of Savioli, who developed as a professional Civil Engineer, and does not have a theoretical development, but that this slope of 8 dB per octave is linked to his experience and to problems of assembly and construction of the facing. In particular, this slope, which attenuates less than other methods, is made to compensate for the accuracy of the assembly by the construction personnel, the location and placement of fixing points, and other issues that exceed the theoretical framework.

6. References

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[3] Decree Nº740 Regulation of Law Nº1540 (2005)
[4] Colther, Cristian. Review of Predictive Models of Wall Sound Insulation (2010).
[5] Sound Pressure Levels in Churches in Port Harcourt: A Study of Some Catholic, Anglican and Pentecostal Churches, Chibuike Nwosu (2017).
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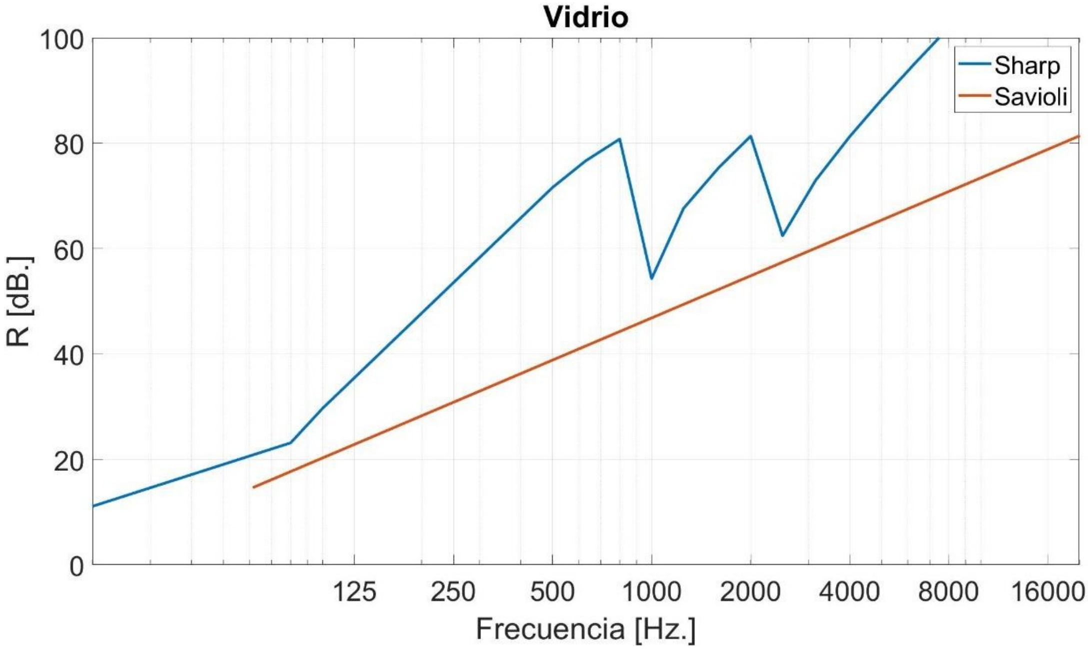
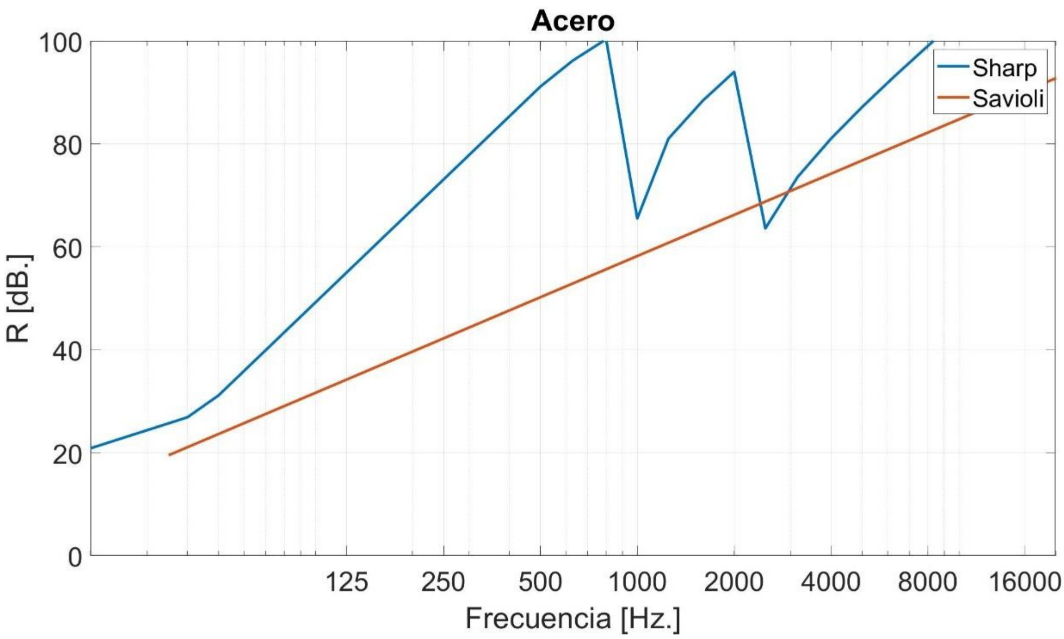
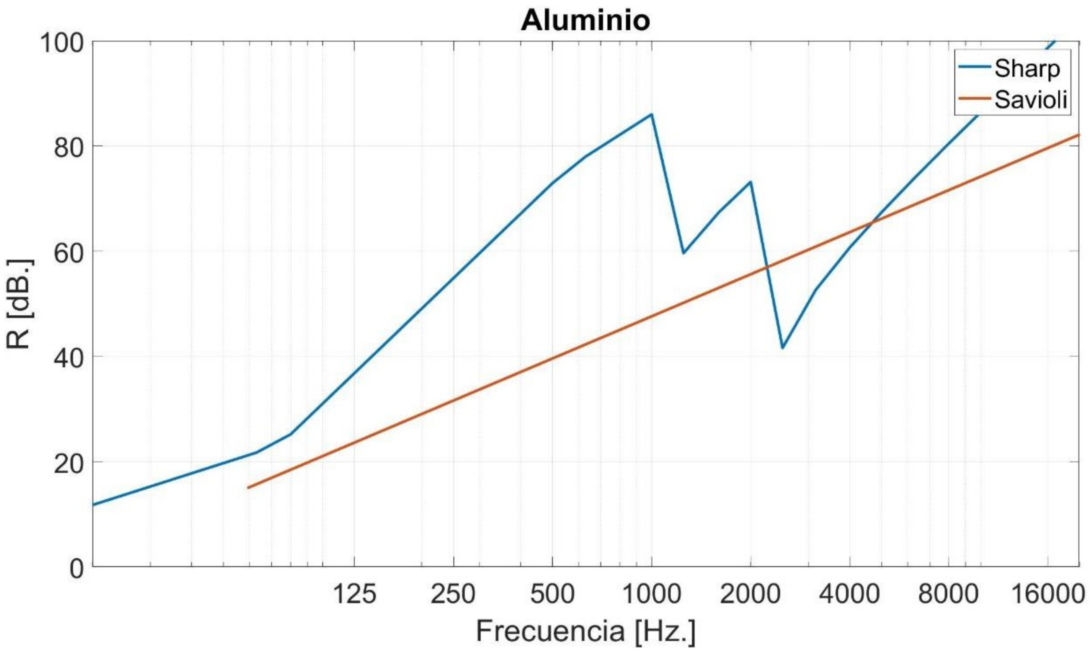
7. Annex

Comparison of Savioli and Sharp method in panels of the same material and thickness for different materials.



