Relations between urban configuration, urban surfaces, and environmental noise in the Aburrá Valley (Colombia).

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Tesis doctoral presentada para optar al título de Doctor en Ingeniería Ambiental

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Facultad de Ingeniería

Doctorado en Ingenieria Ambiental

Medellín, Antioquia, Colombia

2023

Doctorado en Ingenieria Ambiental, Cohorte XIII.

Grupo de Investigación Cements, Ceramics and Composites (CCComposites).

Centro de Investigación Ambientales y de Ingeniería (CIA).

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Dedication

I want to dedicate this achievement to the memory of my father Francisco Javier Rendón Rivas who, with his affection, company, support, and example, gave me what was necessary to achieve my goals.

Thanks

I want to thank all my family for their unconditional support during all this time, you are my reason for being. To Professor Henry A. Colorado for giving me a helping hand and showing me the way. To Professor Carlos Henry Castaño for sharing much more than his time and knowledge. To Professor Diego Mauricio Murillo for his cooperation. I thank the Missouri University of S&T, Universidad de San Buenaventura and the Universidad Católica de Oriente for the loan of equipment and spaces. And I thank the Early Warning System of Medellín and the Aburrá Valley (SIATA) for sharing data and information of interest.

Abstract

The increase in the levels of noise pollution in large cities depends on several factors that are not always linked to the noise source (road traffic, aircrafts traffic, rail traffic, industries, leisure activities, among others). There are other types of variables that greatly affect this type of contamination. This is the case of urban envelopes that, depending on their configuration and materiality, can have a great impact on the propagation of noise.

This research work seeks to study different envelope conditions and urban configuration of facades in the Aburrá Valley Colombia and analyze the possible relationship with noise propagation. For this, the space-time dynamics of environmental noise are characterized based on information collected by seven monitoring stations distributed throughout this urban area. With these data, the main sources, and temporalities of noise in the the Aburrá Valley are identified. Subsequently, different compounds are studied that, given their characteristics, can absorb the noise produced in urban street canyons. For this, an impedance tube is built based on the ISO 10534-1 Standard and the sound absorption coefficient of various compounds and sound-absorbing materials is measured. Subsequently, urban configurations such as urban street canyons are studied where the arrangement of balconies and sound-absorbing material may have an impact on the propagation of noise. Finally, the implications of the results on urban noise mitigation strategies in the Aburrá Valley are discussed. For this, a *1:10* scale model of an average urban street canyon is built in the Aburrá Valley and equivalent continuous level measurements are made by analyzing different configurations on the facade in terms of sound-absorbing materials and balcony configuration to find the insertion loss.

The results of this study provide evidence that porous ceramic materials such as refractory brick, porous minerals such as pumice stone and natural fibers such as cork or rice husks can mitigate environmental noise. In addition, it was possible to appreciate that the urban configurations of facades in which there are balconies cause an increase in the levels of environmental noise, due to the arrangement of the balconies on the pedestrian's platforms, present in the Aburrá Valley, which tend to generate a conservation field for acoustic energy produced by noise sources.

Keywords: Environmental Noise; sound absorbing compounds; Layout of balconies on facades; Noise mitigation.

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Document structure

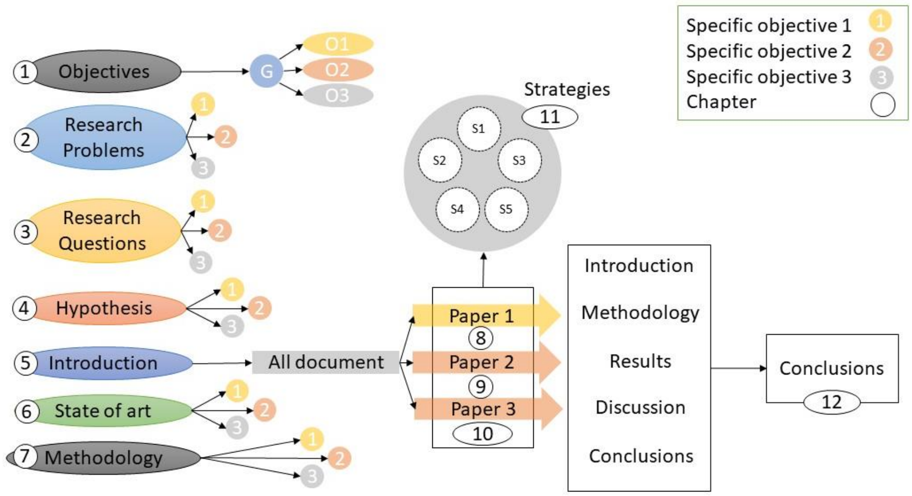

Fig. 1 Thesis structure

This document is structured with the following elements: chapters *1, 2, 3, 4, 5, 6, 7* that contain the objectives, research problems, research questions, hypothesis, introduction, state of the art and methodology, chapters *2-7* address the *3* specific objectives of this research declared in the chapter *1*. Subsequently, three chapters *8, 9* and *10* are presented that cover three publications, the first based on specific objective 1 and the other two based on specific objective 2. In these three chapters, a series of articles are presented that account for the research work as such, presenting: Abstract, Keywords, Introduction, Methodology, Results, Discussion and Conclusions. Based on these three publications, five strategies are developed that can help manage environmental noise in the Aburrá Valley, chapter 11. Finally, the conclusions of the complete work are presented in chapter 12. The annexes section (chapter 13) presents a summary of the publications and congresses that were generated on account of this work and the cooperation with other investigations.

1. GENERAL OBJECTIVE

Studing the relationships between the morphology and urban envelope of the building facades with the levels of environmental noise in the Aburrá Valley.

1.1. Specific objectives

1. Characterize the spatiotemporal dynamics of noise in the Aburrá Valley.
2. Analyze different facade scenarios in a typical urban street canyon configuration in the Aburrá Valley and identify the effects on environmental noise.

3. Discuss the implications of the results on urban noise mitigation strategies in the Aburrá Valley.

2. RESEACH PROBLEM

1. The noise maps that are currently being developed do not present a good temporal representation. The temporal representation of a noise map is usually done for one year. The annual representation is adequate when the variability of the sources is not high. However, in places where there is great variability of noise sources, noise maps fall short of representing environmental noise.

   In the Aburrá Valley, noise maps have been made since 2010. This type of maps especially reflects the environmental noise condition given by road traffic. But there are other types of sources that are highly relevant, such as leisure activities, celebrations, and sporting events. This type of noise events cannot be seen in a noise map since these are developed based on car traffic noise characterization. Main source of noise that is common in cities of developed countries. But conditions in developing countries are often different.

   The investigative problem that is generated by the potholes in the characterization of the noise given by the noise maps in the Aburrá Valley. It is expected to be corrected with a noise monitoring network made up of 7 stations that have data between 2016 and 2019 distributed throughout the Aburrá Valley. With the help of this network of monitors, it is hoped that other types of tools will be used to complement the important information provided by the noise maps.

2. The different materials with which buildings are constructed and the morphological characteristics of urban streets canyons are causing an increase in reverberation times. High reverberation times in urban street canyons tend to increase ambient noise levels. This increase occurs because the acoustic energy generated remains for a longer time in these spaces due to the constant rebound of noise waves from one building to another.

   The generation of this phenomenon is not alien to Aburrá Valley. Different urban street canyons in the city present this characteristic. Based on the characteristics given in the Aburrá Valley, different facade configurations are recognized. Where the balcony is presented as the main protruding element in addition to many reflective materials.

   The following work seeks materials that help reduce environmental noise in the urban street canyons of the Aburrá Valley. And it establishes which are the acoustic conditions of these environments given by the balconies. For this, several typical configurations of urban canyons are used in residential environments of the Aburrá Valley, to which absorbent materials are alternated.

3. Specific objectives 1 and 2 of this work hope to reveal a series of elements that can help mitigate environmental noise in the Aburrá Valley. With these results, it is expected to

propose strategies that are viable against the high levels of noise presented in this urban environment.

3. RESEARCH QUESTIONS

1. ¿It is possible to implement tools for the integration of noise maps on noise different from transportation, infrastructures, and industrial plants in developing countries such as the case of the Aburrá Valley, Colombia?
2. ¿Do the compounds that incorporate rice husk nanoparticles have some effect on the mitigation of noise present in urban street canyons?
3. ¿Can environmental noise be mitigated through the implementation of different materials and alternative balconies on facades on urban streets canyons: from the Aburrá Valley, Colombia?

4. HYPOTHESIS

1. Developing urban areas like Aburrá Valley require complementary tools to the noise map to adequately assess environmental noise.
2. Composites that incorporate rice husk nanoparticles can mitigate the noise present in urban street canyons.
3. The different elements of the facades in an urban street canyon of Aburrá Valley have an impact on the levels of environmental noise.

5. INTRODUCTION

Noise is one of the pollutants that has become more relevant in recent years. The impact of noise on the lives of the inhabitants of urban areas has caused new actions to be taken to mitigate its impact (Thota & Wang, 2017). This type of contamination causes negative and unwanted effects on those who suffer it. (D. A. Harris, 1997). The physical characteristics of noise are common to those of sound. For a sound signal to arise, there must first be a source of vibration, this source of vibration will produce a disturbance in the matter that surrounds it, causing the molecules to lose their state of equilibrium and move, subsequently returning to their natural state. This occurs due to the inertia of the particle, which exceeds the rest position, bringing into play elastic forces in the opposite direction (Everest & Shaw, 2001). This movement of the particles is reproduced in the vicinity and is shared from one to the other, thus generating a wave trip, which upon reaching a receiver is understood by it as a sound (Howard & Angus, 2013). Thus, the sound can be pleasant or annoying. When it is annoying it is considered noise by whoever receives it and depending on its intensity it can be harmful to health. The harm that noise can cause to a person will be linked to the exposure time of the receiver.

The problems generated by noise in the environment have gained relevance in modern cities and have become a scientific challenge. This problem has worsened in recent years due to the high growth and development of urban environments, and this trend seems to continue in ascent. It is estimated that by *2050* two thirds of the population will live in urban areas (Paschalidou et al., 2019) and it is precisely this that leads to aggravate this pollution problem. According to the European Environmental Noise Directive END (Environmental Noise Directive) the main noise effects are generated by crowds; that is, urban areas with more than *100000* inhabitants, roads where more than three million cars circulate per year, railway lines where more than *30000* trains pass per year, or airports with more than *50000* flights per year; in addition to other agglomerations that occur in places such as areas with industrial plants, leisure, wind farms, ports, among others (D'Alessandro & Schiavoni, 2015).

That is why cities need to be designed in such a way that they can offer healthy and comfortable environments. However, this is not what happens at present, since various characteristics can be found that are linked to the detriment of acoustic quality. Some of the problems found in cities include tall buildings, narrow streets, roads with a high traffic flow, facades made of materials such as metal, glass or stone, materials that are highly reflective (W. Yang & Jeon, 2020), or even conditions that are linked to the type of asphalt that covers the roads (Tian et al., 2014). These types of physical characteristics produce highly reverberant environments that increase the acoustic energy generated by noise sources. However, there may also be others that help mitigate this type of contamination, this is the case of the location and shape of the buildings (H.-S. Yang et al., 2017a), or elements on the surfaces that can offer other cover conditions, such as vertical gardens, green areas, bodies of water or porous surfaces (Jang, Lee, et al., 2015a).

The porous surfaces located on the facades of urban street canyons can become a good alternative in mitigating environmental noise, because they act as elements that can reduce reverberation times, and this physical phenomenon directly affects permanence and the level of environmental noise (especially in urban canyons). So that the reverberation times are lower, sound absorbing materials are used on the surfaces that limit the sound projection of the noise source, in this way the reflections that can be caused by these limits on the emitted sound energy are transformed to a great extent in heat energy. For a material to have these sound-absorbing qualities, it must have a high sound absorption coefficient based on the different frequencies of the acoustic energy that impacts against its surface (Calleri et al., 2018). Thus, the control of the reverberation time is intrinsically reflected in the reduction of the acoustic energy that is generated in an urban environment and in this way, it is possible to have silent, calm, and comfortable urban environments (Ba & Kang, 2019; Colorado et al., 2022; Rendón et al., 2022, 2023).

Another element that can act on the reverberant field in urban canyons is the vegetation located on the sides. Since, depending on the density of its foliage, it can absorb some frequencies and avoid reflections from the facades. In addition, it not only has the possibility of serving as an absorbent element (Davis et al., 2017), but it can also have a positive perceptive effect for the people who cohabit these spaces (Van Renterghem, 2019). It has been shown that green environments generate a higher degree of tolerance towards environmental pollutants (Qin et al., 2013). In addition, plants can generate other types of soundscapes such as birdsong, or sounds of leaves against the wind, which can occasionally give shades to noise pollution.

Finally, the urban configuration is mentioned as a determining component for the propagation of noise. Elements such as crowding, positioning, location, building height, road width, plant units, or embankments are crucial when it comes to understanding how noise spreads (Han et al., 2018). These types of variables are important to understand the effect that noise can have and are generally conditioned by the type of source. For example, the location of streets in relation to airplane landing and takeoff routes is crucial to understanding how aircraft noise spreads and how it can affect a community (Flores et al., 2017). Or the irregularity of the urban morphology compared to sources of road traffic may be relevant in reducing noise (Ariza-Villaverde et al., 2014). Among others, the positioning of a building can even serve as an acoustic screen on the micro and macro scale for internal collective environments. Successfully design of an intersection can mitigates traffic car noise (Estévez-Mauriz & Forssén, 2018), or the parking space for private vehicles on the road can increase or decrease noise levels (Montes González et al., 2020). Another of the variations that occurs in the urban configuration derives from the protuberances on the facades. For example, a type of element that can help to mitigate environmental noise is the balcony. Where its shape, location, materiality, and size can be decisive in reducing noise (Badino et al., 2019). This is because the balconies can serve to redirect, diffuse, or absorb noise. Preventing noise from being concentrated in frequency and space, reducing its ability to affect the urban environment. On the other hand, balconies can serve as acoustic screens so that noise does not reach internal spaces, where people require quiet places to work, study or rest. All this can be achieved by optimizing various physical parameters of the balcony such as measurements, angles, and construction materials (Hossam El Dien & Woloszyn, 2004). Thus, there are several variables involved with the urban configuration that are relevant for the mitigation of urban noise.

It is evident then that the quality of life in cities depends on the levels of environmental noise and that to mitigate it, it is necessary to delve into the influence of environmental variables that have an impact in one way or another with this pollutant. In this way, better decisions can be made in urban design and in action plans for noise management (Nardo, M., 2004). From the above it can be deduced that it is necessary to advance in the study of the relationships that exist between the configuration and the urban environment in the noise pollution.

6. STATE OF THE ART

6.1. Specific objective 1

Most of the research relates traffic car noise as the main cause of noise levels in urban areas (Eriksson et al., 2013; Mehdi et al., 2011; Nourmohammadi et al., 2021; Zuo et al., 2014), and the the Aburrá Valley is no stranger to this reality (Rendón et al., 2022). Studies to quantify, characterize and analyze the sources of road traffic noise and its effects on the population that inhabits urban environments have been developed in various places around the world (Nourmohammadi et al., 2021; Paschalidou et al., 2019; W. Yang & Jeon, 2020). All of them address both the temporal and spatial components. However, different ways of approaching it are identified. It is also highlighted that through all the studies consulted that relate the characterization of noise, it is essential to know cultural, economic, and social aspects, since these types of variables have a great incidence on noise behavior (Akpan et al., 2019; Oloruntoba et al., 2012; Uran & Escobar, 2012).

In a study of traffic noise developed in Guangzhou, China, the exposure of the population to noise from urban traffic is evaluated, using a methodology based on POI (Points of Interest) these points of interest are reflected on a noise map to which a statistical cluster analysis is performed. With the results obtained, it was possible to conclude that in this city *23.6 %* of the population is exposed to noise levels above the international norm during the day and at night this percentage increases to *30.5 %*. In the same way, it was found that road traffic noise especially affects densely populated areas, and it is suggested that it is in these areas that action plans should be prioritized (Ryu & Song, 2019).

Another study that involves these same sources was carried out in Athens-Greece by Paschalidou, in this work a noise map is made and later an action plan for this city is proposed. This study highlights that noise management should focus on traffic car, especially through interventions (such as acoustic screens) that reduce noise levels that affect vulnerable communities. For port areas, the adequate location of the terminals and the location of acoustic barriers is also important. In addition, the study shows the importance of recreational and green spaces in cities, since, as noted in other publications, these can increase people's tolerance to noise (Paschalidou et al., 2019).

A study carried out by Zuo et al. (2014) in Toronto, Canada, characterizes automotive noise by means of short random measurements. In this study, it is possible to perceive, by means of Pearson's correlations, less variability in the temporality of the measurements than in spatiality. In this sense, automotive noise presents greater stability over time, but its levels can vary greatly as it is generated in different parts of Toronto.

Studies carried out in countries with socioeconomic and climatic conditions like those of Colombia, are carried out in Kanpur in India, where the tonal components derived from traffic car are studied. This investigation concludes that the *63 Hz* band in low frequency components and the *1000 Hz* band in medium frequency components are the bands that predominate due to this type of contamination (Shukla et al., 2012).

In another city in Iraq called Sanandaj, other authors use the L_{Aeq} parameter of (*15 min*) to evaluate the noise generated by motor vehicles traveling from Sanandaj to Pasdaran and Keshavarz. It is concluded that the main incidence of noise generated by these roads is produced by minibus-vans and light trucks. In addition, it is noted that the action plans should address mitigation actions for these two classes of vehicle, and that acoustic screens should be implemented in some sections of the roads where communities highly affected by noise can be seen (Dehrashid & Nassiri, 2015).

At the local level, some studies that address urban noise stand out, for example, a local publication issued by the Center for Opinion Studies of the Faculty of Social and Human Sciences of the University of Antioquia (Uran & Escobar, 2012), studies noise from a sociological approach, involving cultural subjectivities and socioeconomic and political relationships related to this pollutant. This article shows how a public environment of economic competitiveness is generated that leads to the generation and increase of noise levels, as is the case of passenger transporters that in the so-called "penny war" maintain driving behaviors that noise levels increase in the city.

Other job developed by (Rendón et al., 2010), shows how the implementation of the day without a car in the city of Medellín, fails to be a good measure for the mitigation of environmental noise. This is since, in the absence of private vehicles, a greater number of public service vehicles travel on the roads, with which the noise levels remain during this measure.

The article published by (Ortega & Cardona, 2005) develops a methodology to assess the degree of exposure to noise presented by the inhabitants of the city of Medellín. To this end, surveys were carried out on the population and noise levels measured were compared with the identification of the different land uses that the city has. For this, in addition to environmental noise measurements, dosimetry measurements were used. In addition, the representation of noise contours through the interpolation of measurement points in 200x200 meter grids. With this study, it was possible to establish a way to assess whether the population of Medellín is exposed to levels above the noise standard that governs the nation (Ministerio de ambiente, vivienda y desarrollo territorial, 2006). Among the results produced by the study, it was verified through a pilot test in the La Candelaria commune that *81 %* of the population reports discomfort due to automotive noise during daytime hours, corroborated with *94 %* of the measured points that exceed the national standard.

It stands out from previous research that most involve short-term measurements. However, it is highlighted that long characterizations are more useful since they allow us to identify periods of maximums and minimums, trends and recurring situations. In this sense, noise pollution can be more easily related to the activities of the population. For this reason, continuous monitoring networks are usually a great tool to complement noise maps. Since although the noise maps address an integral spatiality, they are scarce in temporal representation because commonly only two scenarios are used: day and night. (European Noise Directive 2002/49/EC)(Eriksson et al., 2013).

For this reason, other studies are now mentioned that try to take noise analysis to a more detailed temporal level, and for which they almost always base their analysis on noise monitoring networks.

For example, a weekly analysis is dealt with in works such as that of Hueso et al (2017) in the city of Valencia, Spain. That supports the idea of carrying out analysis for periods of work week, and weekend for this uses a statistical test (Kruskal Wallis). In this way you can make comparisons between days of the week and find out which periods present peaks and valleys throughout the year.

Another author Geraghty and O'Mahony (2016) uses a noise monitoring network located in the city of Dublin, Ireland. In this work, considerable differences are found between months, weeks, days, and hours using ANOVA statistical analysis of variance and a Post Hoc test. All this corroborating the high variability of the noise throughout the different temporalities in which a year can be covered.

In the work of Barrigón and Gajardo (2014) in the city of Madrid, Spain, ways to reduce the error during short noise measurements carried out in the environment are studied. For this, it was necessary to address different measurement strategies in which, by varying the periodicity, it is possible to approximate a continuous measurement throughout the year through the standard deviation. This work concludes that the best strategy is to take random measurement days. To obtain a *90 %* coincidence, it is necessary to measure *9* days randomly distributed throughout the year. For *95 %* matches, the number of days should be increased between *25* and *30*.

Or, for example, Quintero et al. (2018) in the city of Barcelona, Spain, where he manages to identify that on weekends noise tends to decrease and have greater variability than on the rest of the weekdays. In this work, new ways of making shorter environmental noise measurements are established based on the error that can be generated from short measurements in front of a noise monitoring network.

Although in Quintero's work it is possible to see that noise decreases on weekends, contrary conditions can develop in other cities where there is a high influence of leisure noise. For example, in Machala, Ecuador, where, through a work carried out by Zambrano-Monserrate and Ruano (2019) it can be seen how the property price has depreciated due to high noise levels from high-powered sound systems and high pedestrian traffic during the weekends.

And this occurs in other parts of the world in urban areas of developing countries. Like in Noronha, Brazil where music coming from bars and boats dismays the inhabitants due to the increase in tourism (Cristiano et al., 2020). In Ibadan, Nigeria, whereby means of population density descriptors and *in situ* measurements, it is possible to identify the impact on the health of the inhabitants due to loudspeaker noise emitted by different types of commerce (Oloruntoba et al., 2012). Music from tourist attractions and amplified sound waves causing constant disturbance to the inhabitants of uMlazi, South Africa (Nsizwazikhona, 2018). In hospital areas of New Delhi, India where, through noise exposure measurements, it is possible to identify the incidence of noise generated by loud music (Khaiwal et al., 2016).

It is important to note that leisure areas in developing countries have similar characteristics. The first is that the vast majority are in the same space as urban dwellings. The second is that most of the commercial properties used natural ventilation (given the climatic conditions commonly present in the tropical climate). This characteristic means that buildings where commercial properties operate have many openings in the facade (Barclay et al., 2012). The third thing is that the places where these leisure activities take place do not have any type of sound insulation control. Many of these properties even place tables or chairs in public spaces to increase attention span and bring their music to these places (Rendón et al., 2022). In this work by Rendón et al. (2022) it can also be seen how there is a high incidence of traffic car during work periods when mobility increases. Due to the high car traffic flow, a constant noise level is maintained from the early hours of the morning (6:00 a.m.) until late at night (11:00 p.m.).

For this reason, it is necessary to consider in any evaluation of environmental noise the high variability that can occur and how the modeling carried out in the noise maps must have a previous study of monitoring networks to know the moments and spaces where a short measurement can become representative of the annual period. This is because this type of situation has already been reported in other investigations, such as Przysucha et al. (2020) in the city of Gdansk, Poland, where only 3% of the data collected at 69 monitoring stations presented a normal distribution. However, according to this study, noise behavior can be well represented by mixing two normal distributions with different statistical properties.

