



Low-cost acoustic ventilated elements for social housing facades

Guilherme Fagerlande¹, Thiago Melo Grabois², Maria Lygia Niemeyer³

Universidade Federal do Rio de Janeiro

Av. Pedro Calmon, 550 - sala 433 - Cidade Universitária, Rio de Janeiro - RJ

ABSTRACT

The humid tropical climate, common in several regions of Brazil, requires specific design guidelines to ensure thermal and acoustic comfort in buildings. While natural ventilation is recommended, it is equally crucial to mitigate external noise, particularly in large urban centers. An effective solution to this problem is the use of ventilated construction elements with acoustic properties on facades. This work is divided into the following stages: 1) theoretical foundation on the importance of ventilated elements with acoustic attenuation for facades; 2) literature review and geometric analysis of ventilated facade elements with potential applications in low-cost construction, exploring the relationship between geometry and acoustic performance; and 3) proposal of an optimized ventilated element geometry to be developed in a later stage of the doctoral research, based on the findings from previous investigations. By advancing these solutions, the study aims to enhance compliance with performance and thermoacoustic comfort standards. Its findings could have a significant impact, particularly in developing countries like Brazil, by improving building energy efficiency, promoting user health and comfort, and offering cost-effective alternatives to existing industrial solutions.

1. INTRODUCTION

In urban centers, one of the growing demands is the acoustic attenuation of facades. However, most noise control devices do not allow natural ventilation, requiring continuous artificial climate control and resulting in buildings with low energy efficiency. Therefore, future cities demand the development of sound insulation solutions for facades that also allow acceptable levels of natural ventilation for users [1].

The rising cost of land leads to urban densification, where residential, commercial, and industrial buildings are often constructed close to one another. In such contexts, ventilation equipment that generates noise and cannot be fully enclosed requires solutions that permit air exchange without causing noise pollution to the building itself or its surroundings [2].

Natural ventilation is the most efficient bioclimatic strategy for thermal comfort in hot and humid tropical climates. In addition to dissipating building heat loads, studies show that users prefer naturally ventilated spaces, associating them with increased productivity, particularly in commercial buildings.

¹ guilherme.fagerlande@fau.ufrj.br

² grabois@fau.ufrj.br

³ maria.niemeyer@fau.ufrj.br

However, its application in urban areas is challenged by noise and air pollution from road traffic—problems that are intensifying with urban growth and global urbanization. Research over the past two decades has investigated human comfort, acoustics, and thermal behavior, but has primarily focused on temperate climates such as those in China and Europe. There is a gap in studies concerning the impact of such technologies in tropical climates, where natural ventilation is advisable. Yet, it demands large openings, while acoustic comfort requires closed facades, creating conflict in design decisions. Therefore, designers must seek balanced facade solutions that permit ventilation while blocking external noise [3].

Enhancing the acoustic insulation of facades can be achieved using specific materials, constructive modifications, changes in facade geometry, or the incorporation of balconies as sound insulation elements. The European standard EN ISO 12354-3 [4] provides a simplified method for assessing the impact of facade geometry on the reduction of a building's external sound power levels. The evaluation considers facade typology, sound directionality, and the acoustic absorption coefficient of the balcony's lower surface. Simulations show that larger balconies and deeper facade setbacks lead to less noise incidence. In staggered facades with solid parapets, noise level reductions can reach up to 10 dB [5].

Architectural shading devices – such as brise-soleils, “cobogós”, pergolas, shutters, and mashrabiya – serve to shield facades from direct sunlight while maintaining ventilation and lighting, in addition to ensuring indoor privacy. These elements reduce internal heat gain and contribute to facade design. They are particularly suitable for hot and humid tropical regions, such as most of Brazil. Depending on building orientation and solar exposure, different elements can be used, and their position and tilt influence thermal performance [6].

Before the invention of mechanical cooling systems, humans creatively harnessed natural resources for ventilation and thermal comfort in hot climates. One example is the wind tower – a structure mounted atop buildings to capture high-altitude winds and direct them indoors. In the Middle East, especially in the Gulf countries, wind towers have been used for centuries to cool and ventilate buildings, ensuring occupant comfort. Although their exact origin is hard to determine, excavations in the 1970s revealed evidence of wind towers in Tappeh Chackmaq, Iran, dating back to 4000 BCE. These architectural features are common in countries like Iran, Egypt, Syria, Iraq, and the Gulf states [7].