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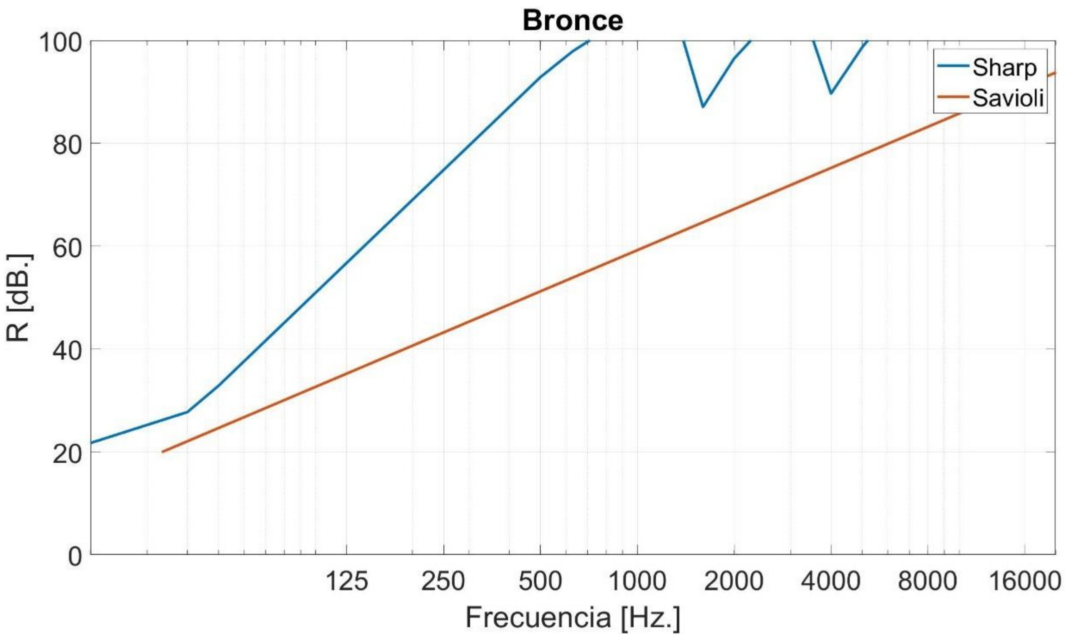
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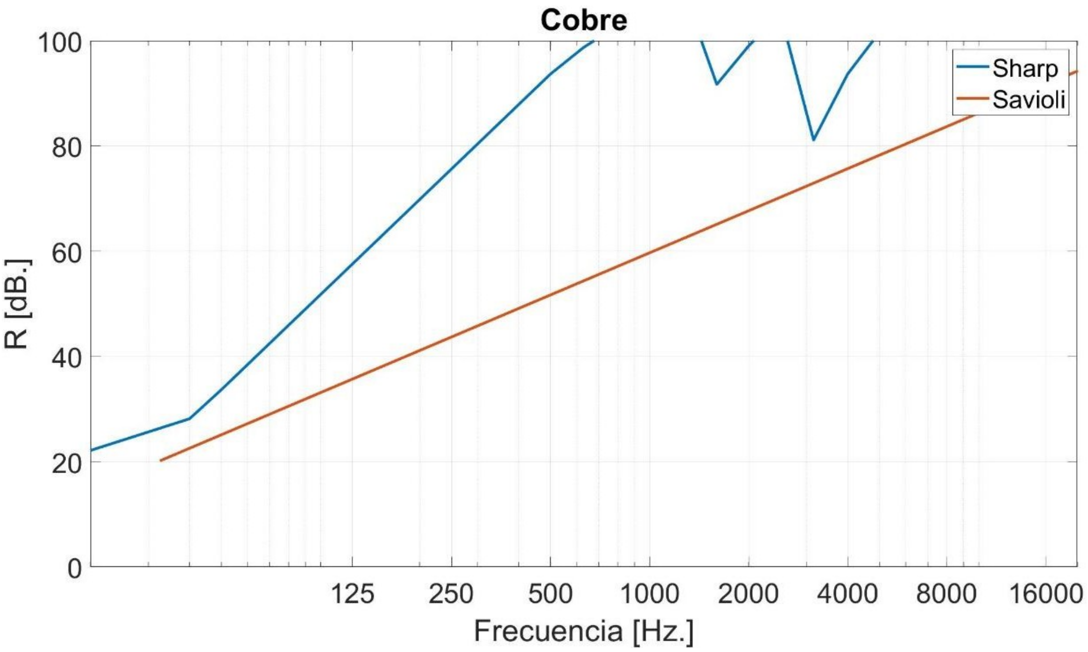