It is also important to emphasize how festive and celebratory activities tend to be more popular in certain countries. Just as the festive atmosphere of certain cities is also characteristic, where various high-level music celebrations, crowds of people and a greater flow of pedestrians and cars are accompanied. In addition, they can also include pyrotechnics as reported in the work developed by Garagin et al. (2021) in various regions of Russia. In this work it is possible to appreciate the implementation of different legislative measures for the protection of the population against noise. This study highlights the inclusion of different time periods for the evaluation of environmental noise, including "rest day", "afternoon", "weekend" and "holiday". Similar situations can be seen in Chhattisgarh, India (Ahirwar, AV & Bajpai, Samir, 2015) where measurements were taken *in situ* and compared with local regulations. This study reports how government authorities have acted against high-level and impulsive noise caused during the celebration of Deepavali, an important Hindu festival. This same problem is reported by other authors in cities such as Sambalpur, Haridwar, Raipur, and Kohalapur India during the same festival (Sahu et al., 2020).

Other festival celebrations apart from those already mentioned during Deepavali are reported in Allahabad, India during Mela Day (Nafees & Nath, 2019) in these celebrations the noise is caused by loudspeakers and different musical instruments. To identify noise periods, comparisons are made between normal days and festival days. In another African city Calabar, Nigeria, high levels of noise caused by shouting, firecrackers and different musical instruments are reported. This work finds these levels by making comparisons before, during and after days of typical festivals of the region. In this study, noise measurements are made with a sound level meter using fast integration times due to the impulsive nature of several of the noise sources (Akpan et al., 2019). Other festivals that present such noise pollution and that use comparisons of noise measurements made with a sound level meter are listed below (Ak & Cs, 2015; Emmanuel et al., s. f.; Lynch, 2019). It is common that many of these celebrations may have religious connotations. In addition to the religious celebration of Deepavali, other publications that relate religious celebrations to noise events are highlighted below (Hume et al., 2012; Mesene & Mengistu, 2021; Zannin et al., 2003). These investigations deal with different methodologies to analyze noise, among which are mentioned: exposure measurements, noise measurements, interviews, and questionnaires.

In addition to the religious ones and the festivities typical of each region, the celebrations associated with soccer also have a great incidence in several countries. Studies that record noise associated with soccer are reported in some publications such as (Abulude et al., 2018). In this research, *in situ* measurements are used at the time of the events and compared with regulations. In another investigation carried out by Carrieri-Rocha, comparisons of measurements are made on game days and non-game days in residences around a stadium in Brazil between 250 and 400 meters away (Carrieri-Rocha et al., 2020). In this study, it is possible to perceive a great affectation for people and pets that live on the periphery of the stadium. And finally, the study carried out by Gaja et al. (2003) is related, where the peaks generated by this type of celebration can be seen in continuous measurements of several years.

Another important factor in a good noise characterization is accounting for areas that may be representative of other areas in an urban environment. For example, the leisure areas mentioned above where it is important to identify specific sources of noise such as commercial properties with a high-power sound system. In the case of commercial areas, it explains the occurrence of recurring events and the involvement of those responsible.

Research that interprets spatial versus temporal noise, different from the traditional map with noise contours, is addressed in some studies. For example, the maps presented by Ramazani et al. (2018) in the city of Tabriz, Iran, stand out. Where the noise levels are represented on a map with circles whose diameters are related to a range of noise. Or for example (Mehdi et al., 2011) who studies the problem of noise in Karachi, Pakistan. Several very interesting representations are proposed in this work in which the location of different population densities and noise sources are highlighted in six periods, day, night, and evening, both during the week and on weekends.

It is therefore worth emphasizing the different tools that can be used based on a continuous noise monitoring network. And that they can be cooperative in evaluating noise for noise maps. Since, as could be seen in the literature consulted, there are a series of temporalities that it is important to recognize to carry out adequate noise management in an urban environment.

As it has been seen, there are many problems generated by traffic car noise in urban environments. And although different methodologies are known to evaluate it, it must be considered that any evaluation must be supported on two dimensions, one temporal and the other spatial. To properly establish the noise, both components are required to be represented in detail. However, to fully cover an urban environment, a monitoring network with multiple fixed noise stations that work for long periods of time will be needed. This is expensive and difficult to achieve, and modeling is commonly carried out based on specific measurements and for short periods of time that represent general conditions throughout the year. This is where it is important to be cautious when extrapolating short, one-off measurements to annual representations.

6.2. Specific objective 2

The urban configuration brings great challenges for current cities, different shapes, and elements that cities have helped to mitigate the effects of noise that are caused in cities mainly due to crowds. This type of configuration is not only important for noise pollution, but there are also other pollutants or urban conditions that are directly related to urban configuration and surface characteristics. For example, the heat island effect can be mitigated with an adequate urban distribution, where various elements such as green areas and bodies of water reduce high temperatures during summers (Yue et al., 2019). Likewise, urban planning can be related to connectivity, accessibility, landscaping, among others (Bierwagen, 2007; Okba et al., 2021; Xiao et al., 2016). However, within all the variables that interfere with the urban configuration, it is important to refer to the one that derives from the different canyons that form in streets and avenues, where different elements of the microclimate, such as radioactivity exchanges, Wind turbulence or noise play an important role in pollution treatment (Andreou, 2013; Vallati et al., 2017; Vladimir & Madalina, 2019).

Since urban canyons may have unfavorable conditions for contamination in various urban areas (Can et al., 2015), it is important to relate them to the surfaces and morphology that is subject to their structure, since these types of variables can reach to have weight in the treatment of environmental problems. In the case of noise, both elements (surface and morphology) are important to mitigate noise pollution (Badino et al., 2019). In the case of morphology, one of the main elements in urban canyons are the facades. This can have different characteristics, and in the case of the Aburrá Valley the main variation that occurs in the facades are the balconies. The balconies can be used as an element that manages to diffract, redirect, or absorb noise that surrounds an urban street canyon, avoiding reverberant fields. However, currently this element has been working more as a barrier to control the noise that affects private property, that is, to avoid affectations to internal spaces of the building; and little is used as an element to improve the environment of the urban environment (K. M. Li et al., 2003; Magrini & Lisot, 2015; Naish et al., 2013). However, the materials that the facade or balcony may have on the surface have been treated with greater enthusiasm in the literature for the control of urban noise (Cao et al., 2018; Laxmi et al., 2022; Rendón et al., 2023). Now, although several research show the mitigation that can occur in urban street canyons due to the absorbent materials located on the facades, the conditions that these sound absorbent materials must have to be located outdoors are not clear (W. Yang & Jeon, 2020). In this sense, it is important to work on materials or compounds that, given their characteristics, are viable for their location on the facade of a building.

Now, to know how the materials in the facades of urban street canyons can mitigate noise, it is important to study this phenomenon considering the relationship between noise source, surface, and morphology. For this, several methodologies can be used, among which modeling, field measurement, and scale representation can be mentioned. For this type of scale representations, it is key to understand the scaling that can occur of the frequencies. However, the most complex aspect of this type of modeling is achieving a similar representation in the materiality of the scale model. This is because the absorption coefficients of a scaled material rarely match perfectly with that of a material in real life. Other methodologies such as modeling are treated in some studies, however, their limitations are well known. Several investigations that address this type of issue are listed below.

For example, in Calleri et al. (2018), the influence of different facades on the behavior of sound propagation through adjacent urban canyons is analyzed through field measurements and simulations in ODEON software (v.13). It was shown that the relationship between the perceptual aspects depends to a great extent on the listening position. Furthermore, statistical analysis showed that the three factors (absorption coefficients, dispersion of facade envelopes and listening position) influence the acoustic characteristics. Statistical analysis performed on the results corresponding to a single listening position at a time, most It was found that the absorption coefficient of the facades influences the evaluation of the amplitude of the space, evidencing an important relationship between urban configuration and noise propagation.

A study developed by Jang et al. (2015a) investigates the influence of green facades on the propagation of automotive noise in urban canyons. In this article it was possible to appreciate reductions of up to *2 dB* at the pedestrian level on one of the platforms. The scale model method suggested by this author can be useful for evaluating noise reduction by considering realistic characteristics such as absorption, scattering, and diffraction associated with sound sources and materials. It is highlighted with great relevance in this article, as a *1:10* scale model is very useful when modeling the acoustic conditions of an urban canyon without resorting to software that in most cases does not contemplate many variables present in these types of environments.

Other study developed by Badino et al. (2019) contribute with different facade design solutions to the reduction of leisure noise in an urban street canyon is studied, considering the A-weighted SPL expected on the facade itself and on the opposite. It can be stated that the geometrically optimized facade clad with sound-absorbing materials achieves reductions of up to *10 dB* in the A-weighted average SPL given by the shape and acoustic cladding of a facade. In this study, the software Rhinoceros 5 SR14, Grasshopper 0.9.0076 and Pachyderm Acoustics 2.0.0.2 were used. Grasshopper (GH) a graphical algorithm editor that was used to create the parametric models and set up the acoustic simulations. Pachyderm is a free acoustic simulator based on geometric acoustics (GA), which combines the image source method with ray tracing.

A work carried out in 2011 study the influence of urban forms on environmental noise in the city of Aracaju, Brazil (Guedes et al., 2011). The study, which involved *in situ* measurements and acoustic simulations using SoundPLAN software, beginning with an analysis of the current acoustic scenario, followed by the creation and simulation of hypothetical scenarios in still unoccupied sectors of the region under study. The acoustic modeling and simulations were based on continuous equivalent sound pressure level measurements, L_{Aeq} and vehicle flow data, and on the geometry of the region. The results reveal that the physical characteristics of the urban form, such as the density of construction, the existence of open spaces, and the shape and position of the buildings exert a significant influence on environmental noise.

Among the software used to simulate the propagation of noise in the presence of different urban environments is Odeon (Calleri et al., 2018), Axman (Ariza-Villaverde et al., 2014), Pachyderm (Badino et al., 2019), I -Simpa (Can et al., 2015), SoundPLAN (Guedes et al., 2011), Cadnaa (L. T. Silva et al., 2014). However, among all these software models that are based on lightning code algorithms do not reproduce phenomena adjusted to the reality of the generalized propagation of sound outdoors. The capacity of the I-Simpa software is highlighted, which with a sound particle tracking corrects the errors made by not considering the acoustic diffusion and which involves physical variables such as: width, height, distance between the point source and the receiver. Others such as: facade diffusion and absorption coefficient, floor absorption coefficient, and the acoustic properties of the elements such as: mean free path and mean absorption coefficient, in the case of a receiver height of *1.5 m.*

A paper published by Han et al. (2018) focuses on the interference that certain urban spaces have in noise mitigation, understanding the effects of urban morphology on urban environmental noise at a regional scale, to create a nice urban acoustic environment. This study seeks to investigate how urban morphology influences environmental noise in the Shenzhen metropolitan area, China, by using remote sensing data and geographic information. In this study it was possible to find that the environment in which the noise propagates is correlated with the intensity of light at night and the surface temperature, and with the configuration and composition of the urban landscape; for example, it is possible to mitigate noise with urban vegetation and spaced distribution of buildings. It can also be demonstrated how areas of vehicular traffic and mixed residential and commercial land uses are the ones that contribute the most to the increase in environmental noise.

According to the consulted bibliography, it can be seen how scale models are a great tool to know the behavior of absorbent materials in urban canyons against environmental noise.

6.3. Specific objective 3

From the bibliographical review given on the first specific objective of this proposal, it can be deduced that the adequate characterization of noise pollution is of great help for the elaboration of action plans. Since the tasks can be prioritized based on the occurrence and level of environmental noise, also because they can be replicated in sectors with similar conditions. Regarding the situation in developing countries, it is noted that commercial properties, celebrations, and announcements with high-power sound systems are responsible for high noise levels, and it is essential that the authorities take legal measures regarding isolation acoustics that must be implemented in these activities. For this, it is important to avoid the economic, political, and social pressures that the beneficiaries of these activities commonly exert on decision makers (Nardo, M., 2004). Likewise, different aspects related to the celebrations, especially those related to fireworks, must be controlled. Regarding other celebrations, it is important to emphasize that it would be relevant to know exposure measurements to know the degree of affectation that these celebrations have on the population (this is in the case of soccer, festivals, and religious celebrations). Thus, to implement action plans in cities of developing countries, action plans are required that include legal measures, engineering developments accompanied by the implementation of cultural and educational campaigns (Gozalo et al., 2013; Licitra et al., 2017; Morillas et al., 2018). It is important to highlight that the possible limitations that occur with respect to this type of analysis will depend a lot on the representativeness of each monitoring station.

Likewise, as could be observed in the bibliographical analysis of specific objective 2, the envelope and the urban morphology can have an influence on the behavior of noise propagation under certain circumstances; for this reason, it can be interpreted that the understanding of this relationship can help to outline actions in noise management plans in any city. It can even serve as a support to adjust noise models to the various urban configurations that a city presents (Trikootam & Hornikx, 2019).

Although some recent studies consider different ways to manage noise, other types of variables are used than those already mentioned. For example, the study carried out by (Hammad et al., 2017), proposes ways to manage noise by adjusting land use planning to the location of noise-sensitive and noise-generating facilities; or promoting sustainable solutions under optimization models, minimizing the total levels of violation of the noise threshold and the total travel time of the system on the underlying road network between nodes of the urban system. The model presented in this study shows several limitations including the assumption of deterministic demand induced within the model itself.

Another study carried out by Di et al. (2018), points out that the rapid and effective evaluation of the quality of an urban acoustic environment is an important challenge for urban planning and management. To achieve this type of evaluation, a traffic noise propagation model was proposed for the city of Changchun in China, which provides instantaneous noise levels, facilitates the evaluation of the quality of the acoustic environment and provides a reference for noise control management. Some measures that must be taken to control noise pollution from traffic are installation of noise barriers, installation of soundproofing windows, and increase in green areas on the sides of roads.

Other studies that address the incidence of envelope and morphological conditions on noise propagation, such as Yang & Jeon (2020). Highlights the importance of advancing in the characterization of noise under various surface conditions and morphology; considering various conditions and variables that occur in urban environments. In addition, the importance of considering the local reality is highlighted; for example: urban morphology, the conformation and age of the vehicle fleet, mobility, and road planning (Can et al., 2015); or even, the same design of the buildings against noise pollution and acoustic comfort. The above shows the context of the proposed research questions, and their special relevance for developing or highly dynamic cities.

7. METHODOLOGY

7.1. Specific Objective 1

The methodology for this specific objective was developed based on seven noise monitoring stations distributed throughout the metropolitan area of the Aburrá Valley. These stations carried out measurement for a period of approximately *3* years of the equivalent continuous level of environmental noise every hour and covered a large part of the sources present in this city (ISO 1996-1). Emphasis was placed on temporal resolution, to identify peak and valley periods along resolutions of hour, day, month, week, and year. For this, several tools were used that, based on comparisons, could provide relevant information about the behavior of environmental noise in this urban area. The different sources of noise present in the surroundings of each station were also considered and compared together with the periods of high and low noise level to clarify their contribution to environmental noise levels.

7.2. Specific Objective 2

The methodology addressed in this specific objective in the first instance resorted to the development of an impedance tube (ISO 10534-1). The impedance tube gave information about the sound absorption coefficient of the materials and compounds addressed in this research. Subsequently, a *1:10* scale model was built that represented a typical urban street canyon of a residential area in the Aburrá Valley. The scale model was excited with a linear array of speakers that, given their characteristics, represented the noise produced by car traffic. The scale model was built based on materials that represented the acoustic absorption conditions present in the approached urban street canyons and on materials whose absorption simulated the real conditions of the proposed materials. Subsequently, measurements of the equivalent continuous level were carried out at different points at the pedestrian reception level by means of measurements of the equivalent continuous level with a sound level meter based on the ISO 1996-1 standard. These measurements gave information to find the insertion loss that compared the condition of the barrel with and without sound absorbent material.

7.3. Specific Objective 3

Based on what was found in the results of the objectives, a series of recommendations were made to manage the noise that occurs in the Aburrá Valley.

8. USEFUL TOOLS FOR INTEGRATING NOISE MAPS ABOUT NOISES OTHER THAN THOSE OF TRANSPORT, INFRASTRUCTURES, AND INDUSTRIAL PLANTS IN DEVELOPING COUNTRIES: CASEWORK OF THE ABURRÁ VALLEY, COLOMBIA (Research component related to specific objective 1).

Abstract

The behavior of environmental noise in developing countries is conditioned by characteristics that are not only linked to transport, infrastructures, and industrial plants in the annuity (common representation in noise maps), but also to other types of sources and periodicities that can influence significantly in noise levels. For this reason, this work proposes different temporal analyzes during the annuity that can be linked to the noisy activities typical of developing countries. To do this, a noise monitoring network composed of seven monitors representing different sources present in the Aburrá Valley in Colombia is analyzed with measurements of L_{Aeq}, every hour, in a period between August *2016* and July *2019*. The results show that the Aburrá Valley noise is strongly influenced by leisure activities related to high-power sound systems, different celebrations, and continuous noise from car traffic that affect the population mainly on weekends and nights. Reaching equivalent continuous levels near to 90 dBA for annual averages and differences around to *13.5 dBA* between celebration days and normal days. This work marks a clear path to precisely address noise pollution in the action plans of developing countries.
Keywords: Environmental noise; Traffic car noise; Leisure noise; Noise-monitoring network; Action plans; Developing countries.

8.1. Introduction

In recent decades, the rapid growth of cities and the different anthropic activities have caused an increase in noise pollution. This source of contamination is evident to the community and affects it directly and indirectly (Gan, McLean, et al., 2012; Ma et al., 2018; Yuan et al., 2019). There are many studies that mention different affections such as tinnitus, hearing loss, and hyperacusis. In addition, there is a whole series of diseases that are caused by noise and that are far from those that can occur in the auditory system such as high blood pressure, stroke, preeclampsia, diabetes, cardiac and respiratory problems, depression among others (Auger et al., 2018; Di et al., 2018; Dzhambov et al., 2017; Gan, Davies, et al., 2012; Ma et al., 2018; Sears et al., 2018; Seidler et al., 2017; Sørensen et al., 2014). Also, variety of community neighbors' conflicts related to this contaminant (Stokoe, 2013; Ufkes et al., 2012; H. Yang et al., 2016). Conflicts are generated especially by the noise generated by a neighbor at a time when another is trying to rest. Or in general for the different spaces of comfort that a person may need to work, study or relax. Where noise can be harmful to achieve the fullness of these spaces.

Although there are different studies of urban noise, many of them commonly refer to road traffic (Collins et al., 2019; Di et al., 2018; Flores et al., 2017; Jagniatinskis et al., 2017; Nourmohammadi et al., 2021; Quintero et al., 2018; Ragettli et al., 2016; W. Yang et al., 2020), railway traffic (Bunn & Zannin, 2016; Kouroussis et al., 2014; Socoró et al., 2017), aircraft traffic noise (Filippone, 2014; Flores et al., 2017; Kephalopoulos et al., 2014; Lawton & Fujiwara, 2016; Vogiatzis & Remy, 2014), or industrial plants (Chui et al., 2005; Dehghan et al., 2013; Moravec et al., 2021; Pierrette et al., 2012). However, it is important to consider that this type of literature is generated mainly in developed countries where noise emissions from leisure sources are controlled by environmental authorities and where studies are only limited to studying the effect of exposure to noise generated by interior of these entertainment venues. (Ballesteros, 2015), (Wendl et al., 2021), (Weilnhammer et al., 2021), (Degeest et al., 2021), (Pienkowski, 2021).

In addition, the climatic conditions of the countries with seasons have given a development of thermal insulation in walls, windows, doors and other openings of roofs and facades, which also works for acoustic insulation (Feng et al., 2016; Islam & Bhat, 2019; Moretti et al., 2016). This condition is different in tropical climate countries, where it is common for sources related to leisure and celebrations to significantly influence annual noise levels (González & Giraldo, 2010; Gordziejczuk & Mikkelsen, 2018; Guedes et al., 2011; Zambrano-Monserrate & Ruano, 2019). And due to the tropical climate, there is little thermal insulation of building openings (Moreno-Rangel et al., 2021; Zepeda-Gil & Natarajan, 2020).

Moreover, the behavior of transport is different from developing countries to developed countries in many aspects, since the vehicle fleet is old and constantly increasing, the infrastructure is worse, driving behaviors are more aggressive, among others in developing cities. (Abbaspour et al., 2015), (Cardoso, s. f.), (Cari Mendoza et al., 2018), (Morillas et al., 2018). In this way, it is important to approach methodologies that study these especial conditions in the evaluation of environmental noise, preparation of noise maps, and action plans for these urban areas.

Respect to time windows of noise evaluation the international directives like (European Commission. Directorate General for the Environment. et al., 2016) recommend that the effects of noise pollution in a community must be evaluated in a one-year time window and suggest that the noise maps must be made based on this period for the adequate environment acoustic representation (Barrigón Morillas & Prieto Gajardo, 2014). However, in the validation of the L_{Aeq}, a year is often extrapolated from short-term measures. For this reason, some cities use a network of stationary monitors to evaluate and validate the data that come from short-term measurements (Bąkowski et al., 2017).

Exist a lot of techniques for the short-term measurements that represent a year those vary from the time, continuity, selection of days and hours across the year (Barrigón Morillas et al., 2016), (European Commission. Directorate General for the Environment. et al., 2016). Some of the strategies that are used to represent the noise in a year through short-term measures are consecutive days and random days in different week periods (Gaja et al., 2003). However, these techniques have been tested in developed countries and the situation may be different in a developing country. In addition, the distribution of the data for the long-term period does not always present a normal distribution (Przysucha et al., 2020). In this way, extrapolation from short-term measurements to years is something that should be taken with great caution. This considering that among the tools to obtain an annual acoustic map is also the one to use traffic data combined with simulation models.

It is also important to know that due to the temporary variability of noise pollution, one of the most important aspects in noise management is the recognition of the relevant periods. (Geraghty & O'Mahony, 2016), (Hueso et al., 2017), Currently different pre-established time indicators represent different work and rest times (Gaja et al., 2003). Local regulations, for example, contemplate two: day (7:01 am from 9:00 pm) and night (9:01 pm from 7:00 am) (Ministerio de ambiente, vivienda y desarrollo territorial, 2006). And in fact, some international standards establish other pre-established indicators that include the afternoon (Jagniatinskis et al., 2017). However, in hours, days, weeks and months, there are important periods to deal with because they can show special characteristics of noise behavior in the community (Quintero et al., 2018). Unfortunately, in most noise evaluations this type of information is neglected and in the 1-year L_{Aeq} it is calculated only based on business days (Przysucha et al., 2020), (Gaja et al., 2003).

Although the noise of road traffic is one of the main problems of cities worldwide. It is important to recognize that other conditions may exist in developing urban areas. For example, in the case of the Medellin city, according to a study carried out during the years 2013, 2014, 2015 and 2016 by the Medellin Health Department that involves complaints from the population, it was possible to identify that the *52 %* of the nighttime noise source comes from places of entertainment such as discos, bars, and pubs, *30 %* comes from the operation of machines, *8 %* temporary events such as concerts or celebrations, *5 %* restaurants, *2 %* neighborhood stores, *2 %* gyms and *1 %* schools, parks and sports centers (Medellín Health Secretary, 2013), (Medellín Health Secretary, 2014), (Medellín Health

Secretary, 2015), (Medellín Health Secretary, 2016). It is important to bear in mind that these reports do not refer to complaints from the population about road traffic noise during the day or at night, and this is surely due to the great incidence that other sources of noise have on the population, such as leisure or the industry. Emphasizing that the latest citizen surveys for the Medellín city, place noise as the second pollutant with the highest degree of concern for the city after air pollution (Restrepo, 2016).