Oliveira [8] also highlights the use of responsive structures and kinetic components for facade shading through digital tools, aiming to enhance indoor thermal comfort and building energy efficiency. Responsive facades can reduce building energy consumption and carbon emissions by actively responding to environmental stimulus.

Cortês [9] emphasizes the context of Rio de Janeiro:

“Rio de Janeiro also faces the dichotomy between thermal and acoustic comfort, as it requires natural ventilation to maintain hygrometric comfort, thereby increasing exposure to external noise. To enable the use of natural ventilation as a passive cooling strategy, it is essential to address acoustic issues on the urban scale as well. (...) Thus, ventilation is perceived as one of the most important strategies for Brazilian Bioclimatic Zone 8.”

Oliveira [10] notes that colder countries have an advantage regarding acoustic comfort, as thermal comfort in these regions requires greater sealing of facades – resulting in convergent design guidelines, unlike the scenario in Brazilian Bioclimatic Zone 8.

Maciel [11] analyzed passive industrial acoustic louvers and observed that, in the cases investigated, the transmission loss at frequencies below 500 Hz was lower than 20 dB, regardless of the model or manufacturer. It was also noted that increasing the thickness of these louvers contributes to greater transmission loss only at frequencies above 1 kHz and is therefore not an essential strategy for improving sound insulation at low and mid frequencies.

Based on the literature reviews by Coutinho et al. [3] and Costa et al. [1], and subsequent publications, this work aims to identify effective geometries for ventilated acoustic elements for facades that can be implemented in low-cost social housing projects, contributing to compliance with thermal-

acoustic comfort standards. Ultimately, the aim is to propose a cost-effective acoustic ventilated element geometry for building facades.

2. METHODOLOGY

To develop this study, a selection of publications was carried out, focusing on the use of passive natural ventilation systems through ventilated elements with acoustic attenuation. The selected works needed to present conventional geometries and materials typically used in building facades and be suitable for low-cost construction applications. The selection criteria included: high levels of acoustic attenuation; geometric configurations that could be executed on-site; the possibility of using widely available, low-cost materials; and the feasibility of employing construction techniques accessible to the general population, without requiring highly specialized labor or industrial-scale manufacturing.

Publications addressing active ventilation or noise control systems, those involving metamaterials or high-cost materials, and those dependent on highly specialized or industrial labor were excluded from the review.

Based on these criteria, the following solutions were selected for further analysis: acoustic “cobogó” [6], ventilated sill [12], crosstalk-type silencers [13], ventilated panel [14], and acoustic louvers [2].

Finally, this study proposes low-cost acoustic ventilated element geometries based on the analyzed references. These geometries aim to provide thermal comfort, acoustic comfort, and energy efficiency in buildings, while also ensuring economic feasibility for construction projects in developing countries, particularly in hot and humid regions such as Bioclimatic Zone 8 in Brazil.

These proposed geometries will be evaluated in laboratory settings during subsequent phases of the doctoral research, using full-scale prototypes.

2.1. Ventilated Sill

Oiticica [12] proposed a solution combining thermal and acoustic comfort through a ventilated sill, where measurements were taken using different materials and cavity compositions, both with and without mineral wool. The ventilated sill allows airflow through an opening of 1.19 m x 0.20 m (0.238 m² cross-sectional area). Results showed facade sound insulation ($D_{2m,nT,w}$) of up to 26 dB in configurations using layered assemblies of reflective panels, mineral wool, and perforated plates made of metal and PVC. This represented a 14 dB improvement over a louvered window, which achieved only 12 dB. These materials are commonly available in the Brazilian construction market, although their application on-site requires skilled labor, typically associated with HVAC installations and PVC window frames.

2.2. Acoustic “Cobogó”

Araújo [6] presented another solution: an acoustic “cobogó” constructed on-site using a 1:3 mortar mix of cement and sand. Acoustic insulation tests were carried out on facades with different configurations, using large and small “cobogós”, both with and without mineral wool in their internal cavities. Small “cobogós” measured 20 cm x 20 cm x 20 cm, with 3 cm wall thickness and a 5 cm x 17 cm airflow opening. Large units measured 30 cm x 20 cm x 30 cm, also with 3 cm walls, and a 5 cm x 27 cm opening. Both the small and large “cobogós” achieved facade sound insulation values ($D_{2m,nT,w}$) of 27 dB, performing better at mid and high frequencies. In this study, mineral wool did not significantly increase sound attenuation.