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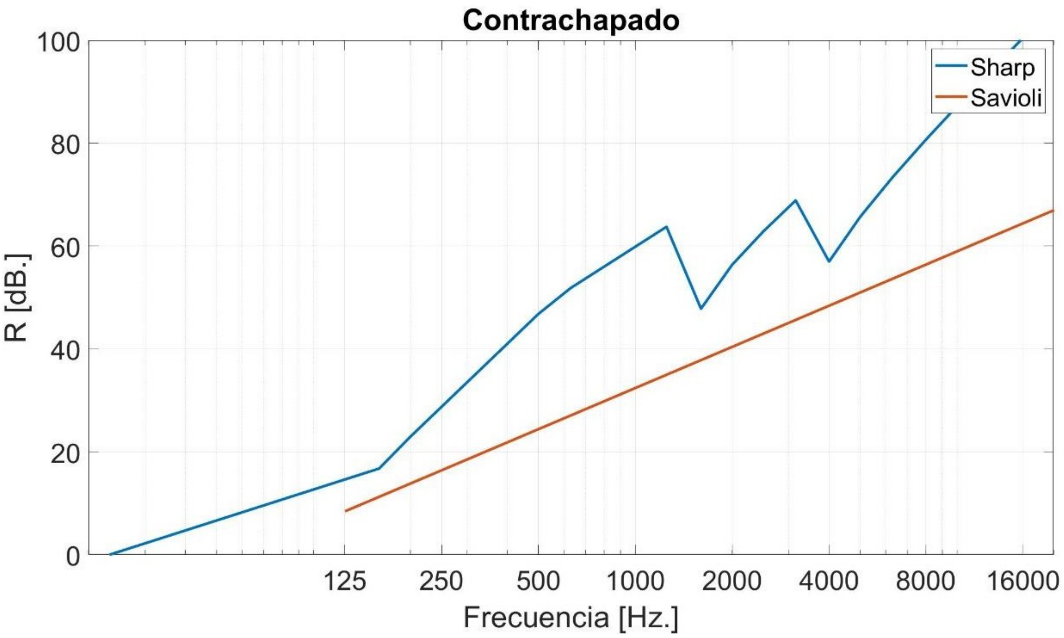
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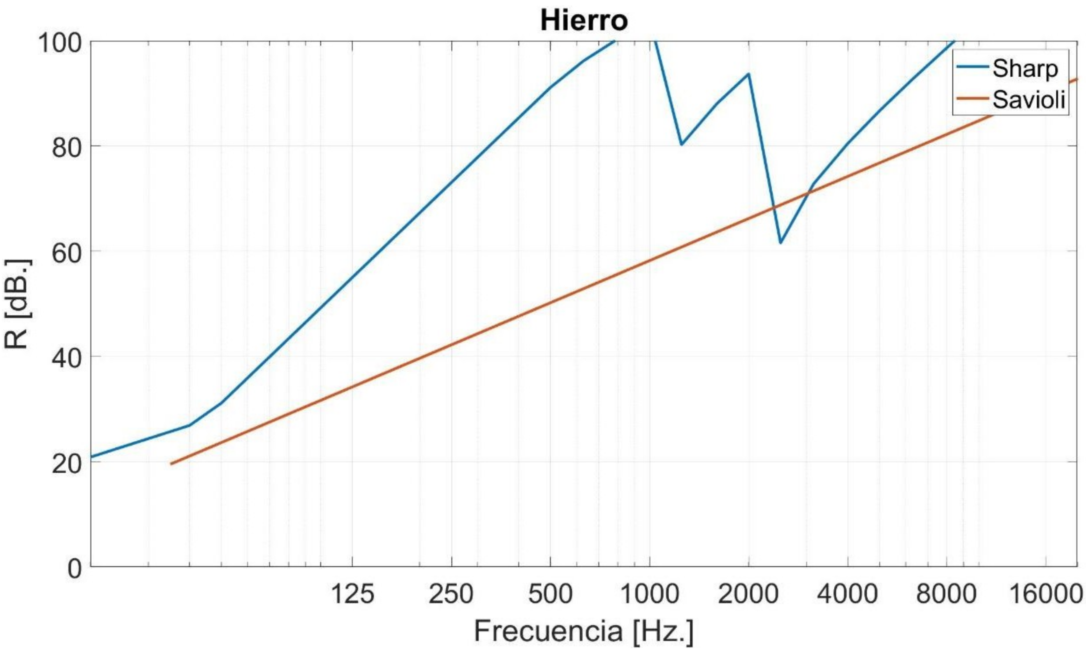