Thus, to evaluate the noise conditions in an environment, the temporal situation of the noise must be known in greater detail. For this, noise-monitoring networks can be of great help. Next, the following study seeks to address a useful tool for integrating noise maps about noises other than those of transport, infrastructures, and industrial plants by identifying different periods and associating different sources of noise present in the spatiality of the network. Therefore, the causes of noise pollution in tropical developing countries can be understood in detail, and in this way, accurate information can be generated to aid noise mitigation.

8.2. Methodology

For the development of the methodology, see Fig. 2, different Spatio-temporal analyzes are proposed in which data from the noise monitoring network are used. The temporal data collected provide relevant information on the periodicities of noise and calm, on the other hand, although the spatial data are not sufficiently representative for the study area (a condition that may be similar in developing cities with few resources to provide a wide noise monitoring network), it is possible to characterize the main noise sources by superimposing temporality and spatiality, and to establish the critical noise periods associated with each source.

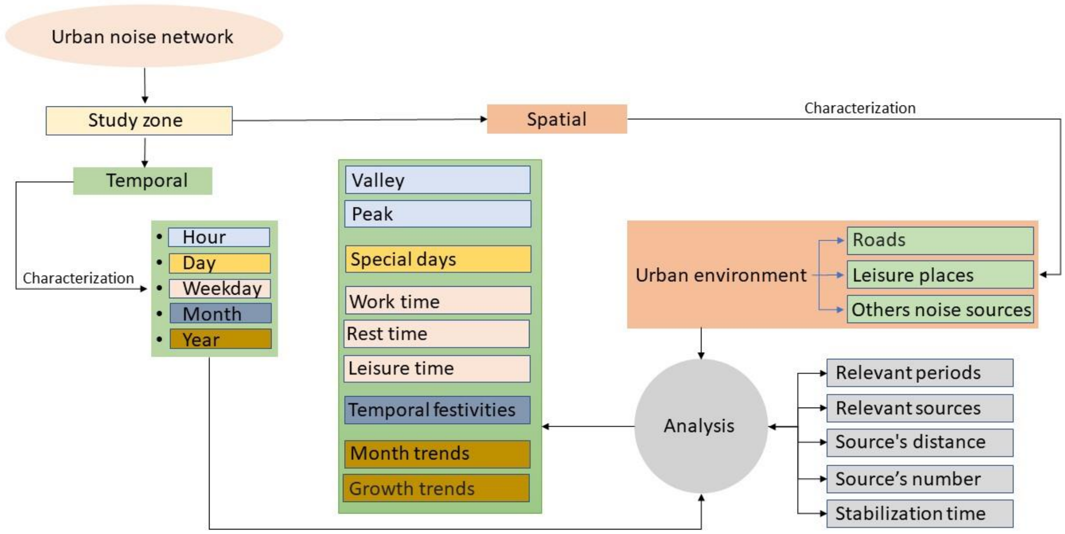

Fig. 2. Methodology flowchart. (Taken from own source).

The previous figure shows the methodology to carry out this work. The temporal resolution that includes time (hour) resolution provides information to identify the peak and valley periods, the resolution associated with (day) is used to distinguish noise from special days with well-marked festive and cultural influences, the days of the week associated with the resolution (hour-day-week) can provide relevant information regarding the periods of work, rest, and leisure, the monthly trend over the 3 *years* of measurement can provide information on the loudest and calmest months and festivities, finally, the resolution (year) gives information on annual behaviors in 3 measurement periods. About spatiality, this is used to know the characteristics of the sources and how their influence is on the different temporalities mentioned above.

8.2.1. Study area and data

In the metropolitan area of Aburrá Valley, 7 monitors have been recording L_{Aeq} since 2016. However, 2 monitors moved to another location in 2019. These monitors are in 4 of the 10 locations that make up the Aburrá Valley Metropolitan Area. The nomenclature given to each monitor is related in the first three letters to the locality in which it is operating and in the next four letters it is related to the name of a nearby building in the sector. There are three monitors in Medellín one in Politécnico Jaime Isaza Cadavid MED-PJIC, in the SIATA tower MED-SIAT and in the Plaza Mayor Event Center MED-PLMA, two in Girardota one near to Bótica Junin pharmacy GIR-BOTJ and other near to

Comprehensive Risk Management System (SOS) Norte GIR-SOSN, one in Itagüí in the Complex Ditaires ITA-CODI, and one in Sabaneta near to an Education Department SAB-SEMS. These monitors are grouped especially in Medellín, which is the most populated area in the Aburrá Valley. The Aburrá Valley has a population of *312165* people, with an area of around *1157* square kilometers, corresponding to the second most populated metropolitan area in Colombia. The spatial location of the seven monitoring stations can be seen in Fig 2 and includes the two new positions of the moved monitors in Medellín CEN-TRAF and MED-ZOOL. All monitors are installed following ISO 1996 (ISO, 2003) see Fig. 3 to Fig. 10.

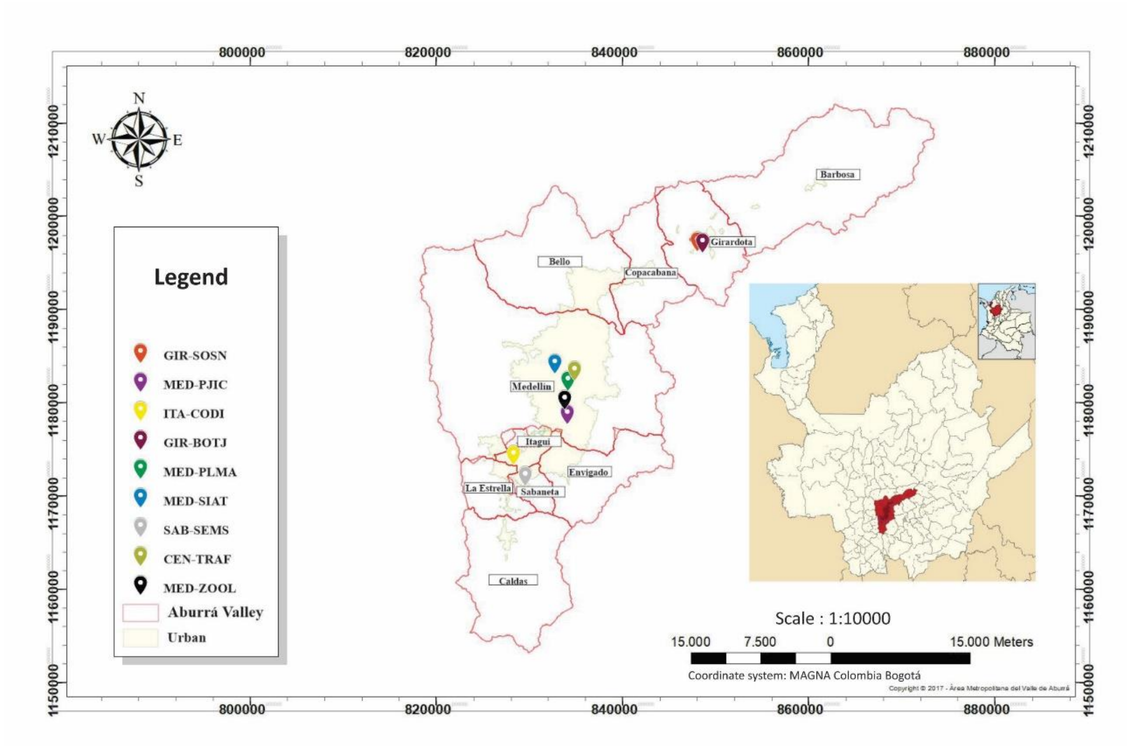

Fig. 3 Location of monitoring stations. (Taken from own source).

Fig. 4 GIR-BOTJ Monitor. (Taken from AMVA).

Fig. 5 GIR-SOSN Monitor. (Taken from AMVA).

Fig. 6 ITA-CODI Monitor. (Taken from AMVA).

Fig. 7 MED-PLMA Monitor. (Taken from AMVA).

Fig. 8 MED-PJIC Monitor. (Taken from AMVA).

Fig. 9 MED-SIAT Monitor. (Taken from AMVA).

Fig. 10 SAB-SEMS Monitor. (Taken from AMVA).

The stations of the monitoring network, which are shown in the above figures Fig. 4, Fig. 5, Fig. 6, Fig. 7, Fig. 8, Fig. 9, Fig. 10, are in places that represent some of the main sources of noise present in the Aburrá Valley. There are 3 stations that represent leisure activities (one of the main causes of complaints by the population). Noise in these sectors is generally generated by restaurants, bars, liquor stores, discos, and nightclubs. This is the case of the stations: ITA-CODI, SAB-SEMS and GIR-BOTJ. This last station, in addition to having the noise sources already mentioned, is also influenced by activities typical of a municipal park, where the main institutions of the Municipality are located, including the mayor's office and the main church, in addition to having a large crowd of people, shops, and stores. Then there are two other stations that have a high incidence of traffic car noise, these are the MED-PJIC stations, which are influenced by Las Vegas Avenue, and MED-PLMA, which is mainly influenced by the traffic car noise that travels along El Ferrocarril Avenue. The GIR-SOSN station is in a residential area where there is influence of mechanical workshops that are located approximately $20\ m$ from the source. Finally, the MED-SIAT station is influenced by activities related to sports celebrations, especially soccer, which is recurrent in terms of celebrations. The Atanasio Girardot stadium, where soccer matches are commonly held, is approximately $200\ m$ from the monitor. It should be noted that traffic car noise has a high presence in this area, for this reason most of the monitors show incidence of road traffic noise in some period. Tab. 1 shows the main noise sources associated to each monitor.

Monitor	Main sources of noise	Coordinates WGS84
GIR-BOTJ	Leisure, road, and pedestrians	6.37737, -75.44566
GIR-SOSN	Community noise, and workshops	6.37845, -75.45099
ITA-CODI	Leisure, road, and pedestrians	6.17012, -75.62874
MED-PJIC	Road, and parking	6.21034, -75.57668
MED-PLMA	Road, live events, and parking	6.24309, -75.57572
MED-SIAT	Road, parking, soccer, and sports	6.25925, -75.58863
SAB-SEMS	Leisure, road, and pedestrians	6.15041, -75.61684

Tab. 1 Noise sources near of each monitor and coordinates in WGS84. (Taken from AMVA).

It is clarified that the ITA-CODI and SAB-SEMS stations are close to sources of noise produced by the agglomeration of places with high-power sound systems such as discos, bars, and pubs. However, the GIR-BOTJ station has a greater influence from places such as restaurants, ice cream parlors, clothing stores, and religious activities, other sources with high-power sound systems are somewhat removed from the measurement point.

8.2.2. Temporal characterization

The analysis of the variability of noise levels between different periodicities is carried out by grouping different temporalities such as hour, day of the week, month, and year. Thus, this work proposes graphs in which, combining different temporalities, there is revealed differences such as periods of greater and less noise (peak and valley hours), periods of high and low activity on weekends, and noise behavior between workdays and weekends.

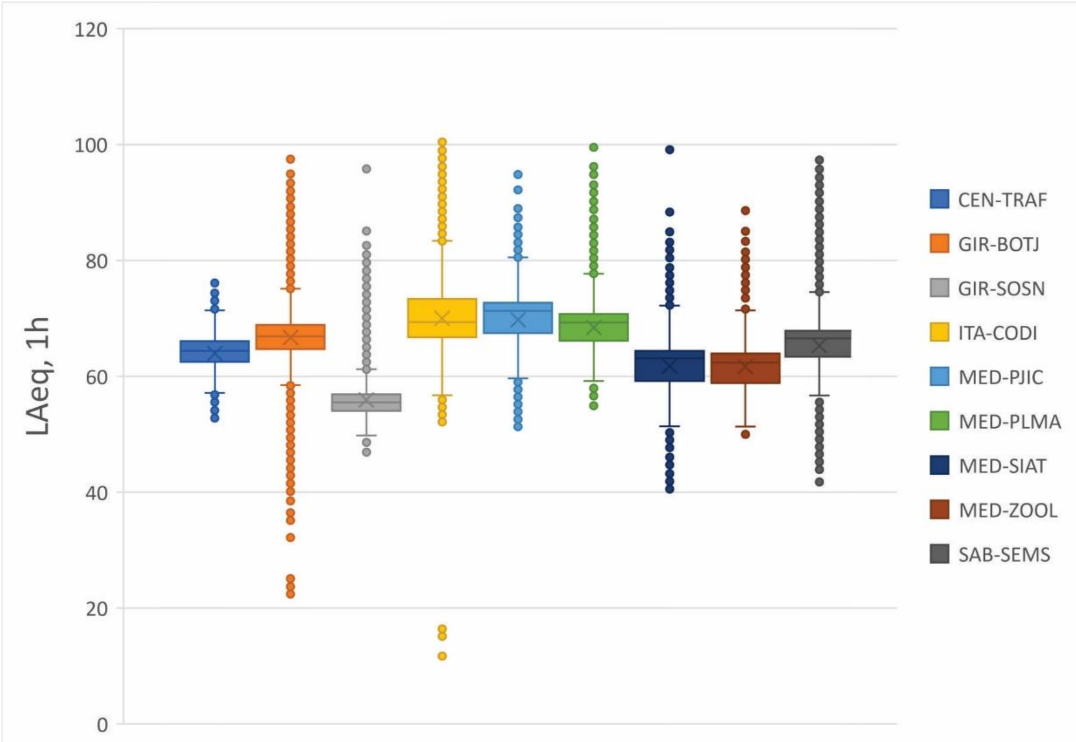

Fig. 11 Box Plot of all monitors. (Taken from own source).

Is important in the preliminary stages used different standardized diagrams to represent numerical data (Hueso et al., 2017), (Geraghty & O'Mahony, 2016), (Przysucha et al., 2020). This type of graph (usually box-whisker plot) Fig. 11 can display highly relevant information in a small space for the understanding of each monitor behavior such as outliers, midrange, data distribution, and can indicate the kurtosis.

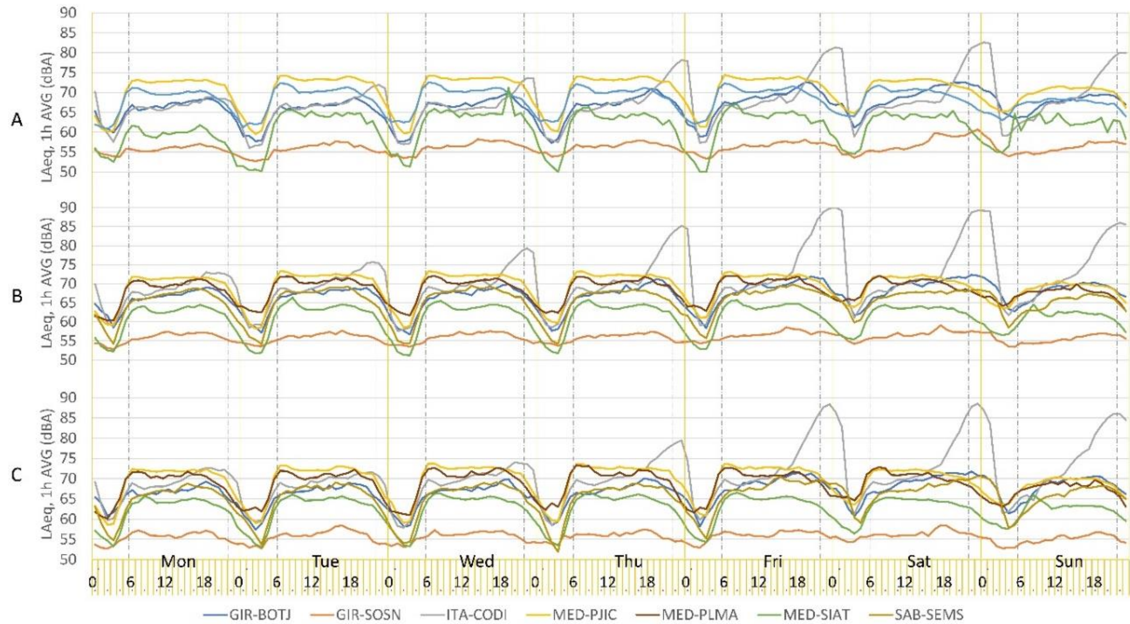

Fig. 12 Day cycle on the days of the week (A. 2016-2017. B. 2017-2018. C. 2018-2019). (Taken from own source).

The cycle of days of the week Fig. 12 is used to represent variability. This graph is obtained from the data of the monitors that are classified first considering the year *2016-2017, 2017-2018, and 2018-2019,* then the different days of the week, and finally, using the arithmetic mean (μ) of the value of each hour that corresponds to L_{Aeq}, *1h* of the data obtained by each sound level meter.

$$\mu = \left(\frac{1}{N}\sum_{i=i-1}^{i=N} x_i\right) \tag{1}$$

The arithmetic average is used in the diurnal cycle graph since it is expected to observe the distribution of the data and the importance of each equivalent continuous level. Otherwise, in an energy average, the higher noise levels would predominate and the variability between periods would not be appreciated. Since the diurnal cycle graph uses arithmetic mean, it is important to calculate the standard deviation for each hour (equation *2*), in this way it will be possible to know the variability at different times (Barrigón Morillas & Prieto Gajardo, 2014; Hueso et al., 2017; Przysucha et al., 2020). Another approach to the variability can be matrices with post hoc or Kruskal Wallis tests (Geraghty & O'Mahony, 2016; Hueso et al., 2017).

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=i-1}^{i=N}(x_i - \mu)^2} \tag{2}$$

Comparisons between annual and monthly data are calculating each year's and month's equivalent level L_{Aeq}, *year* and L_{Aeq}, *month* (equation *3*). Where (*N*) is the L_{Aeq}, *1h* given by the sound level meter. Where T can be assumed like month or year.

$$LAeq,T = 10Log\left(\frac{1}{N}\sum_{t=1h}^{N} 10^{\left(\frac{LAeq,1h}{10}\right)}\right) \tag{3}$$

The comparison between special days with celebrations is made based on L_{Aeq}, *24 h*. The day of the celebration is calculated using (equation *3*) based on L_{Aeq}, *1 h* that the monitors give. Since the measurement span is *3* years, an arithmetic mean (equation *1*) is performed for the weekdays involved. This average is compared with an arithmetic mean of L_{Aeq}, *24 h* on the same normal weekday throughout the *3* years of measurement.

As the games have well-established schedules for the celebrations associated with soccer, the comparison is associated with the same day and hour. Thus, the L_{Aeq},*1h* (for the hours and the days of the game) is compared with the arithmetic mean of the L_{Aeq}, *1h* (for the same hours and weekdays throughout the *3* years).

The stabilization times are built with the data collected for each monitor. While studies such as those González and Giraldo (2010), and Torija et al. (2010) developed methodologies to evaluate the stabilization time of short-term measures. This study focuses on the use of stabilization time for long-term measurements, based on L_{Aeq}, *1 h*. These types of evaluations serve to understand the variability of L_{Aeq}, *T* (Barrigón Morillas & Prieto Gajardo, 2014) and that is used to evaluate the acoustic condition of an environment in a long period. With this temporal resolution for the L_{Aeq}, T of the total hours measured is calculated using (Equation *3*), finding that the records of the monitors have a discontinuity. For the calculation of L_{Aeq}, *T*, the periods with missing data were extracted. This extraction is carried out considering continuous hours. That is, it is carried out in such a way that the total equivalent continuous level (L_{Aeq}, *T*) does not lose continuity. For example, if data is absent at *03:00* hours, the next splice of the following data is made at *04:00* hours of the day with data. This tactic guarantees that the L_{Aeq}, T will not show sudden jumps, due to the different noise values present throughout the day, and that could affect the total equivalent continuous level.

Monitor	LAeq, T (dBA)	Stabilization ± 1dB (Hours)	E.T. > LAeq, T (%)	E.T. > 55 dBA(%)	E.T. > 45 dBA (%)	S.D
GIR-BOTJ	73	6037	17,5	96,4	99,7	5,9
GIR-SOSN	59.8	4755	8,1	60,3	100	3,3
ITA-CODI	80.7	11662	13,8	97,5	98,4	10,6
MED-PJIC	71.7	92	42,9	99,9	100	4,5
MED-PLMA	71.5	10047	15,0	100	100	4,0
MED-SIAT	65.2	9576	14,4	89,4	99,9	4,7
SAB-SEMS	71.4	10469	5,8	93,8	99,9	5,6

Tab. 2 For all monitors: total LAeq, stabilization time, Time of exposure (E.T.) to levels above LAeq, T, Time of exposure to levels above those recommended by the WHO LAeq, day, Time of exposure to levels above those recommended by the WHO LAeq, night, and standard. (Taken from own source).

Finally, noise exposure at each monitoring station is listed in Tab. 2. To find this value, the number of L_{Aeq}, *1h* measurements that exceeded L_{Aeq}, T during the entire measurement period is counted. Then, considering the total hours of measurement, the percentage of time that exceeds: the L_{Aeq}, *T*, the WHO standard for daytime and nighttime environmental noise, is calculated. In this sense, it can be seen how much time this environment is exposed to levels above the L_{Aeq}, *T*, *55 dBA*, and *45 dBA*, respectively.

It should be noted that temporality is evaluated considering spatiality. In this way, point sources can be observed at each monitor. For this, geospatial analysis is used whose metric is distance and the identification of possible sources in the surroundings of each monitor.

8.2.3. Spatial characterization

The spatiality of each monitor can be understood by observing the urban noise environment that is related to the monitor. The sources treated in this work are roads, places of leisure, and other sources that due to their temporal characteristics can appear and disappear. From these sources, two important variables are analyzed: distance to the monitor and quantity. Geospatial tools are used to perform this spatial characterization. This analysis is carried out considering that the proximity of the source to the monitor can raise noise levels, and the quantity of sources can be related to the continuity of the sound level. On-site visits are made to each monitor to verify the main acoustic characteristics of the noise-generating sources.

Another important source to analyze are the celebrations, for example the MED-SIAT monitor has a direct relationship with football, this relationship is due to the proximity of the monitor to the Atanasio Girardot stadium and that commonly before and after football matches, the Celebrations are held by fans of soccer teams. And the GIR-BOTJ monitor is related to the celebrations that take place frequently in the center of a town. This celebration is commonly held in December and on other special days.

8.2.4. Analysis

The first analysis carried out in this work is based on the variability of the noise. To find this variability it is important to recognize the relevant periods, which is achieved with the construction of the weekly diurnal cycle over the years and the trends of the months and years. To identify relevant periods associated with other types of periodicities such as holidays, special days, and celebrations, differences are used between the L_{Aeq}, *24 h* of the day to study, and the mean of L_{Aeq}, *24 h* for the normal weekday throughout the years.

A second analysis is carried out on the sources. Sources associated with noise are identified through geospatial information and site visits. In addition, there are data in this regard provided by SIATA (entity in charge of the monitoring network). Other sources associated with the celebrations can be deduced from the temporality in which they appear and from the festive behavior itself rooted in the culture of the inhabitants of the Aburrá Valley. In addition, the different sources present on each monitor are contrasted with the distance to the monitor, the number of sources, and the noise levels. In this sense, it is expected to relate the level to the proximity, and it can help explain the level differences between monitors.