2.3. Crosstalk-Type Silencers

Bibby and Hodgson [13] evaluated wall-mounted crosstalk silencers – ducts lined internally with sound-absorbing material – in laboratory conditions. Three shapes were tested: straight, L-shaped, and Z-shaped, each with a 0.3 m airflow path. Due to transmission loss limitations in the testing facility,

longer ducts were not examined. Full-scale prototypes were built from 25 mm plywood and lined with 50 mm fiberglass on both sides. Ducts had internal sections of 20 cm x 20 cm without the lining and 10 cm x 10 cm with it. Acoustic performance was similar across formats, with STC values of 9 dB (straight and L-shaped) and 10 dB (Z-shaped). However, the straight silencer performed better in terms of airflow.

2.4. Ventilated Panel

Du et al. [14] investigated acoustic attenuation in ventilated facades using staggered panel openings lined with absorbent materials. The windows measured 1.0 m in width and 1.8 m in height, with partitions made of 9 mm thick calcium silicate boards. Openings were 0.225 m tall and spaced 0.082 m apart. Seven microphones were positioned along the air and sound path between the panels. STC values ranged from 22 dB to 31 dB, an improvement of up to 20 dB compared to untreated configurations. The untreated system showed an STC of 11 dB, while the closed system reached 31 dB. When 25 mm fiberglass was applied along the panel frames, an STC of 22 dB was achieved. Layering this material along the panel increased the STC to 31 dB, while lining only the upper and lower sides of the cavity resulted in 26 dB.

2.5. Acoustic Louvers Lined with Recycled Tire Rubber

Strazdas and Januševicius [2] explored the use of shredded recycled tire rubber to line acoustic louvers in laboratory tests. Nine different rubber panels were initially tested in an impedance tube for absorption and transmission loss, with two configurations selected for further analysis. These panels were mounted on wooden louver structures and tested in a semi-anechoic chamber under ISO 10140-2/2021 standards, with variations in panel thickness, inclination angle (15°, 30°, 45°), and porosity. The test setup featured two identical rooms separated by a 1 m × 1 m aperture housing the louver panel. The receiving room contained a microphone, while the transmitting room used an omnidirectional speaker. The best performance came from 30 mm thick louvers inclined at 45°, achieving a maximum noise reduction of 17.3 dB (at 8000 Hz) and a maximum equivalent sound level (L_{Aeq}) reduction of 7.3 dB(A).

3. PROPOSED LOW-COST ACOUSTIC LOUVER

Based on the reviewed references, several conclusions can be drawn about acoustic perforated elements:

- The ventilated sill [12], acoustic “cobogó” [6], Z-shaped crosstalk silencer [13], and ventilated panel [14] share geometries that create sinuous airflow paths, which allow sound energy to be partially absorbed by cavity walls, with or without added absorbent material.
- Increased internal wall surface area enhances sound attenuation, as observed in the crosstalk silencer comparison [13].
- Except for the acoustic “cobogó” [6], sound attenuation improves with greater surface area covered by absorbent material.
- The reuse of recycled materials, such as tire rubber [2], is essential for sustainable construction.

Based on these insights, the study proposes the development of acoustic ventilated elements suitable for low-cost construction using on-site methods, requiring no specialized labor. These elements aim to meet performance standards for thermal and acoustic comfort. Full-scale prototypes were built and will be acoustically tested in the next research phase.

Reinforced mortar was selected for its potential in fabricating these elements due to its plasticity, ease of use, low cost, and durability, despite high cement content. Orthogonal shapes with 2 cm thickness were chosen to simplify formwork and modular assembly with standard concrete blocks (14 cm thick) as supports. The L-shaped monolithic structure helps eliminate gaps between layers and prevent sound leakage.

Mineral wool will be tested within the internal cavities, as it has proven effective in many reviewed cases. The proposed louver designs are self-supporting and vertically stackable to cover full wall height. Mortar will be used for assembly and sealing.

The doctoral research will also explore the inclusion of waste materials – tires, plastics, concrete residues – and cement substitutes such as lime or natural pozzolans to enhance sustainability. Both proposed louver types incorporate rain protection by orienting the lower opening outward and elevating the mineral wool in moisture-prone areas.