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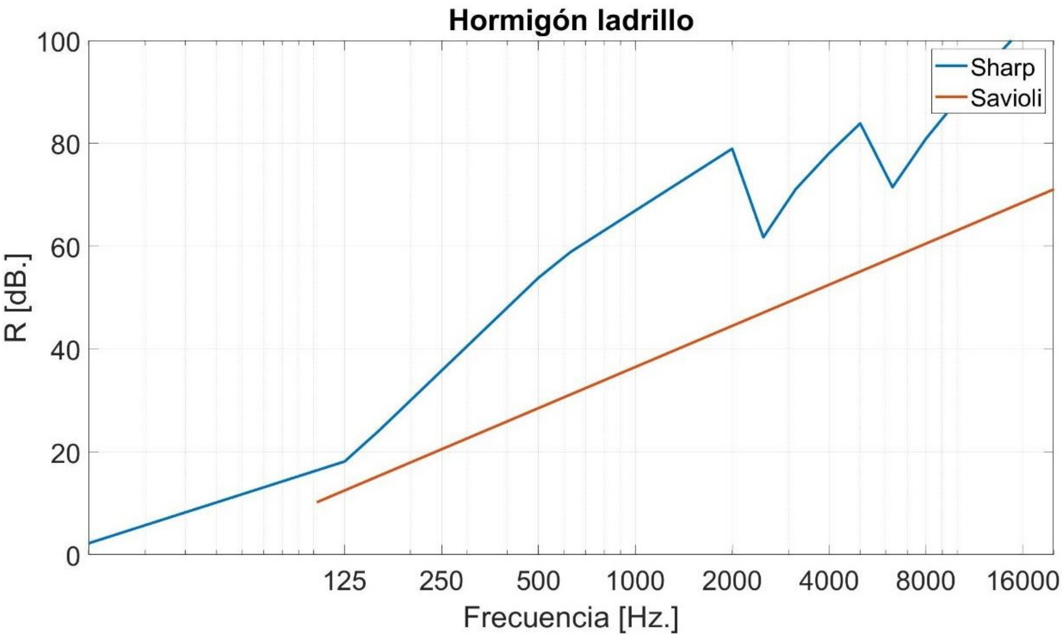
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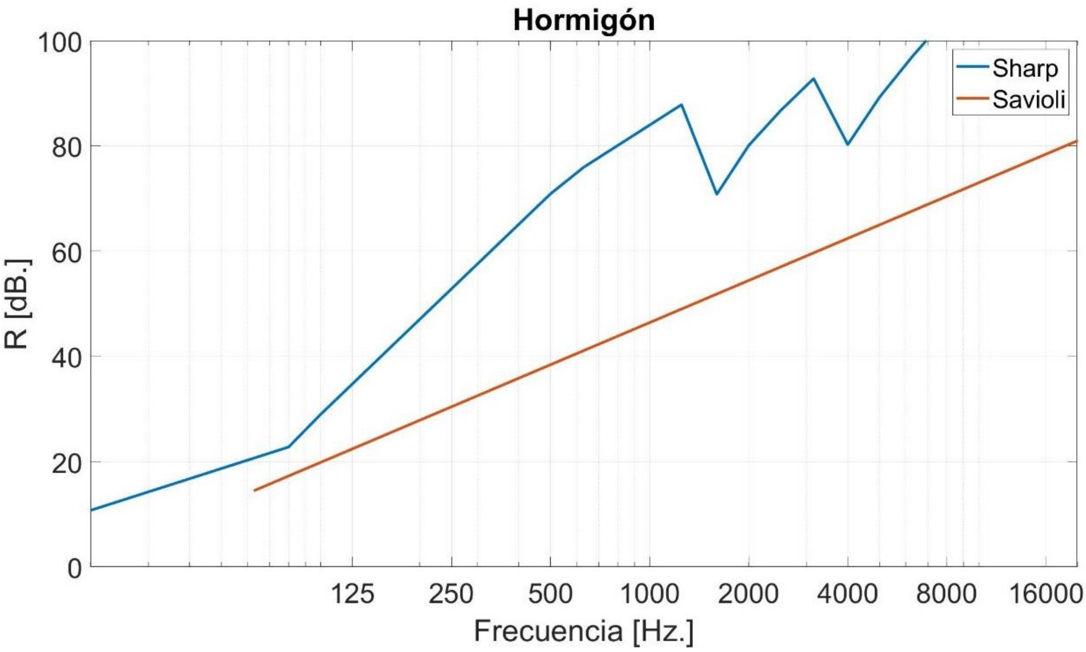