Finally, to analyze the stabilization time, the total time it takes for the L_{Aeq}, *1 h* to be contained in the range of *+1* and *-1 dB,* is considered. This time is a clear indicator of how the noise varies in each monitor. In addition, stabilization time of each monitor is observed in Fig. 13.

8.3. Results

8.3.1. Stabilization time

An average of *8757 h* of measurement are required to stabilize L_{Aeq}, *T* at *7* monitors. Fig. 13 shows the example of the SAB-SEMS monitor that required *10469 h*. In this graph the parameter L_{Aeq}, *1 h* is represented by a solid gray line, the total L_{Aeq}, *T* is represented by a solid line in red, two blue dashed lines represent the *1 dB* variation above and below the full equivalent continuous level.

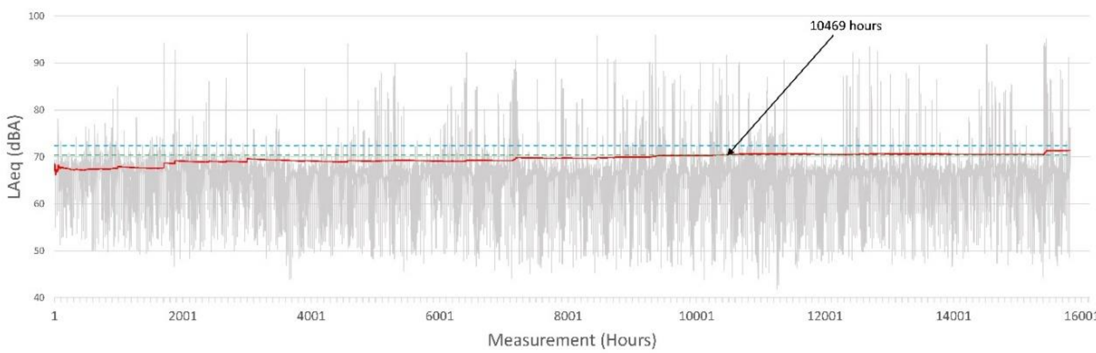

Fig. 13 Stabilization time for SAB-SEMS monitor (Stabilization time 10469 hours). (Taken from own source).

Most monitors take a long time to stabilize L_{Aeq}, *T*, (see Tab. 2). However, the MED-PJIC monitor required the fewest hours to stabilize (*92 h*). This time is quite far from the average and presents a special condition concerning the rest of the monitors. This characteristic occurs because road traffic is the main influence of this monitor (see Tab. 2). The other monitors are influenced by other sources with significant variability. For example, the monitor that required the longest time to stabilize is ITA-CODI (*11662 h*). This circumstance can be attributed to the great influence of leisure activities that present great variability in the L_{Aeq}, *1 h* among hours, days, weeks, months, and years. And it is common in other stations influenced by leisure noise like SAB-SEMS.

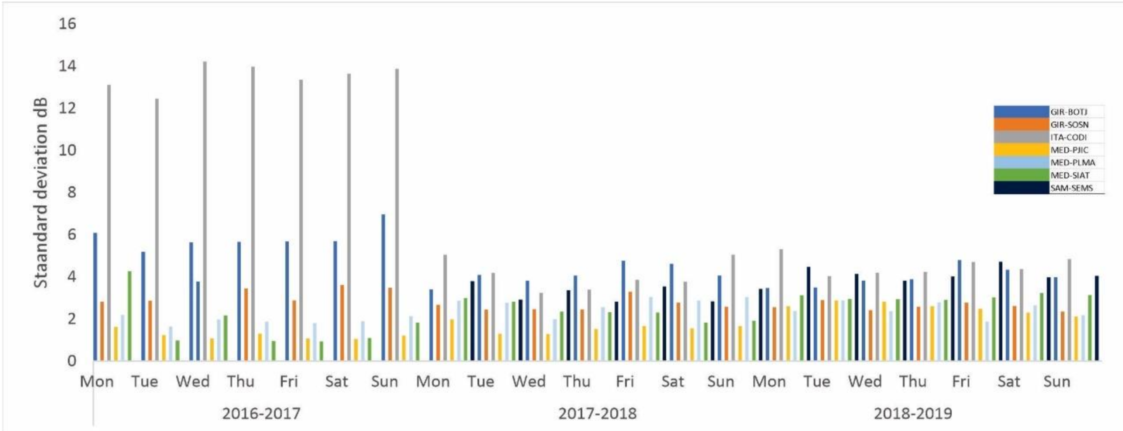

Fig. 14 Standard Deviation for the period 2016-2017 each hour. (Taken from own source).

In the same way, comparing the stabilization time (Tab. 2) with the standard deviation (Fig. 14) the monitors with the highest standard deviation are influenced by leisure activities, in their order ITA-CODI *10.6 dBA*, GIR-BOTJ *5.9 dBA*, and SAB-SEMS *5.6 dBA*. In this sense, leisure activities cause a high variability in noise levels. However, analyzing other years it can be observed that the standard deviation decreases for these three monitors Fig. 14. In this way, it can be deduced that over the years, leisure activities established a more uniform behavior.

8.3.2. Relevant periods

The different curves of the graphs of the weekly diurnal cycle clearly show the different periods of maximum and minimum Fig. 12. Generally, the main peak is generated at *6:00 a.m.* and its runs until approximately *10:00 p.m*. Every day early in the morning a valley is appreciated between *3:00 a.m.* and *4:00 a.m.* However, these valleys are higher on Saturdays and Sundays, coinciding with the leisure periods of the weekend. In addition to the noise generated by the sound systems, leisure activities in the city clearly intensify vehicle traffic at dawn on weekends. This can be seen in the valleys of the different stations that had road traffic as their main source. The noise level at the ITA-CODI monitor is highlighted for nighttime periods around midnight on weekends, which is close to *90 dBA* levels. This is because these types of properties with leisure activities such as bars, discos, pubs do not present any type of acoustic insulation.

Considering the standard deviation for each of the hours analyzed in the graph of the weekly diurnal cycle, the main standard deviation peaks are seen on ITA-CODI monitor on *2016-2017* year (see Fig.

14). The graph Fig. 14 shows the standard deviation for the year *2016-2017, 2017-2018, and 2018-2019* in each day. Other monitors that showed high variability is GIR-BOTJ and SAB-SEMS, especially for the same periods of ITA-CODI. The high standard deviation found on this day of the week and hours for these three monitors again involves leisure activities. The other monitors presented values with non-recurring maximums of *4 dBA* like MED-PJIC.

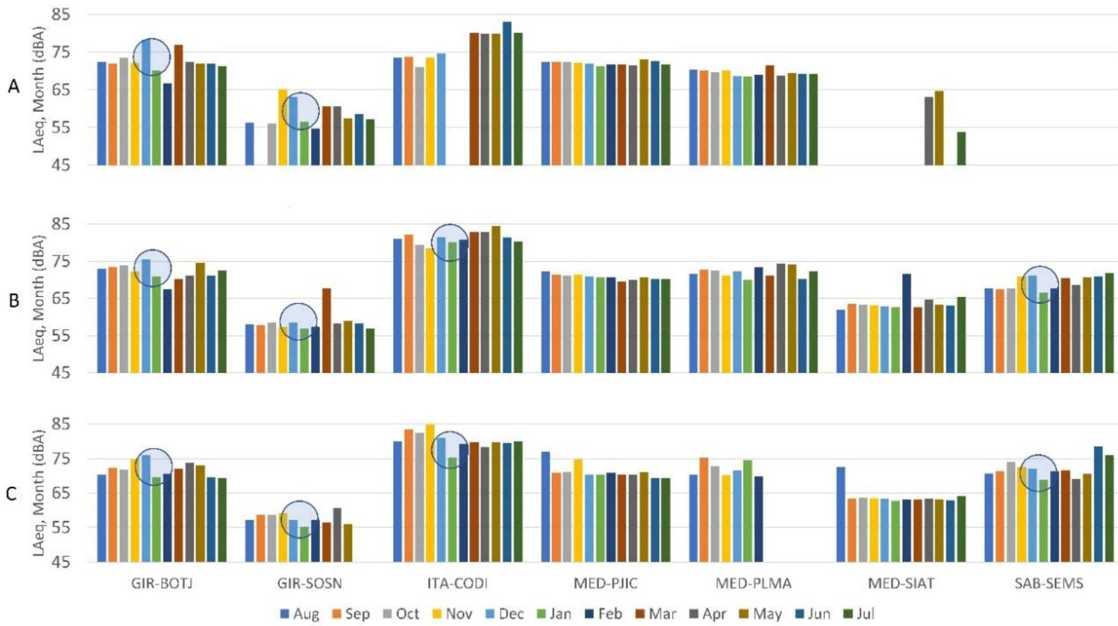

Fig. 15 Noise levels each month between years (A. 2016-2017, B. 2017-2018, C. 2018-2019). (Taken from own source).

The noise behavior between months for each year can be seen in Fig. 15. The monthly behavior graphs show a common trend for the locations where leisure activities are influencing the measurements (GIR-BOTJ, GIR-SOSN, ITA -CODI, SAB-SEMS). This trend shows that between December and January there is a decreasing slope (see blue circles in Fig. 15) and it is linked to the December celebrations that are usually held in this territory. It does not only link medium and high-power sound systems but also increased commercial activity, pedestrians, and pyrotechnics. As for the behavior over the years, there is a small difference. Only two monitors show a significant difference: SAB-SEMS *3.2 dBA* in *2 years* and MED-PLMA *3.5 dBA* in *3 years*. This may be due to the continuous development of this urban area where the number of vehicles circulating is constantly increasing (Covarrubias, 2013).

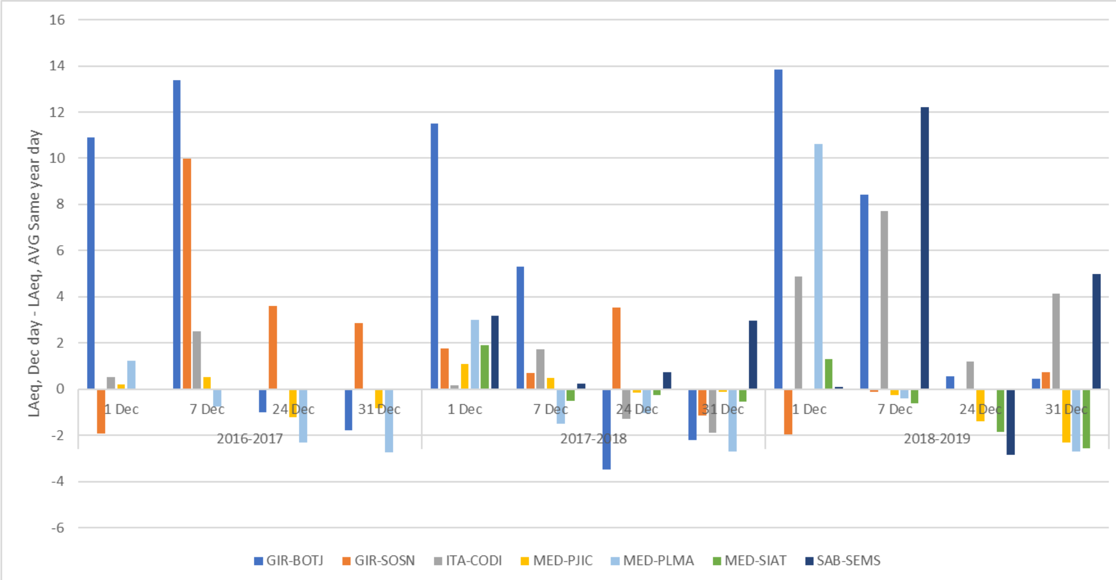

Fig. 16 Noise difference between December special days and annual common days. (Taken from own source).

Now different days are examined, especially those related to celebrations. Analyzing in detail the behavior of noise during December, Fig. 16 shows the difference between the loudest days in December and that same day of the week the rest of the year. As can be seen, days like December *1* and *7* have a great difference, while on December 24 and 31 noise tends to decrease. In general, it can be observed that the monitors most affected by noise in December are those in towns, highly influenced by celebrations especially the GIR-BOTJ monitor. On the contrary, the monitors that have a high incidence of car noise seem to decrease their rates during December *24* and *31*. The high level registered by the monitors on December *1* and *7* may be related to pyrotechnics that during those days it has a great reception from the people. The first is known as "the dawn". On this day, the beginning of Christmas is celebrated with fireworks that are used from the early hours of the morning. On December *7* is celebrated "The day of the candles" which mainly has pyrotechnic activity in the afternoon and at night.

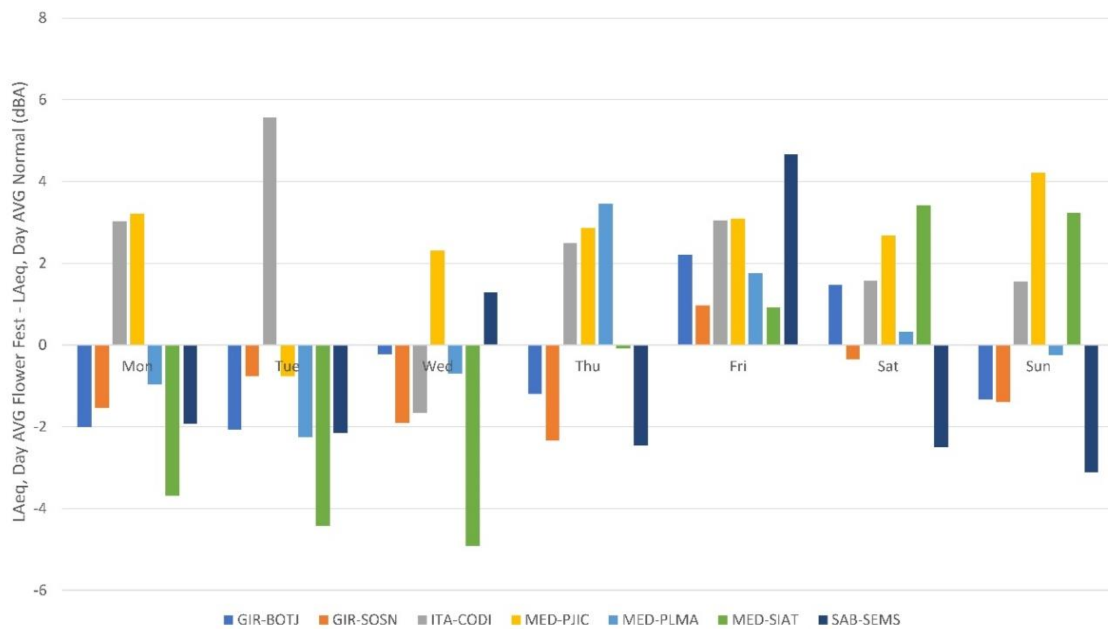

Fig. 17 Noise difference between Flower Fest and annual common days.

Another celebrations day in the Aburrá Valley is the Flower Fest, Fig. 17 shows a difference between the days during the flower festival and the same normal days of the year. Noise levels increase on Thursdays, Fridays, Saturdays. And Sundays. Monday, Tuesday, and Wednesday are usually lower than the rest of the year in most seasons. In the MED-PJIC monitor, there is a significant decrease in noise levels on Mondays, Tuesdays, and Wednesdays during these days of celebration. SAB-SEMS monitor shows similarities for these days except Wednesday and Friday.

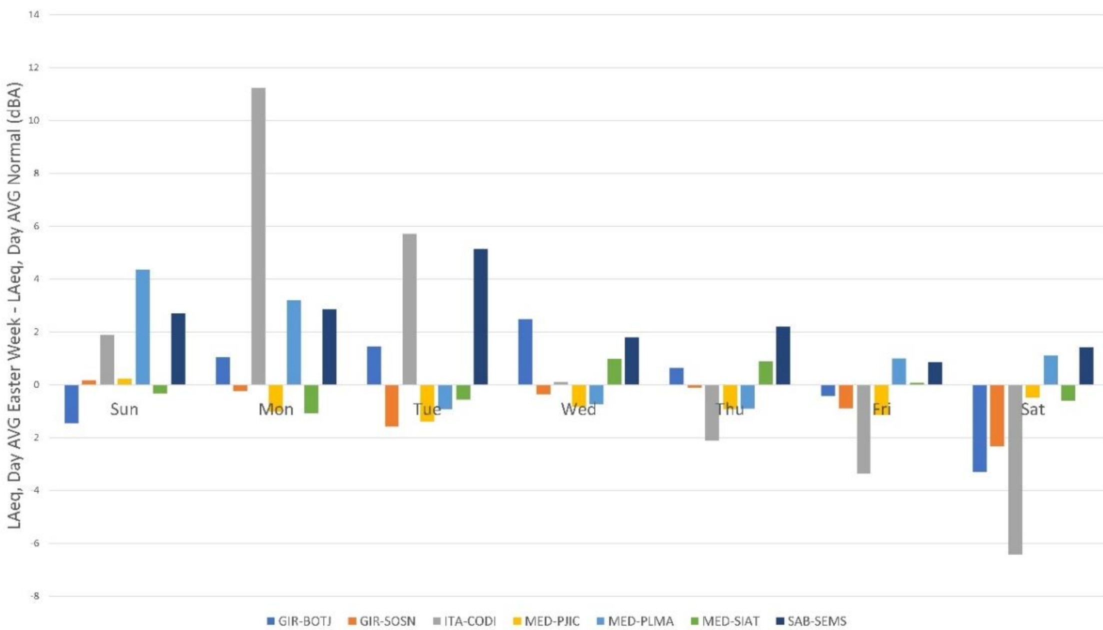

Fig. 18 Noise difference between Easter week and annual common days. (Taken from own source).

A further week that tends to show a different behavior from the rest of the year is Easter. This is due to the high incidence of the Catholic religion in the Aburrá Valley community. Also, this week is used by several people to walk or rest because it is accompanied by Thursday and Friday holidays. Analyzing the difference between Easter and normal days Fig. 18 certain increases are found during Sundays, Monday, and Tuesday, and decreases in the noise level for Thursday, Friday, and Saturday. The increases are marked especially for Monday and Tuesday at the ITA-CODI monitor, which is directly related to noise from leisure. There are also some considerable increases at the GIR-BOTJ, MED-SIAT, and SAB-SEMS monitors. Likewise, there is a significant decrease in noise levels at the ITA-CODI monitor, which increases between Thursday and Saturday.

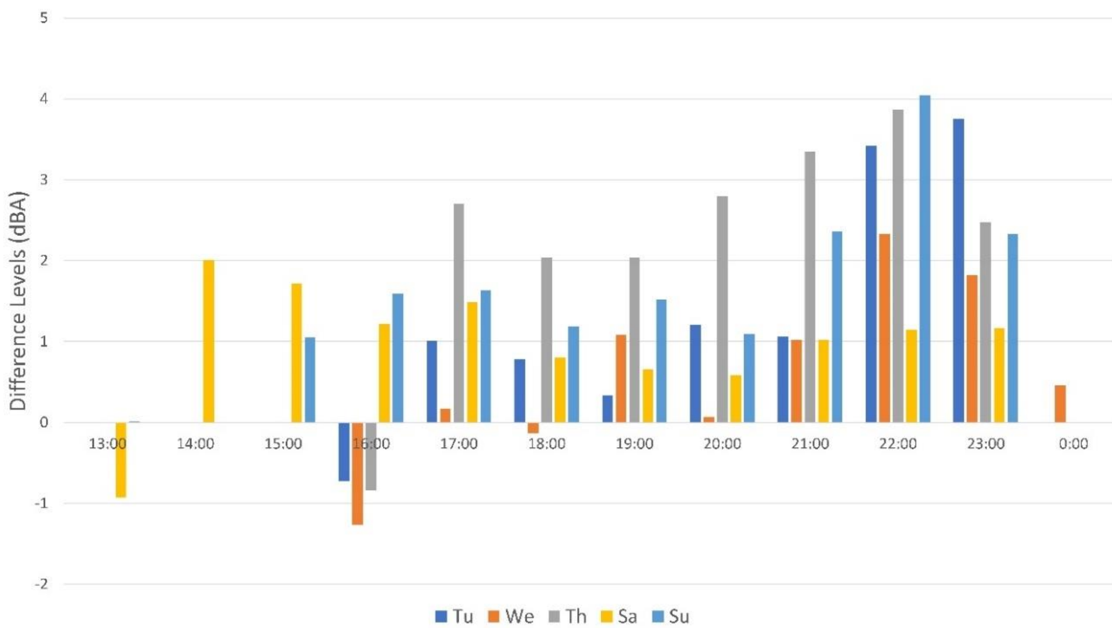

Fig. 19 Noise difference between match days and days without match. (Taken from own source).

Finally, the events associated with soccer are analyzed Fig. 19. Two local teams play at the Atanasio Girardot stadium, Independiente Medellín and Club Atlético Nacional, both with extensive participation in the professional tournament in Colombia and frequently participate in international competitions. During the 2016-2019 period, *91* games were played in the Primera A tournament, *8* in the Libertadores Cup, *3* in the Sudamericana Cup, and 1 in the Recopa. Most games are played on Saturdays followed by Sundays and Wednesdays. The days with the fewest matches are Monday and Friday.

There is a significant difference between days with and without matches for the times corresponding to the matches. Two hours before, during and two hours after each game it is found that there are substantial differences in noise levels associated with soccer activity. The day with the highest incidence of football in noise levels is Sunday. The ~ *4 dBA* difference is found at *2:00 p.m.* and *10:00 p.m.* Thursday also featured many louder events during the days with games taking place between *5:00 p.m.* and *11:00 p.m.* There are also considerable differences on Tuesdays.

8.3.3. Relevant sources

The monitors are positioned in such a way that some important noise sources present in the Aburrá Valley are cover. Sources of noise include roads, pubs, discos, bars, restaurants, workshops, parking lots, event rooms, sports complexes, and pedestrian areas. To give greater clarity on the main sources of noise in each of the monitors see Tab. 1. Making a summary of the spatial characteristics of the monitors in the Aburrá Valley, it is found that in Medellín, MED-PJIC monitor is strongly influenced by noise of road traffic, like MED-PLMA and MED-SIAT monitors. However, MED-SIAT monitor is influenced by sports activities too, especially those carried out in the Atanasio Girardot Stadium. The GIR-BOTJ monitor is predominantly influenced by the noise that occurs in the center of Girardota town. In this central park there are noises from: road traffic, pedestrians and activities related to leisure and celebrations. The GIR-SOSN monitor is further from the urban area and is mainly influenced by community noise. ITA-CODI and SAB-SEMS monitors are influenced generally by leisure activities in nights and weekends and for road traffic in weekdays.

It is important to highlight the coverage provided by the monitoring network see in Tab. 1 it can be shown that there are different sources that are not represented in monitors measurements. This is the case of: rail traffic, air traffic, industrial activities, building construction activities, and other activities such as religious centers, gymnasiums, and educational centers. In addition to other sources of high temporal variability such as domestic activities that involves parties, sound systems, meetings, discussions, shouting, pets, among others. Likewise, there are other sources whose representation is uncertain due to their spatial and temporal variability: street vendors, sirens, car horns, and pyrotechnics.