Figure 1 illustrates Acoustic Louver A geometry, supported by half-blocks ($14 \times 19 \times 19$ cm), while Figure 2 shows Acoustic Louver B, supported by full blocks ($14 \times 19 \times 39$ cm). Both were modeled in the software SketchUp.

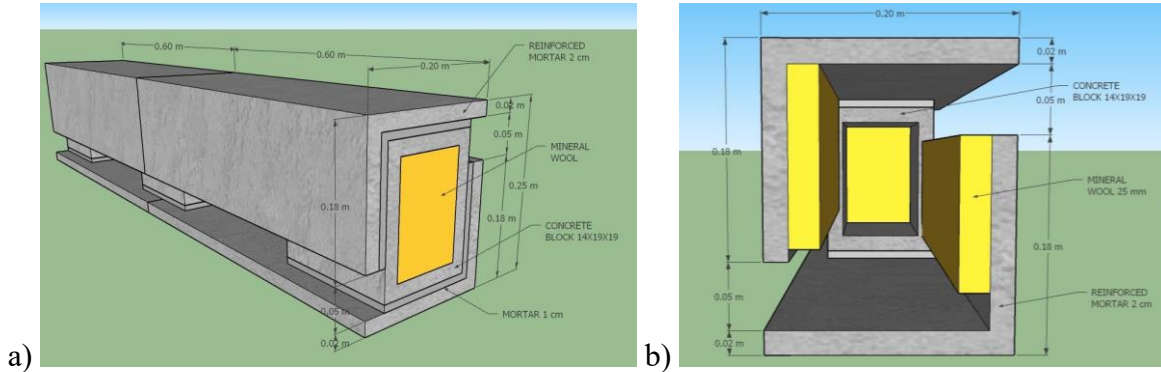


Figure 1: Acoustic Louver A geometry a) perspective and b) section.

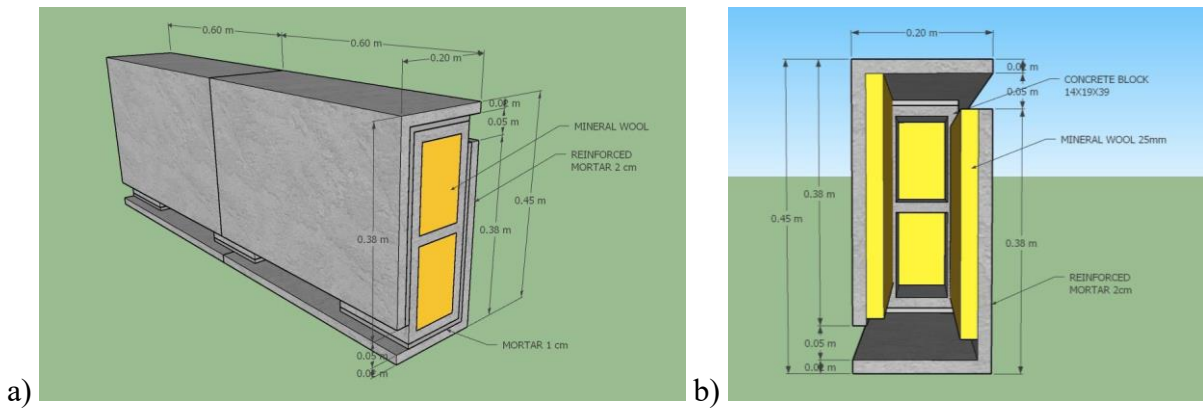


Figure 2: Acoustic Louver B geometry a) perspective and b) section.

3.1. Acoustic simulations

To analyze the relationship between geometry and acoustic insulation, simulations were conducted in the free version of iNoise software. Square-shaped rooms ($3.7 \text{ m} \times 3.7 \text{ m} \times 3.0 \text{ m}$) were modeled, each with a different perforated element or wall condition. A fictitious street emitting 79 dB(A)/m vehicle noise was placed 8 m in front of the facades (Figure 3). Due to software limitations, the elements were modeled vertically rather than horizontally. Nonetheless, meaningful comparisons were made regarding acoustic behavior and geometry.