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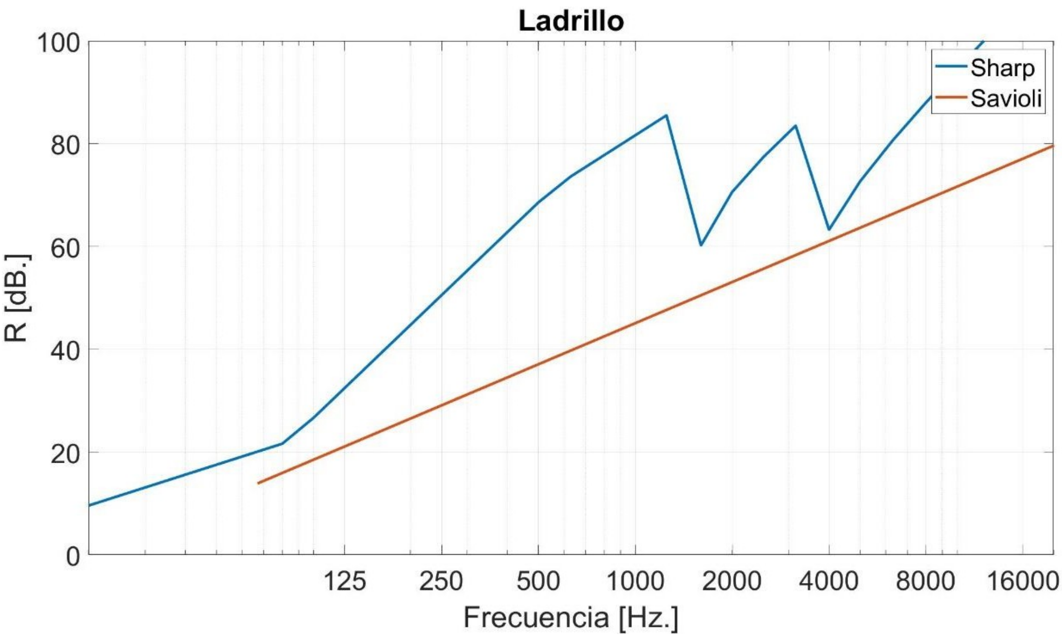
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