8.3.4. Source's distance

The different noise sources are spatially identified to understand the levels found in temporality. First identifying the type of surrounded roads, and second analyzing the distance between monitors and roads. There are *6* road class in the Aburrá Valley: main, secondary, highway, collector, service, rural, and sidewalk. It was found that the further the monitors are from the main roads, the lower the noise levels. A demand of almost 6 dBA is contemplated between monitors close to main roads *(~ 8 m)* and those further away *(~ 35 m)*. It was found that the roads with the greatest influence are the main, collector, and service. The distances found are: GIR-SOSN monitor is *39.2 m* from a secondary road, GIR-BOTJ is *10.0 m* from a main road, ITA-CODI is *15.2 m* from a collector road, MED-PJIC is *8.1 m* from a main road, MED-PLMA is *48.1 m* from a main road, MED-SIAT is *37.2 m* from service road, and SAB-SEMS is *4.3 m* from a main road. These distances are from the wall where is mount the monitor and the axis of the road.

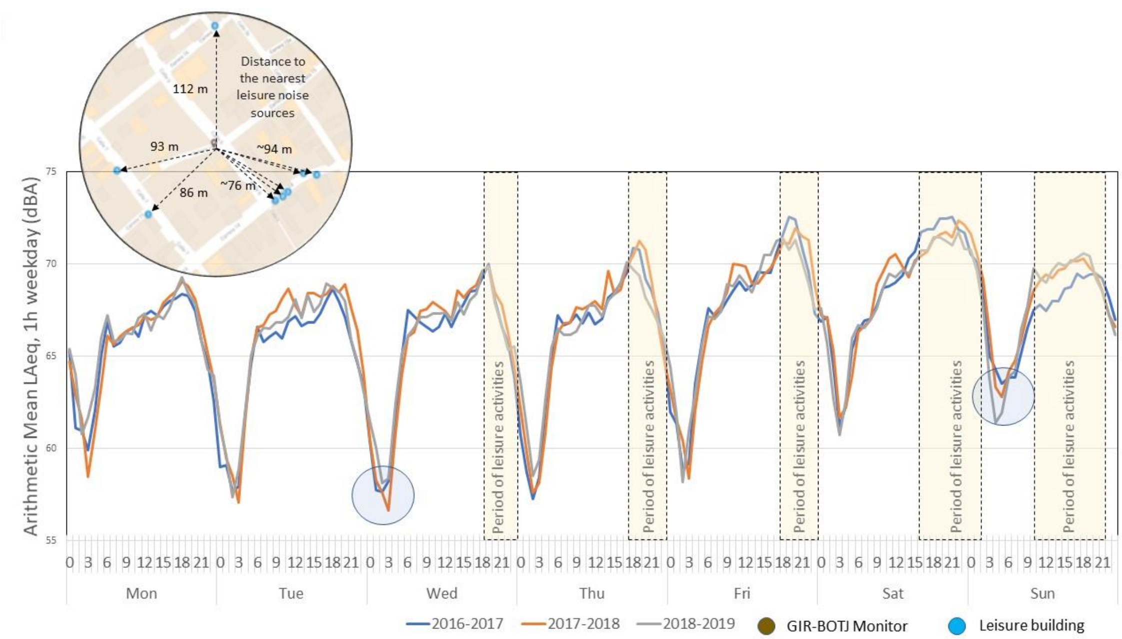

Fig. 20 Weekday noise level on the GIR-BOTJ monitor. (Taken from own source).

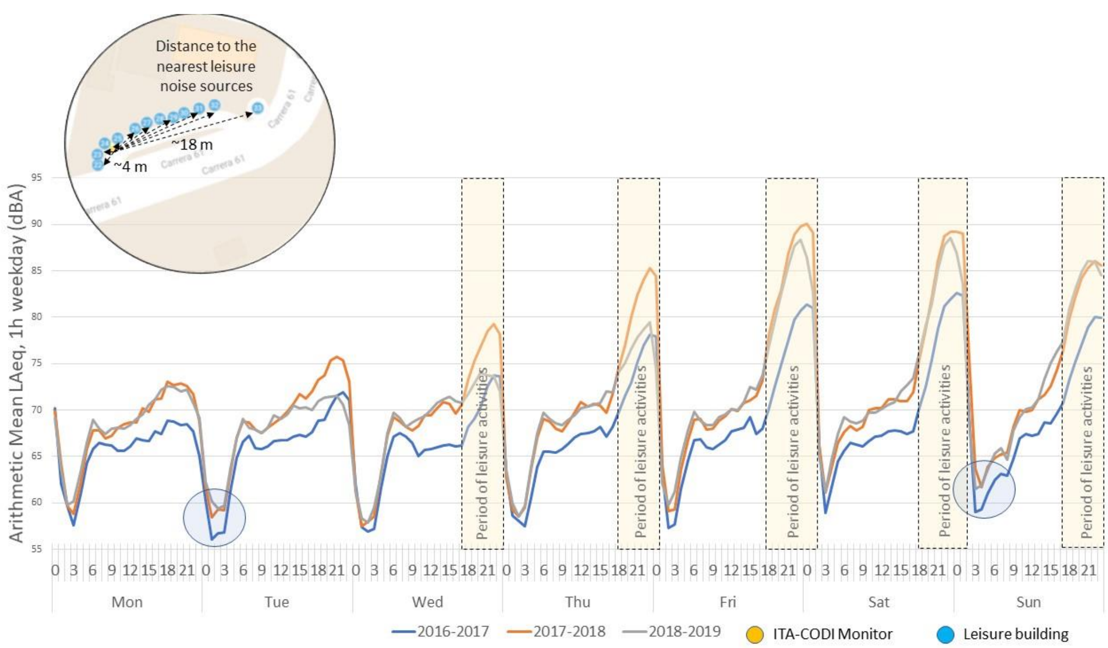

Fig. 21 Weekday noise level on ITA-CODI monitor. (Taken from own source).

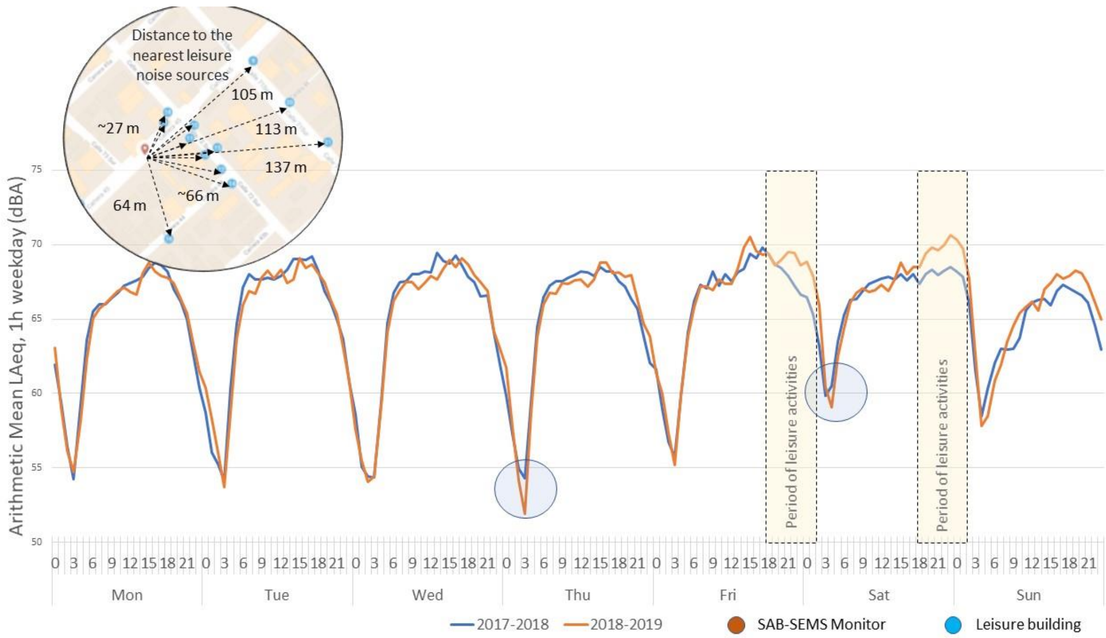

Fig. 22 Weekday noise level on SAB-SEMS monitor. (Taken from own source).

Another important source of noise in this study area that can be identified in Tab. 1 is leisure noise. For this analysis, the three monitors influenced by leisure (GIR-BOTJ, ITA-CODI, and SAB-SEMS) are considered. As already described in the methodology, there are a considerable number of noise sources. In this way it is important to identify the distance and number of noise sources near to monitors. In the following three graphs Fig. 20, Fig. 21, and Fig. 22 it is possible to observe the distance from each source to the monitor, as well as the number of sources that are related to the temporality of the leisure noise. In general, the sources are closer to the ITA-CODI monitor (*12* sources) with an average of *13.3 m*, and that there is a higher noise level with an L_{Aeq}, T of *80.7 dBA*. The other two monitors average *88.4 m* (GIR-BOTJ with *8* Sources) and *61.8 m* (SAB-SEMS with 12 sources) with *73.0 dBA* and *71.4 dBA* respectively.

It is important to mention that the different towns in the Aburrá Valley have different leisure times. However, the high incidence of the commercial properties in the noise levels is appreciated during a period between *6:00 p.m.* and *12:00 a.m.* on Monday through Friday and at *6:00 p.m.* and *2:00 a.m.* on weekends. It is also important to appreciate the blue circle in the graphs Fig. 20, Fig. 21, and Fig. 22 these circles compares the valleys of one day in a week and one day in a weekend. As can be seen, rest periods are seriously affected by leisure activities. However, it is highlighted that the weekly cycle proposed in this work manages to represent in a single graph a large part of the information for the most representative temporalities where valley rises about 5 dBA compared to the week valleys.

8.4. Discussion

The different tools supported by fine temporal representations proved to be useful in the evaluation of noise. Since they allow the identification of maximum and minimum periods, tendencies, and recurrent noise situations, managing to adequately link noise pollution to the activities of a population. Being this type of analysis an ally to noise maps. Although the noise maps address an integral spatiality, it is temporarily meager due to the descriptors it normally uses (day and night) (European Noise Directive 2002/49/EC) (Eriksson et al., 2013). Analyzes like the weekly cycle are dealt with in other studies with prognoses analogous to that of this work. Like for example in the work by Hueso et al. (2017) in the city of Valencia, Spain, which supports the idea of performing analyzes for periods of the work week, week and weekend, supported by a monitoring network and using the Kruskal Wallis test to compare days. Geraghty and O'Mahony (2016) in the city of Dublin, Ireland who finds considerable differences between months, weeks, days and hours using analysis of variance ANOVA and Post Hoc test. Or Barrigon and Prieto (2014) who identifies ways to reduce uncertainty levels, taking random days of measurement in the city of Madrid, Spain. However, it is highlighted that the weekly cycle proposed in this work manages to represent in a single graph a large part of the information for the most representative temporalities.

In the case of the Aburrá Valley, it is shown in Fig. 12 extreme noise situations in the ITA-CODI station. Equivalent continuous levels of around *80-90 dBA* appear each week between *7:00 p.m.* and *2:00 a.m.* Thursday through Sunday. In fact, other stations with similar characteristics manage to show considerable increases in noise on weekends at similar times, even during off-peak hours (*2:00 to 4:00 am*). This is in opposition to what other authors report, such as Quintero et al. (2018) in the city of Barcelona, Spain, where noise tends to decrease on weekends. Nevertheless, the situation evidenced at the ITA-CODI station can occur in approximately *35* pink zones (The pink zone in this region refers to the areas used for leisure activities where many commercial properties agglomerate such as: discos, pubs, bars, among others, with high-power sound systems) that here are along the Aburrá Valley. And it is common in other cities in developing countries such as Machala, Ecuador (Zambrano-Monserrate & Ruano, 2019) where the author explains how the price of the property has depreciated due to this phenomenon. Music that comes from bars and boats due to the increase in tourism and that dismays the inhabitants of Noronha, Brazil (Cristiano et al., 2020). Ibadan, Nigeria where, through population density descriptors and *in situ* measurements, it is possible to identify the impact on the health of the inhabitants due to the noise of loudspeakers emitted by different types of commerce (Oloruntoba et al., 2012). Music from tourist attractions and amplified sound waves causing constant annoyance to the inhabitants of uMlazi, South Africa (Nsizwazikhona, 2018). In hospital areas of New Delhi, India, where by means of noise exposure measurements it is possible to identify the incidence of noise generated by high-level music (Khaiwal et al., 2016).

It is important to note that the pink zones visited during this work had similar characteristics. The first condition is that the vast majority are in the same space as urban dwellings. The second is that most of the commercial properties used natural ventilation (given the climatic conditions present in the Aburrá Valley tropical climate). This characteristic means that the buildings where commercial properties operate have many open facades (Barclay et al., 2012). The third thing is that the places where these leisure activities take place do not have any type of acoustic insulation control. Many of these properties even place tables or chairs in public spaces to increase attention span and bring their music to these places. In the other hand, the high incidence of car traffic in work periods when mobility increases can be seen too in Fig. 12. Due to the high flow of traffic a constant noise level is maintained from early morning (6:00 a.m.) until late at night (10:00 p.m.).

It should be considered that Fig. 12, Fig. 13, Fig. 14, and Fig. 15 show the high variability that noise can have and how the averages made at equivalent continuous noise levels should be treated with caution. This is because situations such as outliers can be observed due to faults in the measurement equipment (example Fig. 11 values below 30 dBA). Permanent variation of the noise reflected in the stabilization time of the L_{Aeq} *1h* (Fig. 14 and Tab. 2). High levels of standard deviation especially for places with leisure noise and during the year 2016-2017. As well as holiday Mondays that increase noise variability throughout the year for this day. This type of situation has already been reported in other investigations such as Przysucha et al. (2020) in the city of Gdansk, Poland, where only *3%* of the data collected in *69* monitoring stations presented a normal distribution. But, according to this study, noise behavior can be well represented by mixing two normal distributions with different statistical properties.

Like Fig. 12 that shows the days in the week, Fig. 15 shows the monthly behavior in the year. This graph highlights the blue circle that shows reciprocal trends in noise reduction between the months of December and January. This for stations related to noise from: pedestrians, leisure activities, commercial properties, community noise, noise from workshops and road traffic (Tab. 1). This characteristic is associated with the December celebrations in which trade, pedestrian crossings, celebrations, high-level music, and pyrotechnics increase. Fig. 15 show too an annual trend for the municipality of Girardota where the noise in December was higher for 2016 than in the rest of the years. Comparisons between months can be seen in research such as that of Geraghty and O'Mahony (2016) where it is possible to appreciate that there are greater differences between the months of February-June and July-December and similarities between the summer months. As corroborated by the work of Zuo et al. (2014) in Toronto, Canada, who manages to perceive similarities between the months of the same season.

To perceive noise events during the days of celebrations and festivities, Fig. 16, Fig. 17, and Fig. 18 were used. Fig. 16 shows differences of up to almost *14 dBA* for December *1* and *7* against the average of the same day the rest of the years. For this, it is important to emphasize the great tradition of pyrotechnics that can be seen on these dates in the Aburrá Valley, mainly in central areas of municipalities such as Girardota. Commonly different explosive materials based on gunpowder (voladores, papeletas, totes and tacos) are detonated on these dates celebrating the beginning of December (December *1*) and the night of lights that has religious connotations (December *7th*). All this accompanied by music at a high level, agglomeration of people and a greater flow of pedestrians and cars. This type of celebrations that include pyrotechnics are reported in works such as that of Garagin et al. (2021) in various regions of Russia. In this work it is possible to appreciate the implementation of different legislative restrictions for the protection of the population against noise. This study highlights the inclusion of different time periods for the evaluation of environmental noise, including "day rest", "evening", "weekends" and "holidays". Similar situations can be seen in Chhattisgarh, India Ahirwar et al. (2015) where measurements were taken *in situ* and compared with local regulations. This study reports how the government authorities have acted against the high level and impulsive noise caused during the celebration of Deepavali, an important Hindu festival. This same problem is reported by other authors in cities such as Sambalpur, Haridwar, Raipur, and Kohalapur India during the same festival (Sahu et al., 2020; Sharma & Joshi, 2010).

Another important celebration in the Aburrá Valley is the flower fest that mainly takes place in Medellin but is also held in other locations of Aburrá Valley. This celebration includes several activities, the main one being the parade of *silleteros* (peasants who parade carrying flower arrangements on their backs). The various activities of the flower fare are accompanied by live sound in the open air, crowds of people, horses, and cars. In Fig. 17, a decrease in noise can be seen around the MED-SIAT station on Mondays, Tuesdays, and Wednesdays. This is presumably due to the closure of roads due to the assembly and disassembly of events that is commonly done in this sector.

In Fig. 17. It can be seen how on Fridays and Saturdays it is common to find increases of more than 4 dBA compared to the rest of the year. This obeys the celebrations that are commonly held on weekends. Compare with others works, festival celebrations apart from those already mentioned during Deepavali are reported in Allahabad, India during Mela Day (Nafees & Nath, 2019) caused by loudspeakers and different musical instruments. In this work, comparisons are made between normal days and festival days. Another study is reported in Calabar, Nigeria where high noise levels are caused by shouting, firecrackers, and different musical instruments. This work finds the high noise levels by making comparisons before, during, and after the festival. In this study sound level meter noise measurements are made using fast integration times due to the impulsive nature of several of the noise sources (Akpan et al., 2019). Other festivals that present noise pollution and that use comparisons of noise measurements made with a sound level meter are listed below (Ak & Cs, 2015; Emmanuel et al., s. f.; Lynch, 2019).

Holy Week is another religious celebration that belongs to the Aburrá Valley that take place in different places of the Aburrá Valley. In this week school activities are postponed for the whole week and work activities from Thursday to Sunday. It can be seen in Fig. 18 how the noise levels can increase during Sunday, Monday, and Tuesday. But they decrease during Thursday, Friday, and Saturday. This trend can be seen more clearly at the ITA-CODI station. This is since at the beginning of the week most people take advantage of these days to be part of religious celebrations or distract themselves with leisure and fun activities. But since Thursday it is common for people to use this long weekend to go for a travel with their families to more rural settings outside the Aburrá Valley. It is even common for several commercial and leisure places to close their doors. In addition to the religious celebration of Deepavali, other publications that relate religious celebrations to noise events are highlighted below (Hume et al., 2012; Mesene & Mengistu, 2021; Yamekeh et al., s. f.; Zannin et al., 2003). These investigations deal with different methodologies to analyze noise, among which are mentioned: exposure measurements, noise measurements, interviews, and questionnaires.

A significant difference between the hours of the day when the football festivities take place with the same hours of the day throughout the years can be seen in Fig. 19. These differences can be seen especially after *5:00 p.m.* and it increases until *11:00 p.m.* The analysis establishes a clear relationship with respect to the influence of noise in the station located in the vicinity of the Atanasio Girardot stadium (MED-SIAT). Where the celebrations generally take place before, during, and after the game, and where the noise is generated by crowds of people, musical instruments, sound devices, pyrotechnics, chants, and shouts. The frequency of the games is greater for Saturday, Sunday, Wednesday, Thursday, and Tuesday in that order and there are no games on Monday or Friday. Nevertheless, the day that presents the greatest difference is Thursday, usually on this day and on Tuesday international cup matches are played. Studies that record noise associated with soccer are reported in some publications such as (Abulude et al., 2018) In this research, *in situ* measurements are used at the time of events and compared with regulations. In another investigation carried out by Carrieri-Rocha, comparisons of measurements are made on game days and on days without games in residences around some stadiums in Brazil, measurements are made in an area between *250 m* and *400 m* in all directions from the stadium (Carrieri-Rocha et al., 2020). In this study, it is possible to perceive a great affectation for people and dogs who live in the periphery of the stadiums.

The spatial analysis linked to three of the stations with the highest exposure to leisure noise can be seen in Fig. 20, Fig. 21, and Fig. 22. These analyzes combine behavior over time and spatial data. High noise levels are evident in the seasonality from Wednesday to Sunday, it can also be seen that off-peak hours are higher on weekends compared to weekdays each year (blue circle). In spatiality, commercial properties such as bars, nightclubs, restaurants, discos, and liquor stores were identified in these sectors, identified through on-site visits and that are clearly responsible for the noise levels on weekends. This analysis highlights the way in which high-resolution temporality can interact with the spatiality of an area. In the case of commercial areas, it explains the occurrence of recurring events and the involvement of those responsible. Other works that interpret spatial versus temporal noise, differently from the traditional map with noise contours, are addressed in some studies. For example, the maps presented by Ramazani et al. (2018) in the city of Tabriz, Iran stand out. Where the noise levels are represented on a map with circles whose diameters are related to a noise range. Or for example Mehdi et al. (2011) who studies the noise problem in Karachi, Pakistan. Several interesting representations are proposed in this work, in which the location of different population densities and noise sources are highlighted in six periods, day, night, and afternoon, both on weekdays and weekends.

Thus, the different tools proposed in this work are of great help for the elaboration of action plans. Since tasks can be prioritized based on the occurrence and level of environmental noise. And that they can also be replicated in sectors with similar conditions. Regarding the Aburrá Valley, it is noted that commercial properties with high-power sound systems are clearly responsible for high noise levels, and it is essential that the authorities take legal measures regarding the acoustic insulation that must be implemented in these premises. For this, it is important to avoid the economic, political, and social pressures that the beneficiaries of these commercial properties commonly exert on decision makers (Nardo, M., 2004). Likewise, different aspects related to celebrations must be controlled, especially those related to pyrotechnics, such as the first and seventh of December. Regarding other celebrations, it is important to emphasize that it would be relevant to know exposure measurements to know the degree of affectation that these celebrations have on the population. This for the case of soccer, the festival of flowers and Easter. Thus, for the Aburrá Valley, action plans are required that involve legal implementations, developments in engineering and the implementation of campaigns in culture and education (Gozalo et al., 2013; Licitra et al., 2017; Morillas et al., 2018). It is important to highlight that the possible limitations that occur with respect to this type of analysis will depend a lot on the representativeness of each monitoring station. For the case study, many sources that are not covered by the monitoring network: railway, aeronautical and industrial noise. In addition to others that due to their variability spatial or temporal are difficult to establish as contributing sources: building construction sites, street vendors, domestic activities, religious centers, gyms, live outdoor events, schools, among others. Many of these noisy activities could be covered by expanding the monitoring network, but others would need different methodologies for their evaluation (Ballesteros, 2015; Palacios-García et al., 2020).

Finally, is also observed that cars represent the most widespread and constant source of noise in the Aburrá Valley, especially due to the constant growth of the vehicle fleet, a phenomenon typical of developing cities (Mehdi et al., 2011). This causes noise levels usually exceed the recommendations given by the WHO (see Tab. 2). More lest, car traffic noise can be linked to the car fleet that there are in developing countries (Chavez, 2019). This problem seems to tend to worsen due to the continuous growth of the vehicle fleet, a phenomenon that is seen both in the study area and in other lower-middle income countries (Chavez, 2019; Covarrubias, 2013; Mehdi et al., 2011). Also, many cars do not meet quality standards not only in terms of noise emissions but also involving economic issues related to driving. One example is the so-called "Penny War" which leads public service drivers to engage in aggressive and stressful driving behaviors (Uran & Escobar, 2012). In addition, it is noted that infrastructure development is not always at par in these types of developing cities, which causes constant traffic jams on the roads that can increase noise levels (Alonso Romero & Lugo-Morín, 2018; Gamero Motta, 2020; Jaramillo, Ciro et al., 2008, 2008).