Each facade was fully covered by a single type of element, and no absorptive materials were included to isolate the impact of geometry. Figure 3a shows, from left to right: an open facade, ventilated sill [12],

crosstalk silencer [13], ventilated panel [14], rubber-lined louvers [2], and another open facade. Figure 3b presents: a closed facade with a rear opening, Acoustic Louver A, Acoustic Louver B, and another closed facade with rear-opening.

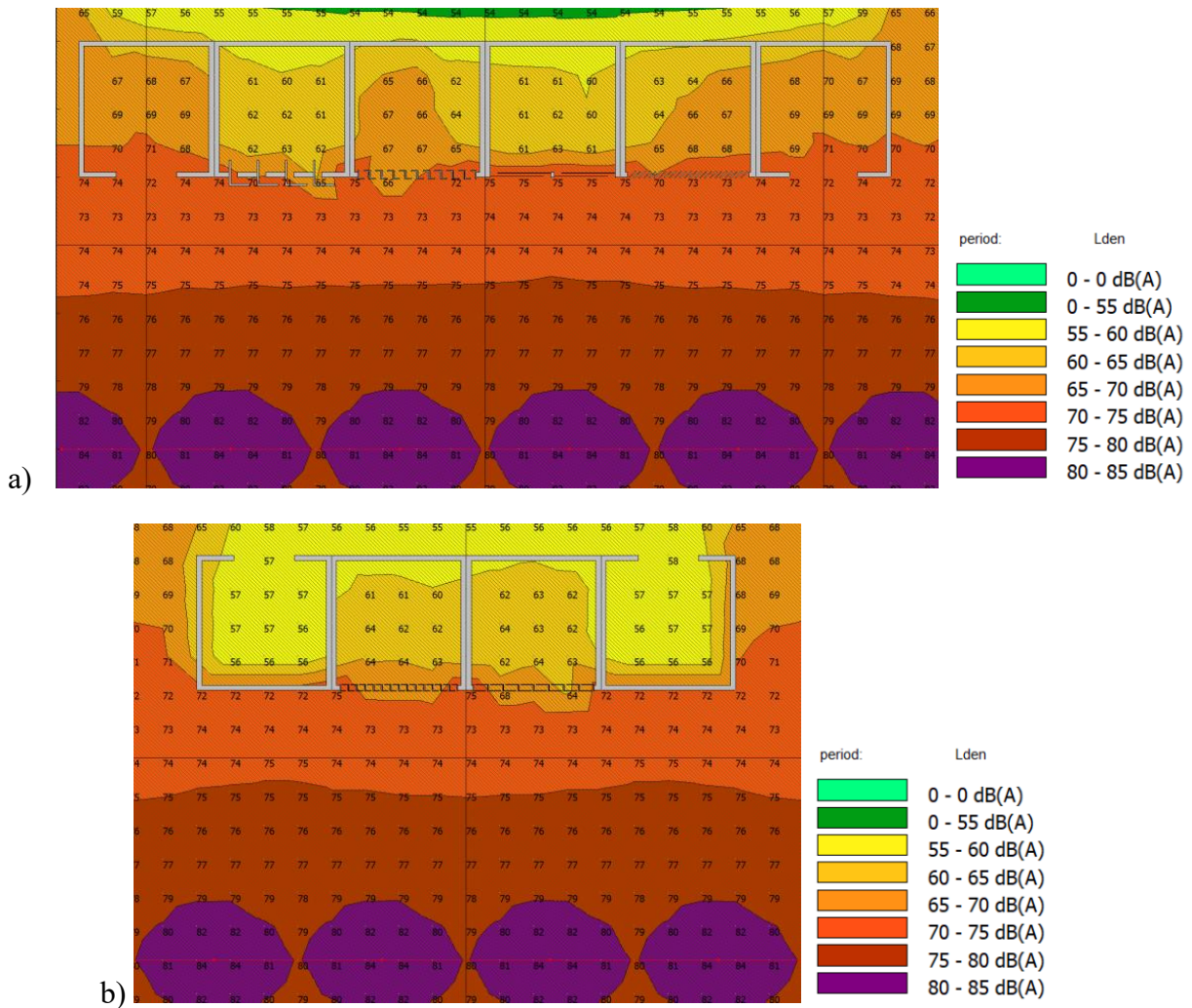


Figure 3: Acoustic simulations of incident noise on facades with a) previous tested elements, and b) proposed elements.