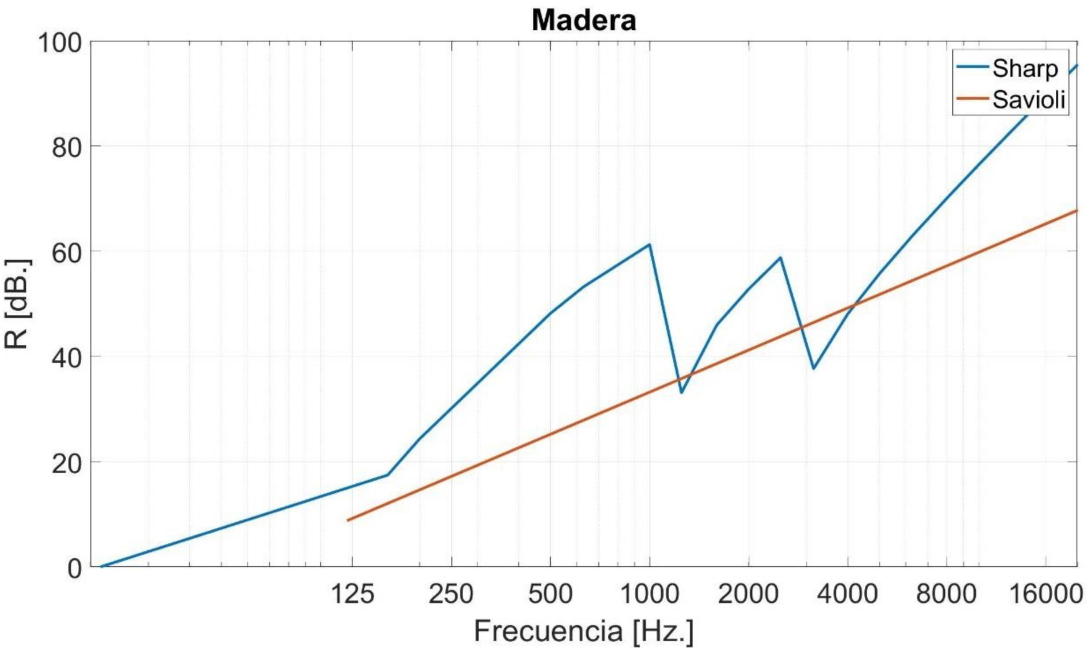
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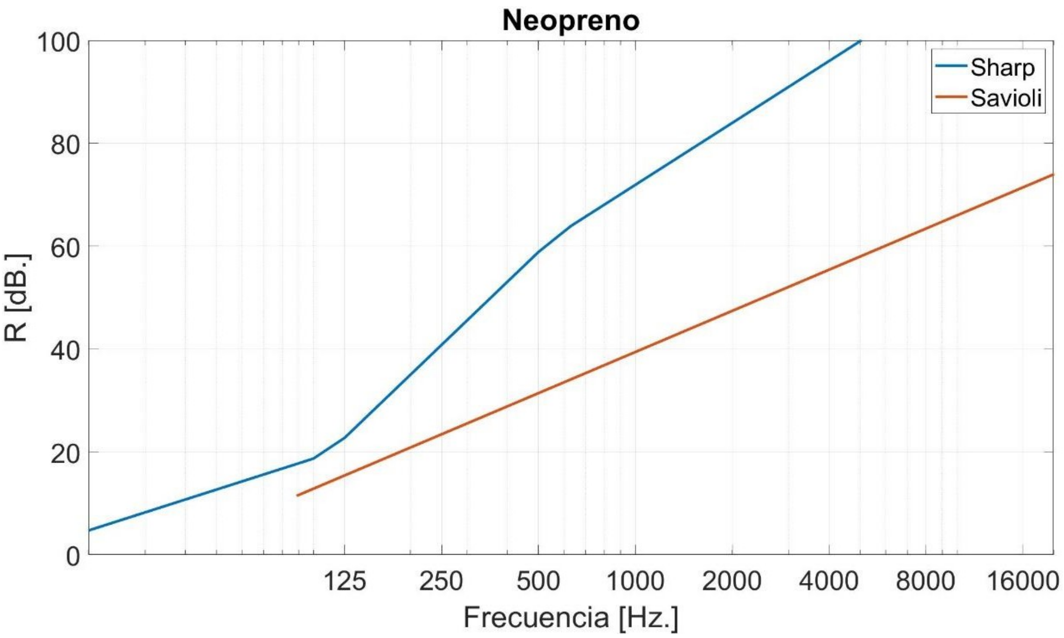
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