8.5. Conclusions

Different temporal analyzes used in this study show the usefulness of a fixed monitoring network to identify frequent periods of environmental noise, visualizing hour-week cycles and compared different hours, days, and months in the years. As can be noticed in this casework the Metropolitan Area of the Aburrá Valley a high incidence of leisure activities was observed in weekends until *2:00 a.m.* In which the lack of control by environmental authorities is evidenced. Also, the different celebrations during Easter Week, Flower Festival, soccer games, and especially December 1 and 7 show important noise periods each year. In addition, the high incidence of road traffic in work and rest periods can be seen in this territory. All this noise pollution means that this urban area always exceeds the levels recommended by the WHO. The methodology used in this work could be replicated in urban areas of countries with socioeconomic features like those of Colombia. And they would be of great help to focus actions plans against noise pollution. This is because the literature currently focuses mainly on problems in developed countries that require different environmental management.

9. EXPERIMENTAL INVESTIGATION ON COMPOSITES INCORPORATING RICE HUSK NANOPARTICLES FOR ENVIRONMENTAL NOISE MANAGEMENT (Research component related to specific objective 2).

Abstract

Environmental noise characteristics are determined by factors besides its source. One such factor is reverberation time, which in city canyons tends to be high due to the reflective characteristics of materials commonly used in building facades. Incorporating sound absorbing materials into building facades can help improve urban environments. This research evaluates different facade materials (concrete mix, mortar mix, vinyl spackling, and epoxy resin) incorporated with rice husk nanoparticles (NPs). Rice husk, in addition to presenting good conditions for acoustic absorption, is one of the main agricultural wastes worldwide. Additionally, the characteristic of rice husk nanoparticles is correlated with milling time (longer grinding times enhance production of rice husk NPs). Sound absorption coefficients levels increase for compounds with a greater amount of rice husk NPs. Considering the optimal conditions on the surface of each sample, the epoxy resin in a *20/80*

mixture presented the best performance with an absorption coefficient of *0.5* in the *1000 Hz* band and an average absorption coefficient of *0.39*.

Keywords: Environmental noise; Nanoparticles; Rice husk; Sound absorbing materials; Urban facade.

9.1. Introduction

Environmental noise is the cause of many deleterious effects on the inhabitants of cities and several diseases related to this pollutant are evidenced in different scientific studies. Some of the effects caused by noise on human health can directly affect the auditory apparatus. Other diseases that seem not to be so related to this pollutant are: hypertension, cardiac arrhythmias, preeclampsia, diabetes, or even depression and early onset of mental illness (Auger et al., 2018; Foraster et al., 2014; Gupta et al., 2018; Hammer et al., 2014; Münzel et al., 2017). In addition, the inhabitants of the city regularly find this pollution annoying, and this is responsible for detriment of the quality of life (Geravandi et al., 2015; Jazani et al., 2015; Park et al., 2018; Tabraiz et al., 2015; Tiesler et al., 2013; Vladimir & Madalina, 2019) including various animal species (Bowen et al., 2020; Kunc & Schmidt, 2019; Mulholland et al., 2018). Environmental noise disturbs urban environments, and this study presents ways to reduce its adverse effects.

Environmental noise is mainly generated by sources such as road, air and rail traffic (Bunn & Zannin, 2016, 2016; Filippone, 2014; Flores et al., 2017; Kouroussis et al., 2014; Lawton & Fujiwara, 2016; Münzel et al., 2017; Seidler et al., 2017). Other sources are: industries, civil works, leisure noise, maritime traffic; also: sports, cultural and religious celebrations; or even street vendors and massive events in public spaces (AbeBer et al., 2018; Badino et al., 2019; Ballesteros, 2015; Fredianelli et al., 2021; Juliot Mpabe Bodjongo, 2020; Mohareb & Maassarani, 2019; Nsizwazikhona, 2018; Rendón et al., 2022). Although environmental noise is recognized as a contemporary problem, more effort is required to have healthier urban environments (Berglund et al., 2000; Di et al., 2018; Morillas et al., 2018; Park et al., 2018; Vladimir & Madalina, 2019).

To mitigate noise contaminant, it is necessary to study its nature, the way it spreads, and how it affects those who perceive it source, transmission medium, and receiver (Harris, 1997; Jhanwar, 2016; Maffei et al., 2014; Singh & Davar, 2004). For example, isolation measures can be taken at the source to prevent noise from being generated (Casalino et al., 2008; Licitra et al., 2017; D. Wang et al., 2020). Inappropriate behaviors can also be modified in those who manipulate noise sources (Hunashal & Patil, 2012; Olayinka, 2013). It is possible to restrict the number, speed, and type of individual sources that pass through sites vulnerable to noise (Homola et al., 2019; Maffei et al., 2014). Barriers are commonly used in the transmission medium to prevent noise from advancing from one place to another (Avsar & Gonullu, 2005; Faturrochman et al., 2018; Ishizuka & Fujiwara, 2004; Morandi et al., 2016). For interior rooms, insulating elements can be used to modify the physical space (Amundsen et al., 2013; Campolieti & Bertoni, 2009; Flores et al., 2019; Jang, Lee, et al., 2015a; Ryu & Song, 2019; Secchi et al., 2017).

However, noise control through absorbent materials gains more strength every day against other ways of control such resonators, active controls, and diffusers. Since these types of materials are low cost, they cover a considerable range of frequencies, and they are easily acquired. However, more work needs to be done on certain characteristics of this type of material, such as expanding the range of frequencies at which they work, and their resistance to different conditions to which they may be exposed. Such as humidity, fire, or solar radiation among others (Cao et al., 2018; W. Yang & Jeon, 2020). An example of this type of control is carried out on facades of urban canyon buildings that are usually made with reflective materials such as glass, smooth stone, metal, flat ceramics, plaster, among others (Krimm, 2018; Thota & Wang, 2017; W. Yang & Jeon, 2020). Such hard surfaces constantly bounce sound generated by noise sources, forming a reverberation field that conserves sound energy (Echevarria Sanchez et al., 2016; Mijić & Šumarac Pavlović, 2012; Thomas et al., 2013). The use of sound absorbing surfaces in urban areas would lead to a decrease in noise pollution (Amaya-Amaya et al., 2021; Davis et al., 2017; Hornikx & Forssén, 2008; Jang, Kim, et al., 2015a).

An early work by Delany and Bazley (1970) covered the acoustic characteristics of certain fibrous sound-absorbing materials. In this work, the acoustic qualities of a porous material with a rigid structure are reinforced from the flow resistivity. The limitations of this study were that the consequences were only applicable for highly porous materials. Subsequently, the model was validated by Bies and Hansen (1980) expanding the frequency range to which the model fits. Then in the work of Dunn and Daver (1986) new constants are calculated working with polyurethane foams. Later Miki (1990) identified some problems with the Delany & Bazley model for low frequencies. In this way, other parameters such as tortuosity, porosity and pore shape factor are included to improve the model. More current works use the Johnson Champoux Allard (JCA) semiphenomenological model (Chevillotte & Perrot, 2017) adding other parameters such as fluid resistivity, porosity, tortuosity, viscous characteristic length, and thermal characteristic length in which the pore structure as a solid and the air inside the pores as a fluid (Meriç et al., 2016).

Various materials are used for sound absorption, for example fiberglass, natural fibers, textiles, foams, and recycled compounds, among others (Adams, 2016; Colorado et al., 2022; Rey et al., 2012; W. Wang et al., 2017). All materials mentioned have porosity, this characteristic makes them better absorb sound energy that hits their surface. The absorption is given by the shear forces that these materials offer to the passage of the sound wave in their internal cavities, converting this energy into heat. Relevant characteristics are: pore size, shape, and tortuosity, among others (Cao et al., 2018; Egab et al., 2014; Kalauni & Pawar, 2019). There are several types of porous materials according to their microstructure (cellular, fibrous, and granular). Foam is a clear example of a cellular porous microstructure, highly absorbent materials such as fiberglass are classified as fibrous microstructure, and absorbent concrete is an example of granular absorbents (Adams, 2016). Several of the characteristics that make a material a good acoustic absorber also make it unsuitable for implementation on an urban surface, since the material's capabilities are required to withstand the rigors of the weather humidity, solar radiation, thermal resistance, structural resistance, and so on (Herzog et al., 2004; J.-S. Lee, 2018, 2021). Sound-absorbing materials on urban surfaces require compounds that serve both purposes, absorbing sound energy while providing protection from the elements.

The main disadvantage of absorbent materials used in facades is their low durability under extreme weather conditions in outdoor spaces. Research conducted so far on such materials does not address their resistance to weathering (W. Yang & Jeon, 2020). Up until now, other possibilities have been explored regarding the diffusion achieved with shape and texture of surfaces leading to the reduction of reverberant fields on urban environments using three mechanisms: surface roughness, edge diffraction, and diffusion (Can et al., 2015; Picaut & Scouarnec, 2009; Rathsam & Wang, 2006; H.-S. Yang et al., 2017b). All these attributes of texture and shape in the facades help to diffuse the frequency spectrum of the noise, avoiding the parallel bounce of the noise between the facades that are facing each other in an urban canyon. In this way reducing the reverberation times and therefore reducing the acoustic energy present in the environment.

There are many fibrous materials that can also absorb noise and can be classified according to their origin including synthetic polymer fibers (polypropylene, polyester, polyethylene, nylon, kevlar), non-polymeric fibers (asbestos, fiberglass, carbon fiber, metal fiber and mineral wool), or natural (both from plants such as cotton, hemp, jute, kenaf, bhimal, and animals such as silk, cobweb, sheep wool, alpaca wool, or camel hair). Several investigations have highlighted the relevance of absorbents derived from natural fibers (Asdrubali et al., 2012; Berardi & Iannace, 2015; C. C. B. da Silva et al., 2019; W. Yang & Li, 2012). Non-fibrous materials include metallic foams, aero-gels, and porous concrete (Kalauni & Pawar, 2019). Concrete is of particular interest as it is commonly used in facades and combination with other materials of natural origin within its granular porous structure and could bring improvements to acoustic absorption. Regarding nanoparticles, there have been various studies into nanoparticles, nanofibers and nanotubes and acoustic absorption (Moghaddam & Naimi-Jamal, 2019; Moradi et al., 2020; Zangiabadi & Hadianfard, 2020). Some of the advantages of these materials include their low weight, their aspect ratio and their specific surface area (Bahrambeygi et al., 2013).

Any natural fibers are classified as waste that require management given the high volume of production. This is the case of rice husks, which is currently one of the main agricultural wastes worldwide (Azat et al., 2019; Memon et al., 2011; Santana Costa & Paranhos, 2018; Yun et al., 2020) in this way the use of rice husk can be considered ecofriendly, cost-effective and huge quantities of this material can be manage. Some studies have been carried out on this material that show good performance when mixed with cement in terms of compressive strength, durability, and even fire (Jung et al., 2018; Ramasamy, 2012; Umasabor & Okovido, 2018). Thus, the present work seeks to study compounds made from rice husk nanoparticles and facade materials such as concrete, mortar, spackling and resin, a compound capable of fulfilling mixed functions both for the protection of facades in buildings and for the noise absorption in urban environments. Although some works that have studied this type of compounds are related (Asadi Khanouki & Ohadi, 2018; Kalauni & Pawar, 2019; Moghaddam & Naimi-Jamal, 2019; Moradi et al., 2020; Zangiabadi & Hadianfard, 2020), unlike the previously related works in which the matrix materials are already absorbents being optimized; this work develops compounds based on non-absorbent construction materials. Nanoparticles of vegetal origin have been little studied in the field of acoustics which is the contribution of this work.

9.2. Methodology

A flow chart of the methodology is shown in Fig. 23 to better understand the process carried out in this work. The milling process was referred in Fig. 24. The rice hulls used in this project were Ballihoo

Homebrew Ohio Rice Hull Brown brand. Fig. 24A. The rice husk was placed in a ball mill *8 ″* per *10 ″* ball mill equipped with *37* stainless steel grinding balls of *1-1/4 ″* overall diameter Fig. 24B and Fig. 24C. Grinding was started, and a sample was taken with a spatula (approx. *3 g*) every hour until a total of *12* samples were completed during *12 h* of grinding. Fig. 24D show rice husk nanoparticle samples with deionized water and PVP *15 ml* deionized water and *9.2 ml* of Polyvinylpyrrolidone (PVP) with a concentration of *90.22 g/l* (PVP MW 360,000 Da) were added to each of the *12* powder samples Fig. 24D. Three independent aliquots of approximately *1 ml* were taken from each sample and analyzed with Dynamic Light Scattering, DLS (Malvern Zetasizer Nano ZS) to determine the number of nanoparticles that were generated for each hour of grinding by means of the particle size distribution.

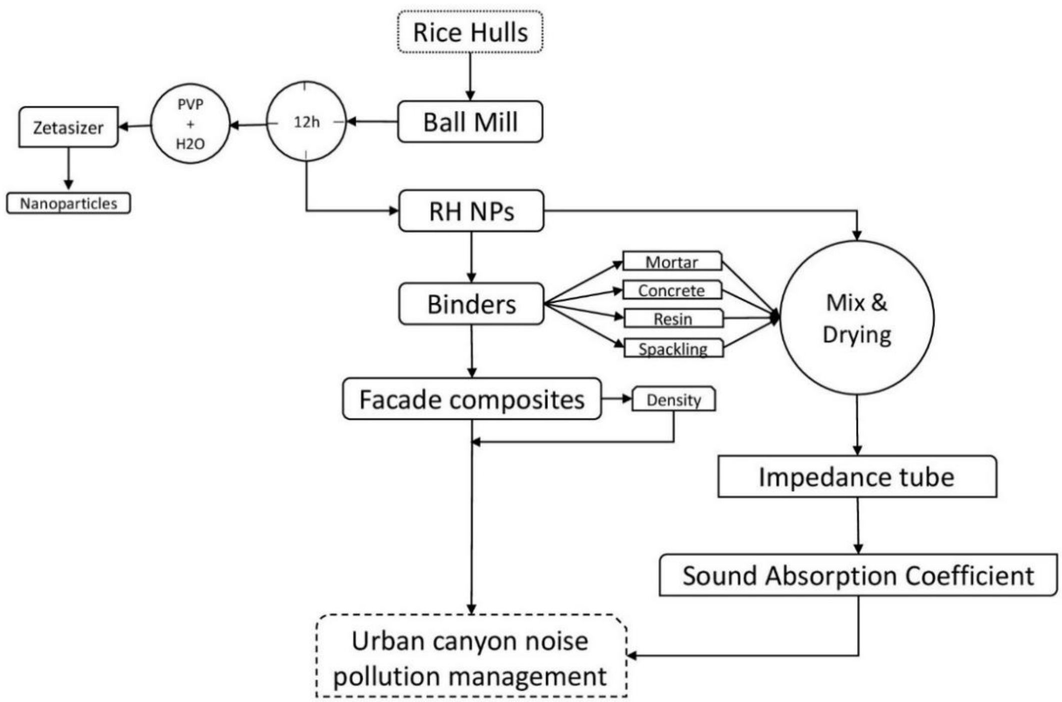

Fig. 23 Methodology flowchart. (Taken from own source).

From the previous methodology it is clarified that although a comparison was made between hours of milling of the rice husk. Only the grinding carried out for twelve hours was used for the manufacturing process of the samples.

Fig. 24 Grinding process. A) Rice husk used for milling. B) Dumping of the rice husk in the ball mill. C) Grinding after 12 hours. D) Rice husk nanoparticle samples with deionized water and PVP. (Taken from own source).

The samples were cast in a Polyvinyl Chloride (PVC) mold with an internal diameter of *4 cm* and a height of *1.5 cm*, which ensured adequate coupling to the impedance tube. Mixtures were made of Epoxy Resin (HXDZFX) Fig. 25A, Mortar Mix (Quikrete) Fig. 25B, commercial Vinyl Spackling (DAP) Fig. 25E and Concrete Mix (Quikrete) Fig. 25D with the nanomaterial generated by grinding the rice husks. The binder/rice husk ratio of these mixtures was calculated by mass, in relation to the dry constituents of the mortar, concrete, putty and the rice husk milling, except for the epoxy resin whose mass came from liquid constituents. The ratio of these compounds (Binder/NP Rice Husk) were *100/0, 80/20, 60/40, 40/60, 20/80 and 0/100.* When necessary, to obtain a homogeneous mixture, an alumina mortar and pestle were used in addition to deionized water (except the epoxy resin), as shown in Fig. 25C. To fit the compound in the mold, a small metal cylinder was used to lightly press down on each compound. A total of *63* samples were produced with the mold (*4 cm* diameter and *1.5 cm* thickness) as shown in Fig. 26 with *3* aliquots of each sample mixture. All samples were air-dried for 24 hours and then demolded and taken to an oven, except the epoxy resin, (Sybron Thermoline 10500 Furnace), they were placed at *90* degrees centigrade and weighed every hour to know to what extent their drying could be carried. It is clarified that this process can be carried out in the open air, but the oven accelerates the drying of the cement by adjusting the times that were used for the investigation.

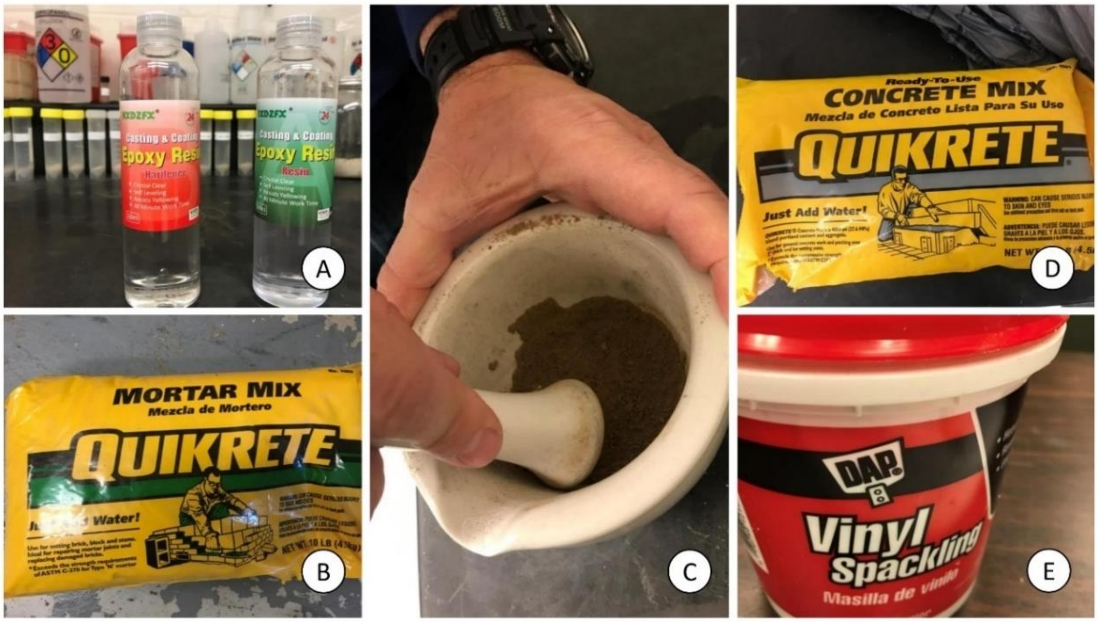

Fig. 25 Facade compounds as a binder. A) Epoxy Resin. B) Mortar Mix. C) Mix of materials with deionized water (except epoxy resin). D) Concrete Mix. E) Vinyl Spackling. (Taken from own source).

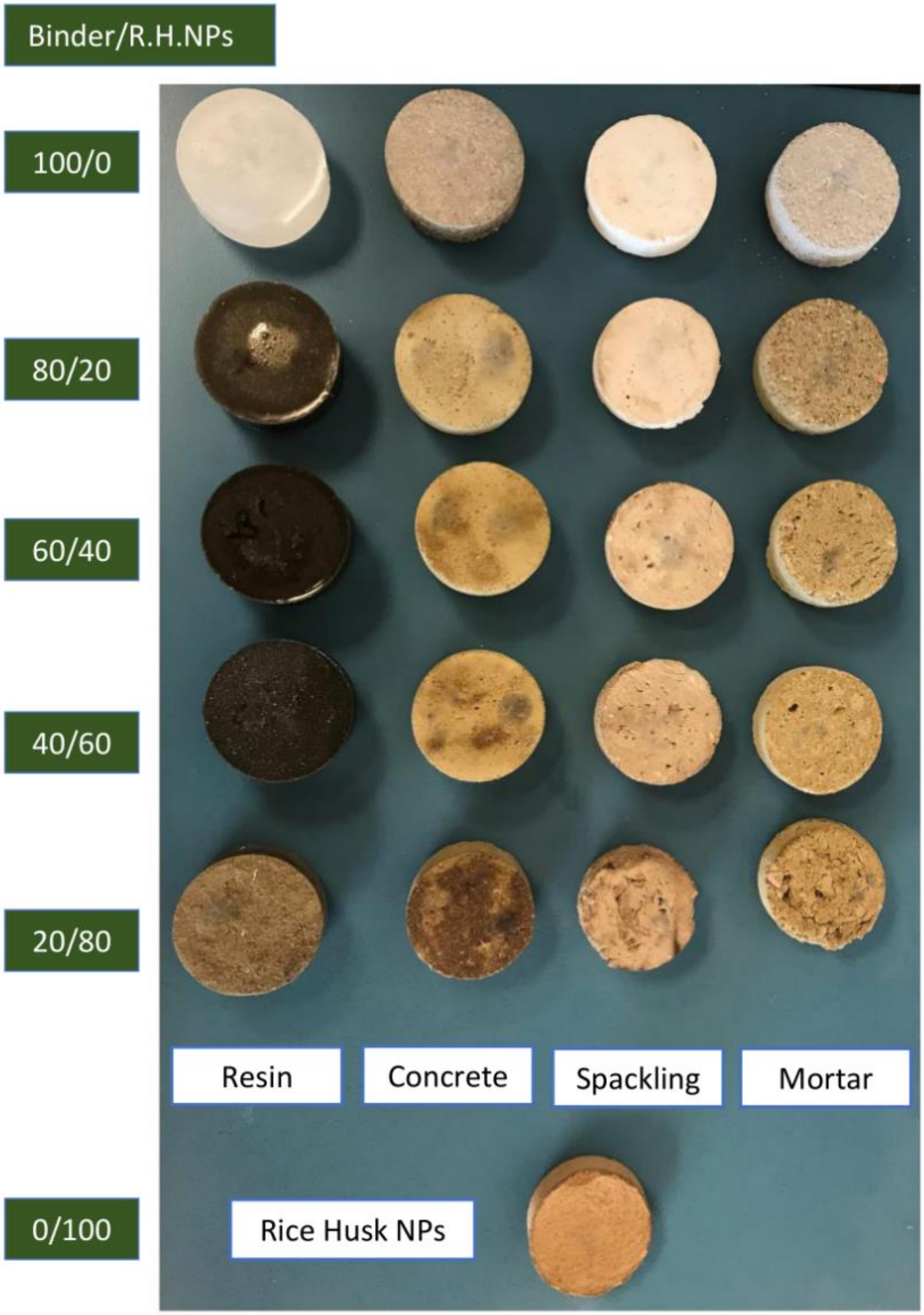

Fig. 26 Experiment design of samples analyzed in the impedance tube. From left to right (Epoxy Resin, Concrete Mix, Vinyl Spackling, Mortar Mix). From top to bottom Composite/Rice Husk NPs (100/0, 80/20, 60/40, 40/60, 20/80, 0/100). (Taken from own source).