Simulation results showed an external noise level of approximately 72 dB(A). Fully open facades had the highest internal noise, while closed facades had the lowest. Among the elements, the ventilated sill [12] and ventilated panel [14] both yielded internal noise levels of 61–63 dB(A), crosstalk silencer [13] ranged from 65–67 dB(A), and the rubber-lined louvers [2] ranged from 65–68 dB(A). Acoustic Louver A produced 63–64 dB(A), while Louver B achieved 62–64 dB(A), indicating strong acoustic performance comparable to the best-performing elements.

These simulations highlight the significant influence of geometry on the acoustic performance of ventilated panels and emphasize the challenge of achieving an effective balance between acoustic, thermal, and lighting comfort. For example, the ventilated panel proposed in [14] demonstrated enhanced acoustic performance; however, this configuration reduces levels of natural lighting and ventilation. On the other hand, the rubber-lined louvers described in [2] presented lower acoustic performance among the solutions evaluated but allow better natural lighting and airflow. Table 1 presents the differences in sound pressure levels, in dB(A), for each solution relative to the open facade condition.

Table 1: Difference in dB(A) simulated in each solution of the ventilated elements.

Solution	Noise Level in dB(A)	Difference in dB(A)
Open facade	68 – 71	–
Ventilated sill [12]	62 – 63	8
Crosstalk silencer [13]	65 – 67	4
Ventilated panel [14]	61 – 63	8
Rubber-lined louvers [2]	65 – 68	3
Acoustic Louver A	63 – 64	7
Acoustic Louver B	62 – 64	7

3.2. Full-scale prototype

A prototype of the Type A louver (composed of two “L”-shaped pieces) was constructed at the laboratory of the Faculty of Architecture and Urbanism at the Federal University of Rio de Janeiro. This initial prototype aimed to evaluate the challenges and possibilities involved in assembling the system. The choice of the Type A louver was based on the lower weight of its components (about 9 kg per piece) compared to the Type B model (about 14 kg per piece), its easier fabrication due to smaller dimensions, the bigger proportional opened area for ventilation, and the negligible performance difference of only 1 dB observed in computational simulations.

First, a wooden mold in the shape of the louver was assembled, measuring 60 cm in length, and intended for use in casting both pieces. Next, the reinforcement mesh (10 x 10 cm grid, 5 mm thickness) was cut and placed inside the mold. The mortar was prepared in accordance with Brazilian Standard NBR 11173 [15], using a 1:3 mix ratio, water/cement factor of 0.55, and sand with a maximum diameter of 4.8 mm, targeting a minimum compressive strength of 25 MPa.

The main challenge in fabricating the components was filling the 2 cm-thick molds containing the internal steel mesh, which required the use of a vibrating table to achieve proper compaction. It is important to note that such vibrating equipment is typically unavailable in low-income housing construction; thus, there is a need to reduce the length of the elements, increase their thickness, and/or modify the mold design. For the second piece, a mesh with a smaller diameter was used to facilitate the casting process. Figure 4 illustrates three stages of the process: mold filling (a), demolding (b), and assembly of the louver using the two components (c).

The next stages of the doctoral research include:

- Computational simulation of new geometries.
- Selection of the geometry with the best performance.
- Fabrication of components.
- Laboratory acoustic insulation testing of the elements.
- Optimization of the geometry for subsequent tests.
- Application of waste and alternative materials in the components.



Figure 4: Stages of the construction of the Acoustic Louver A.

5. FINAL CONSIDERATIONS

This article aimed to investigate low-cost geometric solutions for ventilated acoustic façade elements, intended for application in social housing and to support compliance with performance standards and thermal-acoustic comfort requirements. In addition to enabling natural ventilation and air renewal, these solutions contribute to reducing indoor temperatures and noise levels in buildings located in humid tropical climates. They also enhance building energy efficiency, promote user health and comfort, and represent a more affordable alternative to current industrial products.

As a result of this study, two geometric configurations for acoustic louvers were proposed, one of which was prototyped to anticipate and evaluate practical challenges to be addressed in the next phases of the doctoral research.

The next steps of the research will involve testing new geometries through computational simulations, selecting the most promising configurations, fabricating components, conducting laboratory measurements of acoustic insulation, optimizing the geometries for further testing, and exploring the use of waste and alternative materials in the components.

Following the laboratory insulation tests, the goal is to obtain consistent results that validate the simulation data and enable comparison with the other solutions presented in this study.

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