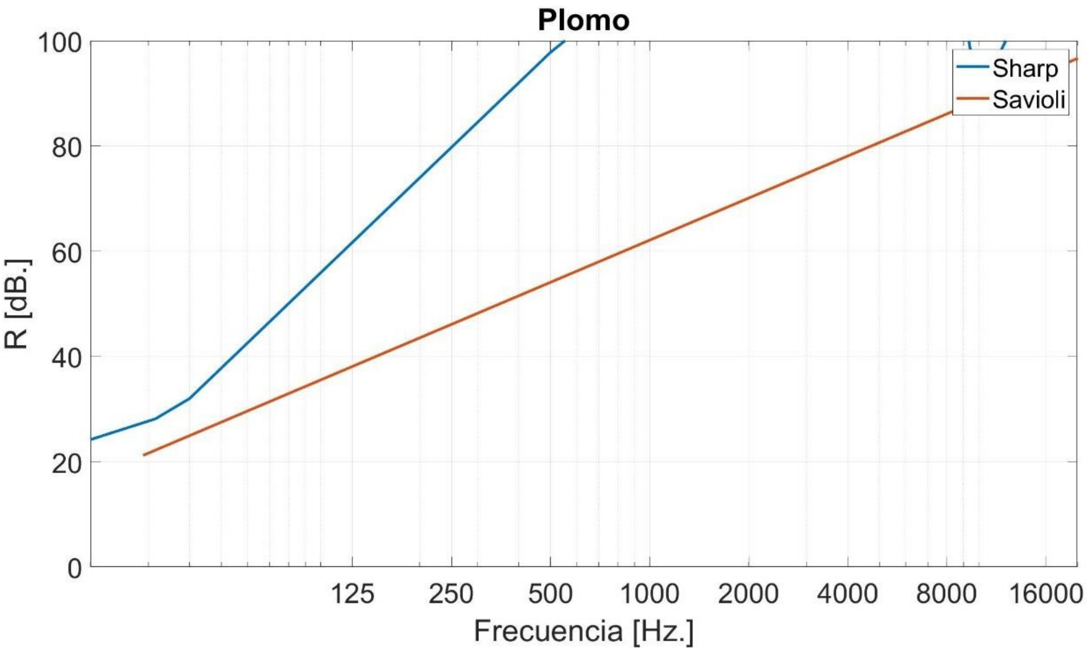
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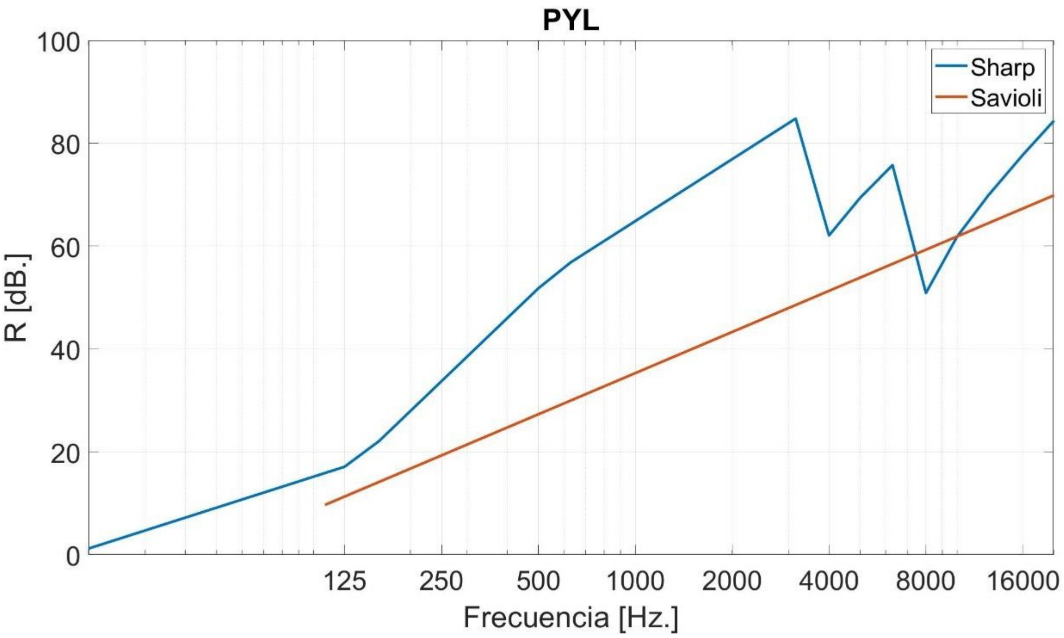
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