A standing wave impedance tube was constructed in accordance with ISO 10534-1 (ISO, 2002). The impedance tube was constructed from a PVC tube with *4.8 cm* external diameter and *4 cm* internal diameter according to the upper limit of the working frequency range (*5000 Hz*) and *200 cm* long according to the range of lower frequency (*125 Hz*) as established in section 6.1.2 of the standard. A Dayton Audio EMM-6 Electret measurement microphone, a HiLetgo PAM8610 stereo audio amplifier *10 w* to *8 Ohm* class *D8 DC8V-12 v*, one Dayton Audio *DMA45-8 1-1/2"* dual magneto aluminum cone *8 Ohm* full range speaker. One *21×29×15 cm* speaker cabinet with rock wool inside, one Focusrite Scarlett audio interface *18i8* with *48 v* Phantom Power to power the measurement microphone, a *3 m* XLR cable, a steel bar to move the microphone inside the impedance tube and a *4 cm* diameter and *2 cm* thick steel cylinder as the sample holder. This is shown in Fig. 27. To avoid noise generated by vibrations on the table, polyurethane foam rectangles were used to support the impedance tube above the table as shown in Fig. 27A. The calibration of the entire measurement chain was carried out in accordance with Annex B of ISO 10534. For each sample, *3* measurements were made in the impedance tube. A normalization procedure with the base that presented a perfectly smooth and rigid surface, by means of a *2 cm* thick polished steel plate where the envelope of the pressure minimums presented a horizontal behavior or a monotonous increase towards the loudspeaker.

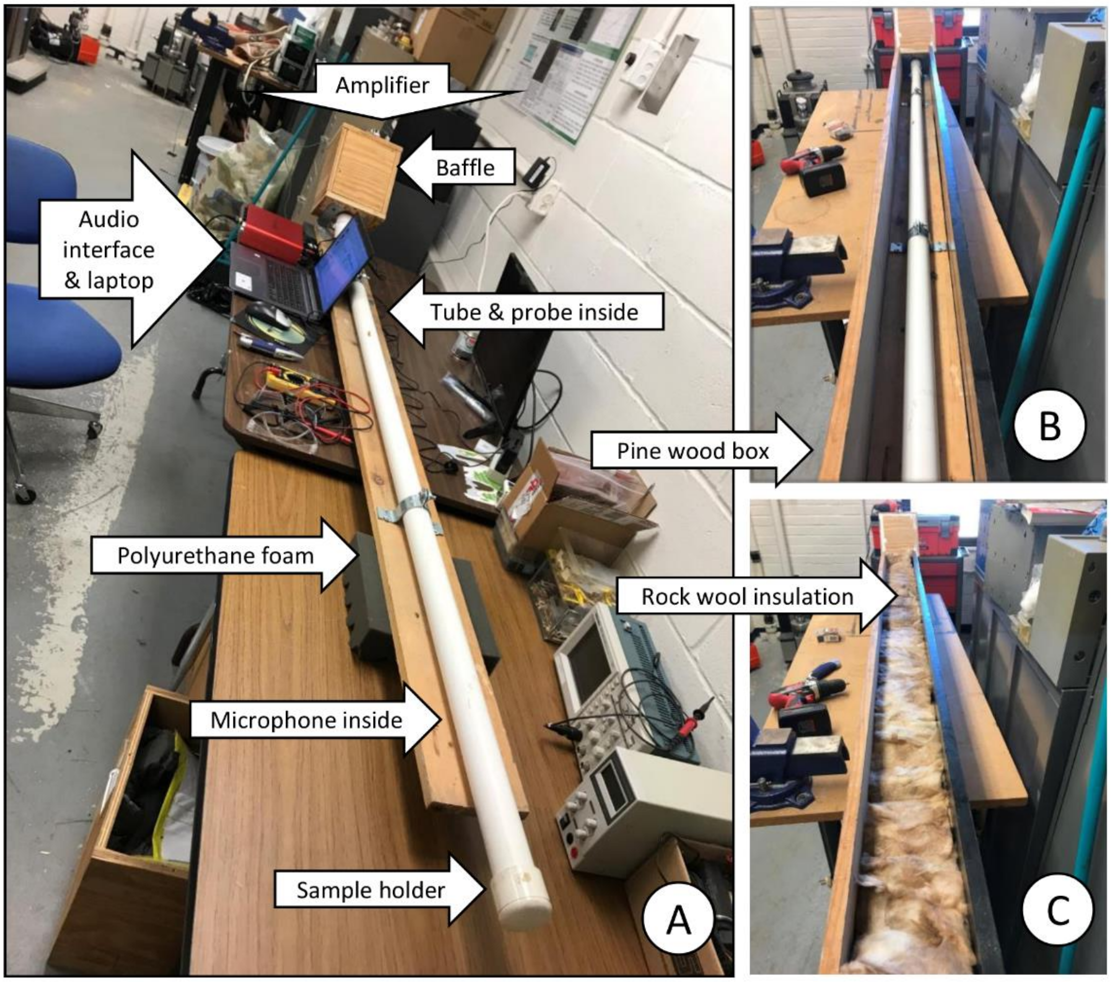

Fig. 27 Impedance tube A) Impedance tube parts. B) Insulate pine box with impedance tube. C) Rock wool insulation between pine wood box and impedance tube. (Taken from own source).

To avoid the incidence of background noise (fan noise in the lab) in the measurements, a box was built with *2.5 cm* thick pine wood and rock wool was placed between the wood box walls and the tube as shown in Fig. 27 B and C. The wooden box was sealed with putty and a movable lid made of the same material, was installed in the place where the samples are exchanged.

The variables of this measurement process in the impedance tube are listed below: independent variable: Frequency, dependent variable: Sound Absorption Coefficient, and control variable: Noise of Fan Noise in the Lab. The last variable is expected to be neutralized to avoid effects on the measurement. REW v5.20.4 software was used to measure the sound pressure levels inside the tube and to produce pure tones by octave bands of *125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz* and *5 kHz* this in accordance with the ISO 10534-1 protocol to measure the maximum and minimum inside the tube. Before carrying out the respective measurements of the samples in the impedance tube, its proper functioning was confirmed by measuring *5.1 cm* rock wool and comparing the absorption coefficient of this material with the existing literature (Delany & Bazley, 1970; Everest & Shaw, 2001; C. M. Harris, 1991; D. A. Harris, 1997; Howard & Angus, 2013) as shown in Fig. 28.

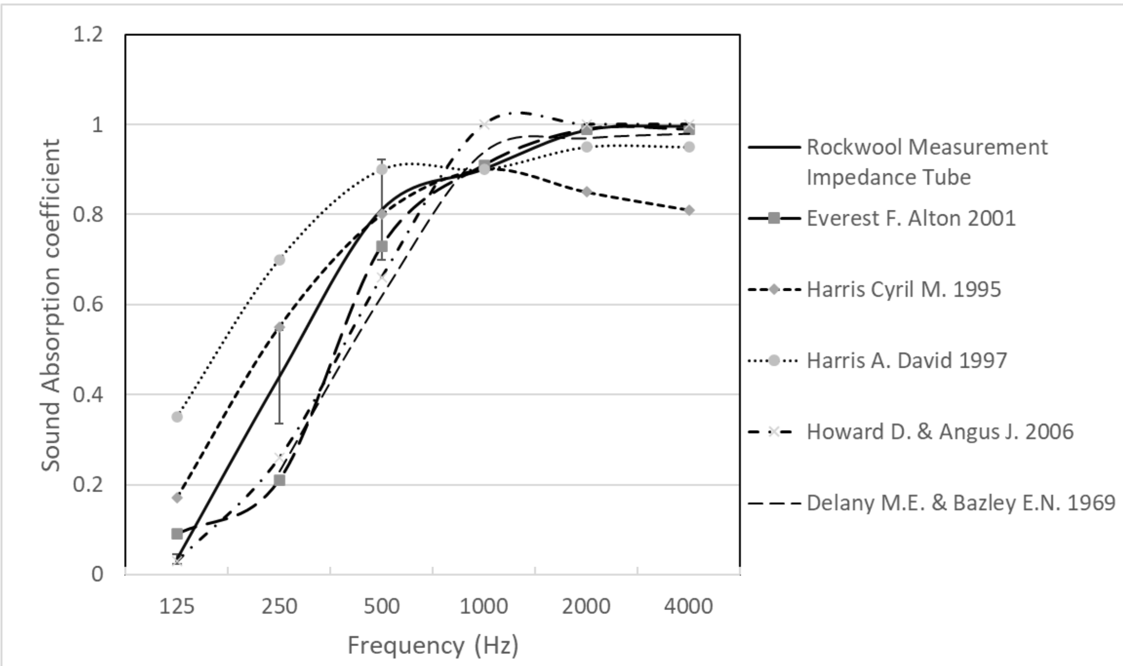

Fig. 28 Comparison coefficient of absorption of rock wool with the literature. Everest F. - Glass Fiber (Height 2.5 cm, density 96.11 Kg/m^3*). Harris C. - Glass wool (Height 5.1 cm, density 24-48 Kg/m*^{3}*). Harris A. - Fiberglass (Height 5.1 cm, density 96.11 Kg/m*^{3}*). Howard D. – Rockwool (Height 2.5 cm, unspecified density). Delany M.E. Fiberglass crown fiber (Height 5.0, density 40 Kg/m*^{3}*). (Taken from own source).*

As can be seen in Fig. 28 the stone wool material measured in an impedance tube presents acoustic absorption qualities like those of other recognized works. Density is an important value to determine acoustic qualities of a material. The weight and volume of each sample was determined. An electronic digital caliper, and a balance (Precisa Bj410c) were used. A digital microscope (Dino-Lite with variable magnification) was used to visually inspect the samples and verify their quality and analyze possible wear, fissures, and cracks.

9.3. Results

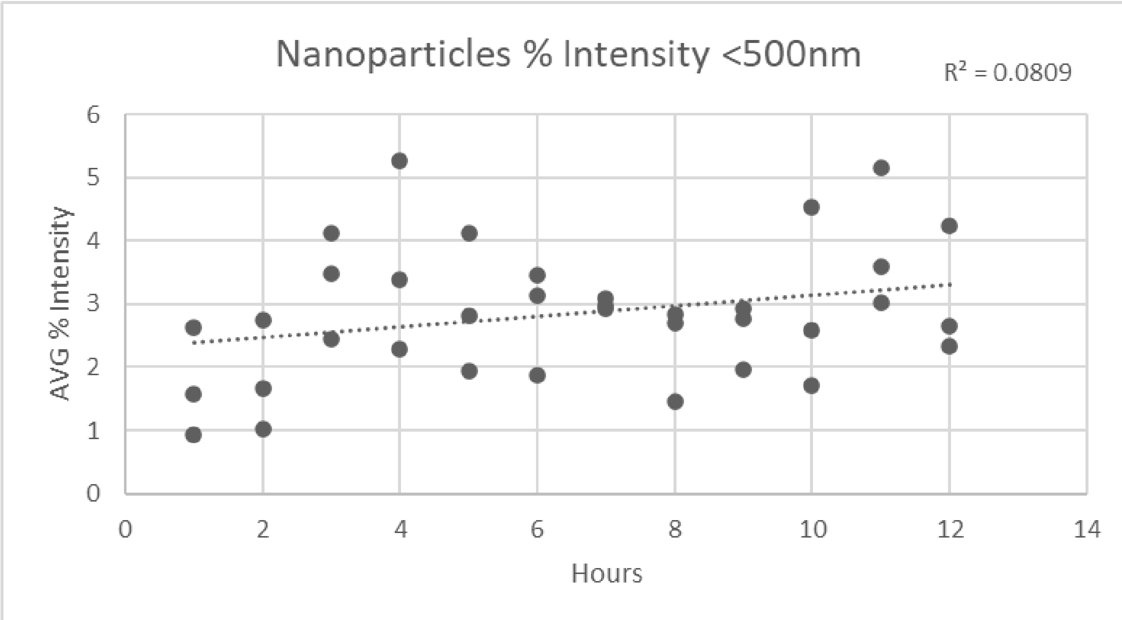

Fig. 29 Nanoparticles % Intensity <500nm. (Taken from own source).

Zetasizer results for all samples showed that 1 (one) sample exhibited one peak, nineteen samples exhibited two peaks, and sixteen samples exhibited three peaks. Typically, the first peak is below *500 nm* (nanoparticles) and the second or third peak is above *500 nm* (particles). Some peaks had a broad base covering intensity percentage for both nanoparticles and particles. All results collected in the Zetasizer show a slight trend of increasing percentage of particles below *500 nm* as the grinding time increased, but a relatively high variability of values Fig. 29.

Oven-dried samples show no further change in weight after about 4 hours of drying. The moisture lose rate is approximately *1.52 g* in the first hour, *0.50 g* in the second hour and only *0.03 g* in the third hour. Some samples showed signs of burning on the surface after *4 h* of drying. Subsequently, the samples were left to rest and acclimatize for *24 h* to later carry out the measurements with the impedance tube.

A commonly used material for acoustic absorption (Rock wool. Height *5.1 cm*, density *60* Kg/m^3) was used to compare the performance of the impedance tube. This material is compared with values in the literature on acoustics in which there are records by octave bands for this material as well as other similar ones, such as fiberglass or rock wool. The comparison is shown in Fig. 28. This graph shows that the rock wool measured in the impedance tube built for this project resembles the sound absorption coefficients reported in the literature.

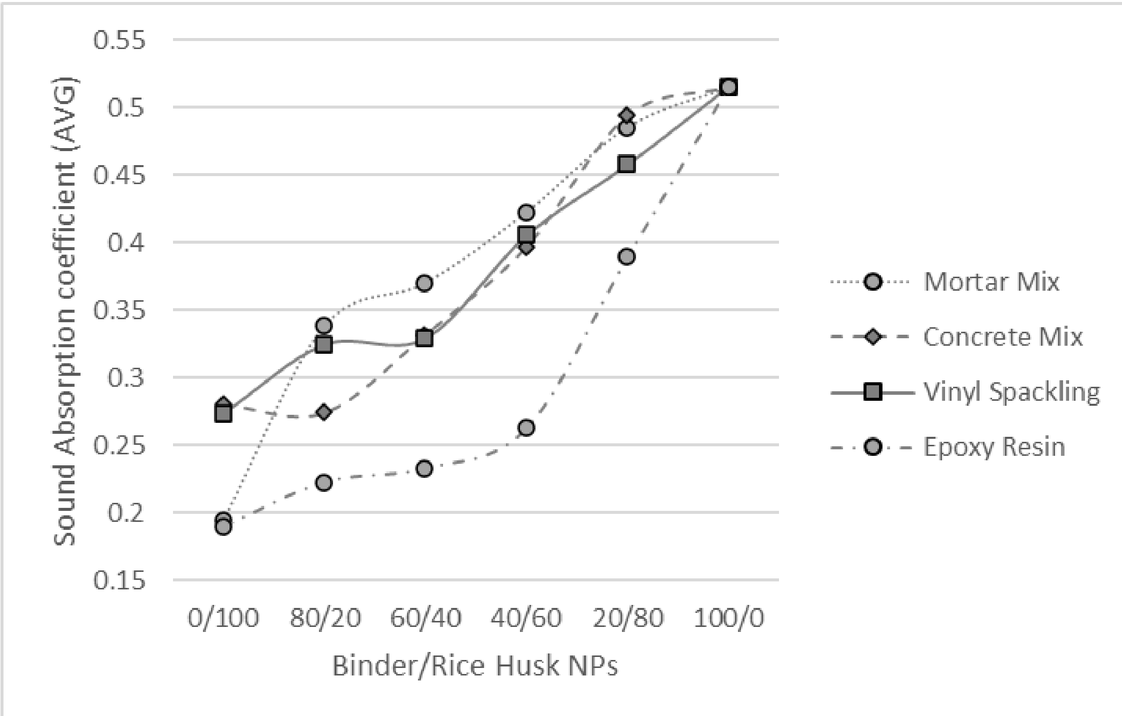

Fig. 30 Average absorption of Mortar Mix, Concrete mix, Epoxy resin and Mortar mix with Rice Husk NPs. (Taken from own source).

The average sound absorption coefficient Fig. 30 , shows a positive trend that is directly corelated to the amount of rice husk NPs added to the compound. The absorption coefficient values at *125 Hz* presented similar values for all sample, these measurements were not considered for the average absorption graphs mentioned in these results. Comparing the initial average *100/0* mix in these four graphs with that given in each binder/rice husk NPs mix. The compound with the best performance improvement is the mortar mix Fig. 30. This compound was able to achieve a sound absorption percentage increase average of *108 %*, the better percentage increase was *149 %* with a *20/80* mix. Epoxy resin has the second average sound absorption improvement, it was able to achieve a sound absorption percentage increase average of *46 %*, the better percentage increase was *105 %* with a *20/80* mix. But, it had relatively the smallest percentages increases to *60/40* and *40/60* mix with a *23 %, 38 %* respectively. Vinyl spackling was able to achieve a sound absorption percentage increase average of *38 %*, the better percentage increase was *67 %* with a *20/80* mix. In last place concrete mix absorption was lower than for others mix for with a sound absorption percentage increase average of *34 %*. This composite has a sound absorption percentage increase of *76 %* with *20/80* mix as shown in Fig. 30.

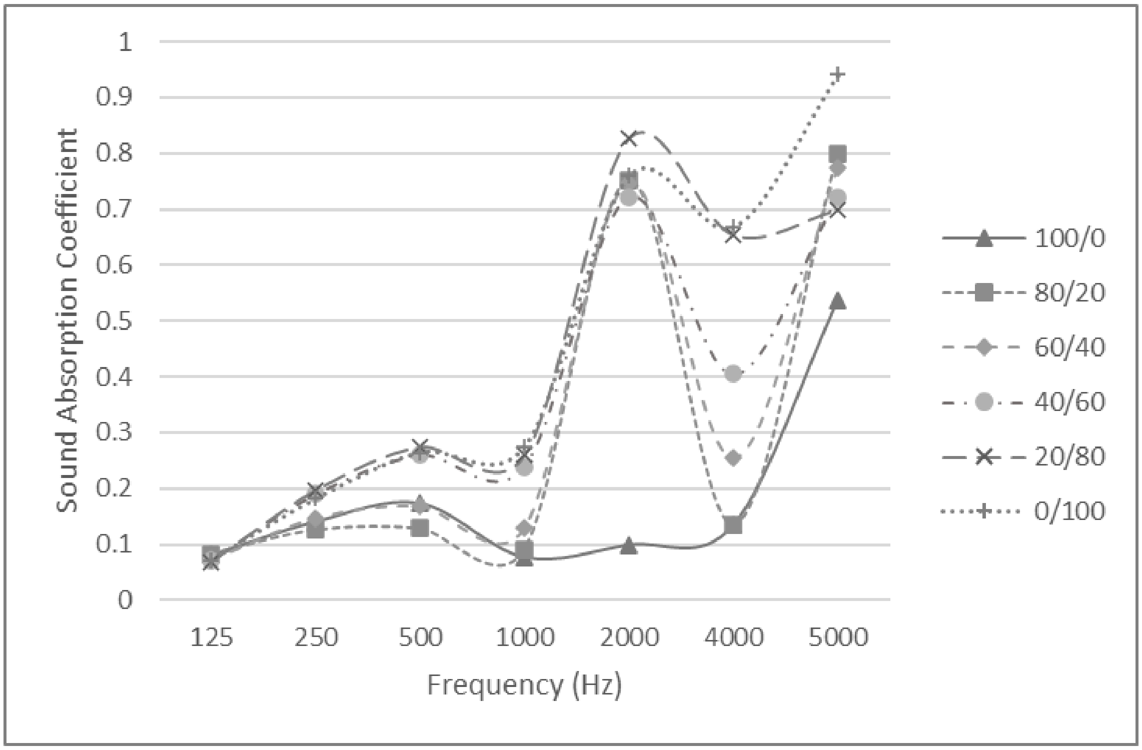

Fig. 31 Absorption coefficient (Mortar Mix/Rice Husk NPs). (Taken from own source).

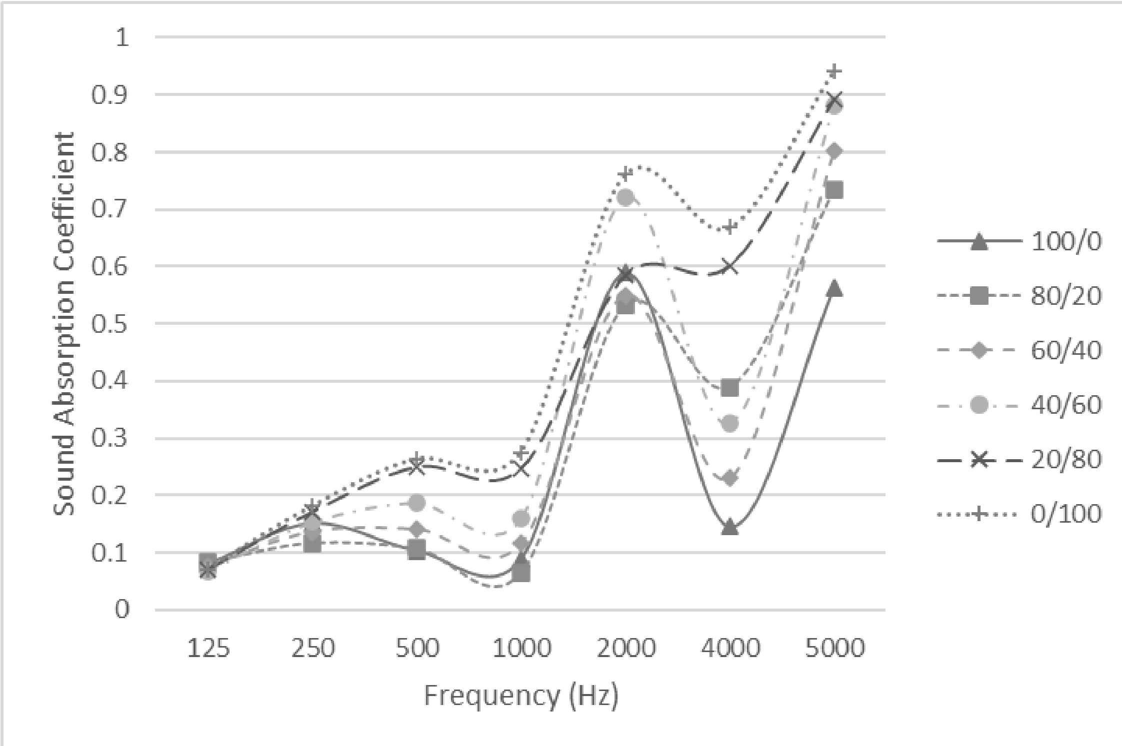

Fig. 32 Absorption coefficient (Vinyl Spackling/Rice Husk NPs). (Taken from own source).

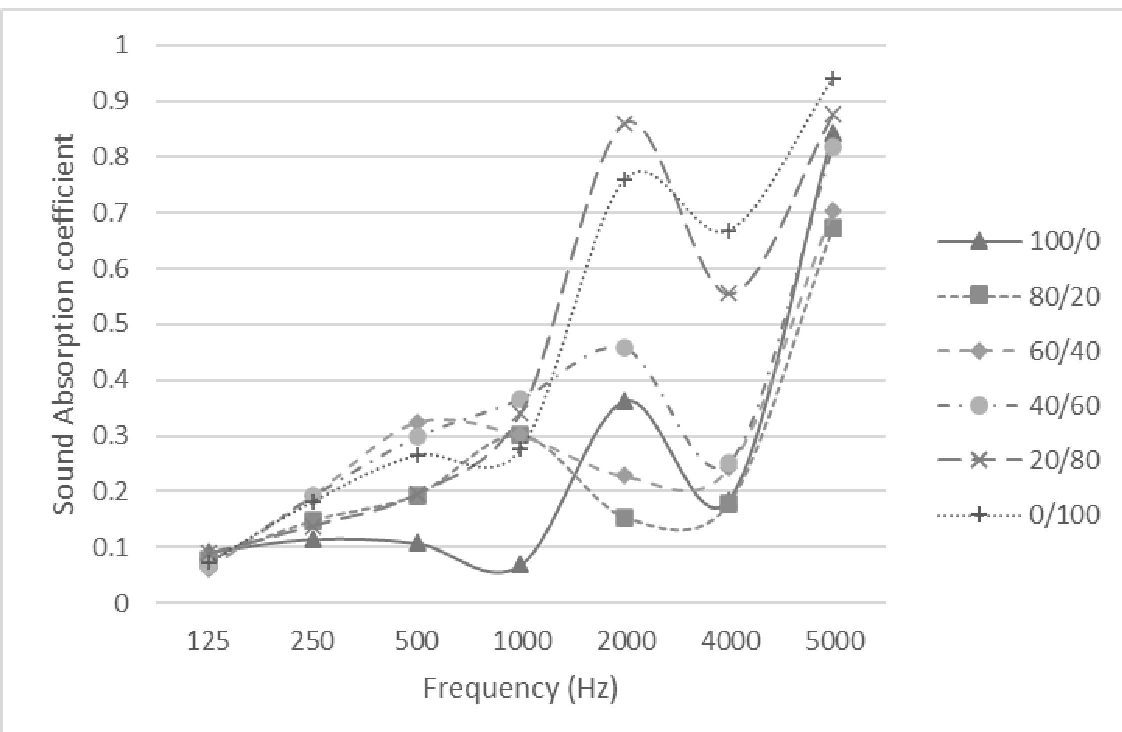

Fig. 33 Absorption coefficient (Concrete Mix/Rice Husk NPs). (Taken from own source).

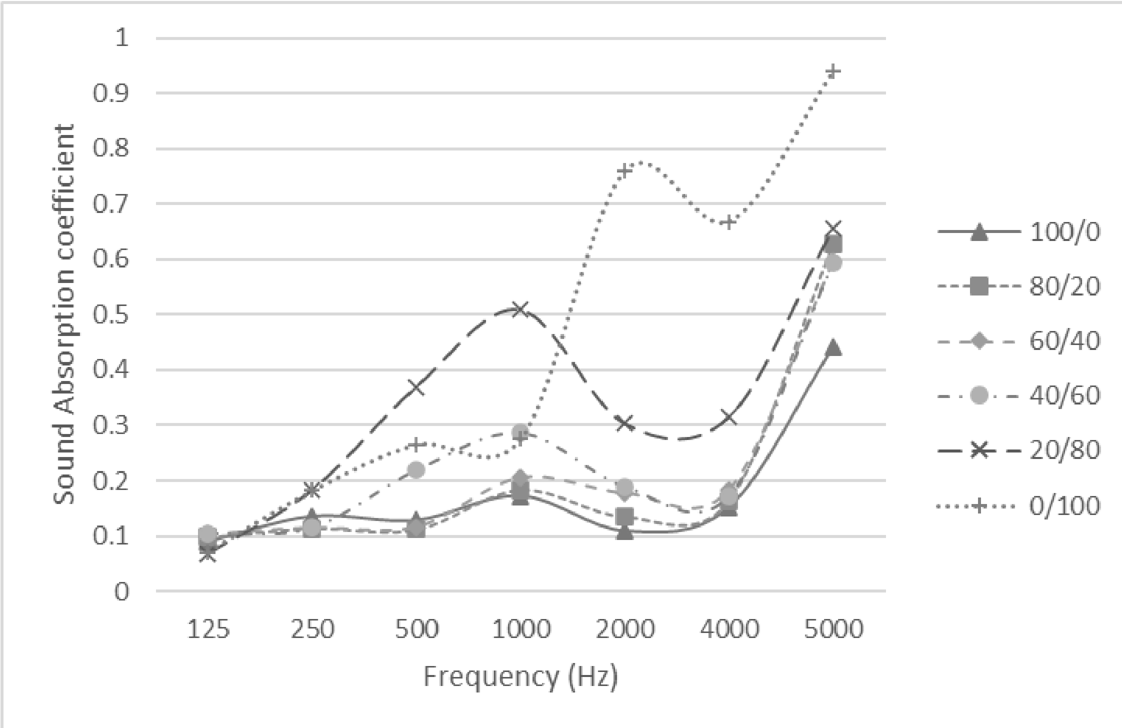

Fig. 34 Absorption coefficient (Epoxy Resin/Rice Husk NPs). (Taken from own source).

The sound absorption coefficient in each frequency Fig. 31, Fig. 32, Fig. 33, Fig. 34 shows that some frequencies are more easily absorbed when the matrix is impregnated with rice husk nanoparticles. Comparing the initial average *100/0* mix with that given in each binder/rice husk NPs mix and considering the octave band frequencies. Those graphs show that mortar mix have a best percentage increase sound absorption coefficient of *728 %* for the *2 kHz* band, in the *20/80* mix, and a *653 %, 648 %* and *622 %* for *2 kHz* too, in the *80/20, 60/40 and 40/60* mix, respectively. In second place appear the concrete mix that have a percentage increase sound absorption coefficient of *433 %* for the *1 kHz* band, in the *40/60* mix, and a *338 %, 338 %* and *395 %* for *1 kHz* too, in the *80/20, 60/40* and *20/80* mix, respectively. In third place, the epoxy resin. It exhibits especially good percentage increases for the *20/80* mix where *195 %* is reached in the *1 kHz* band and percentage increases of *188 %, 178 %* and *107 %* for the *500 Hz, 2 kHz, 4 kHz* and *5 kHz* bands for the same *20/80* composite. Finally, vinyl spackling has the lowest performance. However, highlighting the *20/80* mix where percentage increases of *139 %, 176 %,* and *313 %* can be seen in the *500 Hz, 1 kHz,* and *4 kHz* bands.

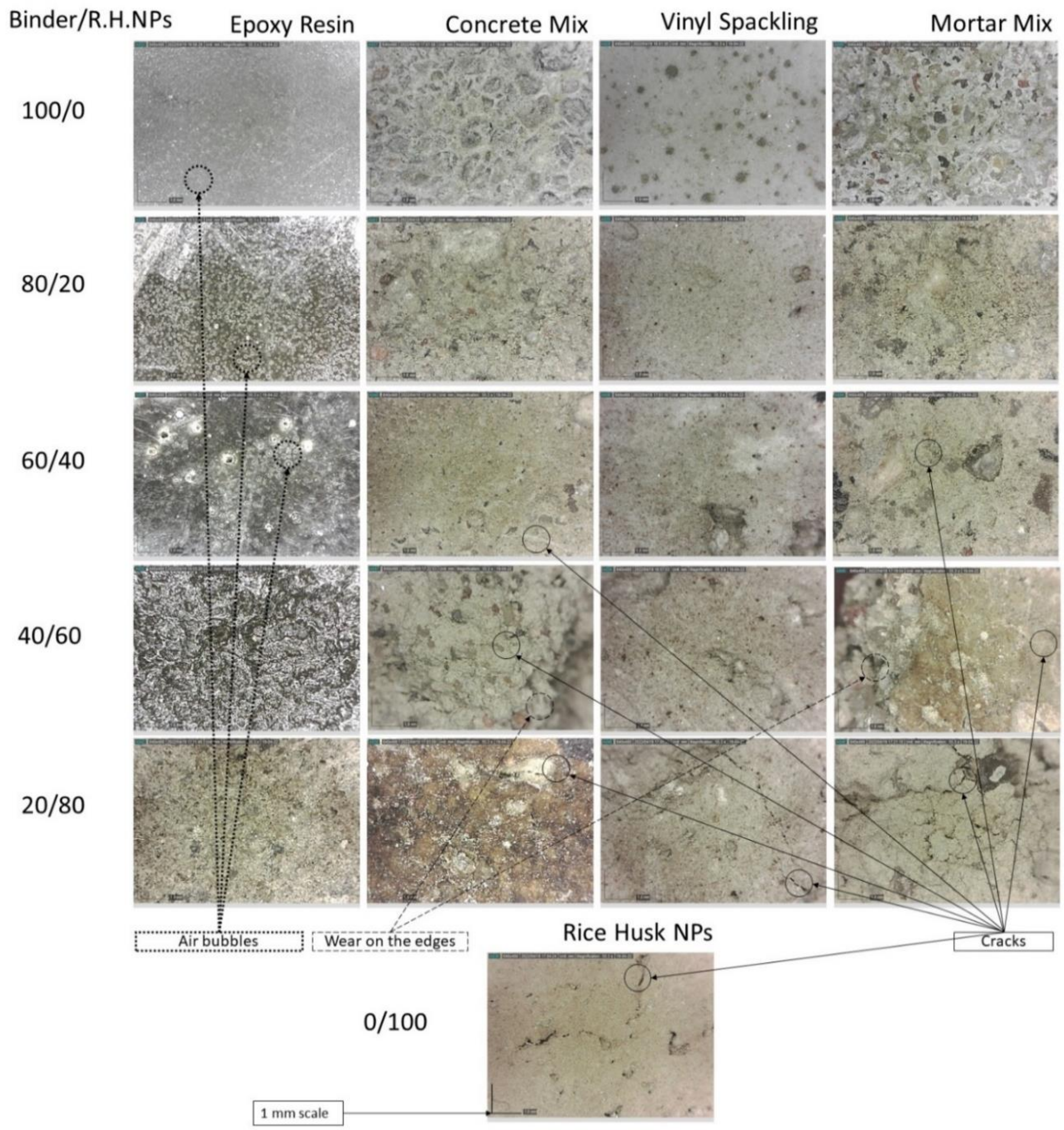

Fig. 35 Microscope imagen of each sampler. (Taken from own source).

Microscopic pictures of all samples are shown in Fig. 35. The epoxy resin samples show bubbles in the *100/0, 80/20,* and *60/40* samples, but they are not perceived in the *40/60* and *20/80* samples. It should be noted that although a careful mixing process was carried out, it is common for these types of bubbles to be generated when mixing the hardener with the resin. The epoxy resin does not show cracks and has a homogeneous surface. The concrete mix and mortar mix samples showed many cracks and edge wear. The *40/60, 60/40,* and *20/80* samples show many cracks in the mortar mix. And for the concrete mix, the *60/40*, and *40/60* samples presented greater cracks and edge wear, the

80/20, and *20/80* sample to a lesser extent. The vinyl spackling samples also showed little cracking (only *20/80* mix) and relatively smooth surfaces. However, Finally, the *0/100* sample presents a homogeneous surface without cracks or wear. It is mentioned how the rice husk nanoparticles without binder become agglomerated because the nanoparticles have a large surface area and naturally tend to agglomerate in many cases (Brunelli et al., 2013; Elzey & Grassian, 2010).

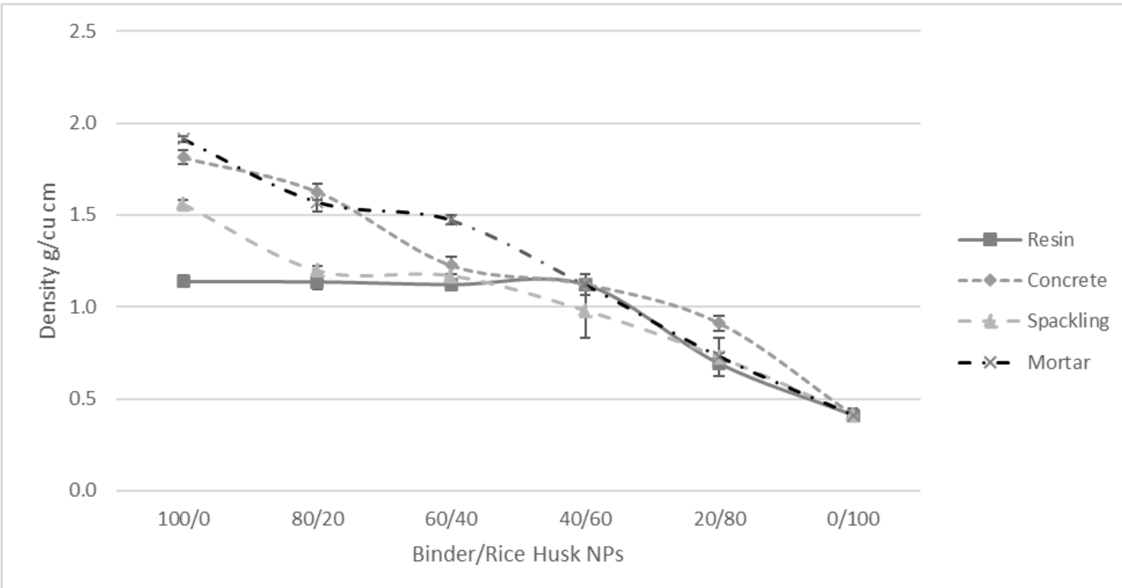

Fig. 36 Density of each sample. (Taken from own source).

The general density trend is shown in Fig. 36, as fiber content increases density decreases. This is due in part to fiber agglomeration and voids due to a lack of matrix impregnation to the fibers, besides rice hunk NPs having smaller density than the matrix materials. A similar decreasing behavior is observed for all samples except for the epoxy resin presented a different behavior from the rest of the samples with density decreasing only for the *40/60* to *0/100* sample. The variation of the data is expressed in the error bars by means of the standard deviation Fig. 36. As can be seen, the main variability of the data occurred with Spackling with a standard deviation $0.15\ g/cm^3$ in 40/60 mix, and the mortar with $0.15\ g/cm^3$ in 20/80 mix. The other samples had standard deviations less than $0.06\ g/cm^3$.

	Resin	**Concrete**	**Spackling**	**Mortar**
Resin	1			
Concrete	0.8722069	1		

Spackling	0.89123208	0.96848866	1	
Mortar	0.89683573	0.96822697	0.99144987	1

Tab. 3 Statistical analysis of correlation between the variables. (Taken from own source).

From the statistical analysis of correlation shown in Tab. 3, it can be deduced that there is a strong direct correlation between all the variables, with epoxy resin presenting less correlation with concrete (*0.87*). It can then be interpreted that in general for the four compounds, as more rice husk nanoparticles were placed in the mixture, a lower density was presented.

9.4. Discussion

A clear absorption trend is presented when rice husk NPs are mixed with concrete mix, mortar mix, vinyl spackling, and epoxy resin increase the average sound absorption coefficient. Fig. 31, Fig. 32, Fig. 33, Fig. 34 show the best improvement sound absorption behavior of the studied compounds by octave bands from *125 Hz* to *4 kHz* including the *5 kHz* band. Rice husk nanoparticles have absorption that is preferential at some frequency bands. For example, the mortar mix compound with rice husk nanoparticles absorbs the *2 kHz* frequency better than others as shown in Fig. 31. Mortar mix also has the capacity to absorb sound in *500 Hz*, *4 kHz* and *5 kHz*, especially with the combination *40/60* mix. While *250 Hz* and *500 Hz* are absorbed less efficiently. Vinyl spackling exhibits a more homogeneous behavior as seen in Fig. 32. Concrete mix exhibits good absorption from *500 Hz* to *5 kHz*, especially for the *60/40* and *80/20* combinations as shown in Fig. 33. Finally, epoxy resin mixes show poorer absorption except for the *80/20*, which again exhibits good sound absorption (~ 0.5 and 0.6) for frequencies between *500 Hz* and *5 kHz* as shown in Fig. 34.

Recently, nanoscale cellulose fibers have shown to be efficient in absorbing frequencies between *1 kHz* and *2 kHz*. And they also show poor absorption of frequencies between *125 Hz* and *1 kHz*. Especially for aerogels with lignin which can reach absorption coefficients of up to *0.94* (C. Wang et al., 2016). One of the main advantages of nanofibers is their large specific surface, which improves sound dissipation due to friction and viscosity (Gao et al., 2016). Even higher absorption performance can be given to absorbent materials by the inclusion of nanofibers. Several studies detailing the optimization of foam absorption through the implementation of nanoparticles have already been reported (J. Lee et al., 2012; Moghaddam & Naimi-Jamal, 2019; Sung et al., 2007; Willemsen & Rao, 2015).

Other studies that relate sound absorption in cements with different binder can be found in different scientific articles. Unfortunately, those studies do not make comparisons of improvement with a base of mix binder. For example (Ngohpok et al., 2018). In this study, average sound absorptions coefficient between *0.36* and *0.43* are found from *60 Hz* to *2.5 kHz*, for pervious concrete mixtures that contain, ordinary Portland cement, water, standard type F superplasticizer, viz crushed limestone aggregate, recycled concrete aggregate, and coal bottom ash aggregate. In addition, it is possible to appreciate absorption peaks that are around the frequencies near of *500 Hz* and *1.5 kHz*. Another study by (Adnan et al., 2020) mixes palm oil fuel ash and expanded polystyrene beads with cement. Sound absorptions coefficients from *0.783* to *0.998* are found for the *250 Hz* band, but lower results for higher frequencies. White cement with hemp short fibers and hemp shives are mixes in the work of (Fernea et al., 2019) in this study absorption coefficients of more than *0.7* are found at frequencies of *500 Hz*, *1 kHz*, and *4 kHz*.

The study carried out by Sekunowo et al. (2020) is highlighted, in which various quantities of calcined rice husk NPs are mixed with epoxy resin in proportions from *0* to *25* for rice husks taking different amounts of the resin and the catalyst. This work reaches absorption coefficients of up to *0.964* in the *5 kHz* band for mixtures of *20 %* rice husk NPs, *54 %* epoxy resin and *26 %* hardener. Good resistance qualities of up to *20 MPa* in flexural strength, 15 Hv in hardness and *3 J* of impact energy were also characterized in mixtures that incorporate *20 %* by weight of rice husk NP.

Densities of both the *20/80* epoxy resin and the *20/80* vinyl spackling are very similar $\sim 0.7\ g/cm^3$, these two compounds, despite having a large amount of rice husk nanoparticles, have a consistency and compact mixtures. This accounts for the viability of rice husk nanocomposites in the manufacture of composites for facades, where compact and resistant mixtures can also be formed, with good strength qualities. Results that have been achieved in works such as those by Aigbodion (2020), Meddah et al. (2020), Praveenkumar et al. (2019). Where it is shown that nanocomposites of vegetal origin can have a considerable performance.

Nanocomposites of vegetal origin like rice husk can have a considerable performance in the control of noise from urban canyons. A great capacity to absorb noise, especially at frequencies above *1 kHz*. Where percentage increase of up to *661 %* in the absorption coefficient are achieved respect to the same facade material used as a binder.

9.5. Conclusions

The results obtained show that the rice husk nanoparticles (NPs) in combination with different compounds commonly used in the facades of buildings manages to have an adequate behavior for the absorption of sound waves. This characteristic becomes relevant for noise control in urban environments since it allows to reduce the reverberation times that can be generated by different noise sources and surface materials in urban canyons.

The compound that presents the best conditions for the proposed mixture is Epoxy Resin/Rice Husk NPs in a *20/80* mixture. The first thing that this compound exhibits is a very homogeneous, resistant, and compact surface without cracks or wear. In addition, it manages to average sound absorption coefficient of *0.39* in all bands and have a maximum sound absorption coefficient of *0.5* in *5 kHz* band. The other compounds show good conditions, but it tends to present cracks and wear that it is important to study in more detail. However, the *20/80* compound of the Vinyl Spackling/Rice Husk NPs can be highlighted since it manages to have good acoustic absorption characteristics and at the same time presents a compact material and presents few cracks and wear. This compound manages an average sound absorption coefficient of *0.46* with *20/80* mixtures in all bands, and a maximum sound absorption coefficient of *0.89* in *5 kHz*. In particular, the rice husk NPs without binder (*0/100* mix) presents a good condition too since it presents an average sound absorption coefficient of *0.52* and a maximus sound absorption coefficient of *0.94* in *5 kHz* band and present littles cracks or wear on its surface. Regarding the materials that presented cracks, it is possible that these cracks in the hydraulic mixtures are related to the curing temperature.

It was possible to corroborate that, in the production process of rice husk nanoparticles by grinding in a ball mill, a greater number of nanoparticles is obtained as the grinding times increase slightly from 1 hour to *12 h*.

Future work should address the ability of these materials to resist outdoor weather conditions such as solar radiation and humidity. Subsequent studies could account for the insertion loss that this type of compound can provide to the acoustic environment of cities and be an alternative in the approach of action plans.

10. EVALUATION OF NOISE MITIGATION THROUGH THE IMPLEMENTATION OF DIFFERENT MATERIALS AND ALTERNATE BALCONIES IN URBAN STREET CANYONS FACADES: CASEWORK ABURRÁ VALLEY, COLOMBIA (Research component related to specific objective 2).

Abstract

The following work evaluates the acoustic performance of different sound absorbing materials and balcony configurations used in the facades of urban street canyons in the Aburrá Valley Colombia. The results show that the absorbent materials that covered up to *16.7 %* of the facade manage to mitigate noise up to *5.1 dB* in some bands between *125* and *500 Hz*. Also show how balconies can increase noise in urban street canyons by up to *5 dB* for some frequencies. All these confirming that these materials may have the conditions to be located outdoors.

Keywords: Noise in urban street canyons; Facade materials; Balcony configuration; Sound absorbing materials; Scale model; Developing countries.

10.1. Introduction

Currently one of the main pollutants in cities is noise, causing different diseases and inconvenience to the population, which is why great efforts are being made to try to mitigate it and thus be able to have healthier and more comfortable urban environments (Bragdon, 1971; Licitra et al., 2017; Morillas et al., 2018; Petri et al., 2021; Vladimir & Madalina, 2019). Major sources resulted to be the most impactful on human life style: road traffic (Cueto et al., 2017; Fredianelli et al., 2022; Ruiz-Padillo et al., 2016). Among others such airplanes (Flores et al., 2017; Gagliardi et al., 2018; Homola et al., 2019; Iglesias-Merchan et al., 2015; Lawton & Fujiwara, 2016), trains (Bunn & Zannin, 2016), port activities (Fredianelli et al., 2021; Nastasi et al., 2020), leisure activities and pedestrians

(Hunashal & Patil, 2012; Rendón et al., 2022; World Health Organization, 2018) are the most diffused ones.

There are several investigations that try to address this problem and provide solutions from different fields of science and technology. Many of them focus on noise mitigation by intervening urban through different materials with good insulating qualities (Chen et al., 2020; Colorado et al., 2022; Jia et al., 2020). New and "futuristic" approaches to materials such as sonic glass in plenum windows is brought to the fore (H. M. Lee et al., 2020; Tong et al., 2015) crystals with nested diffusers in windows that can allow air to pass through but at the same time manage to attenuate noise. Or metamaterials, artificial materials with electromagnetic characteristics that receive their qualities from their structural design and not from their composition, with low-frequency absorption capabilities. As the case of Rubber Granular or Kapok fiber, which turn out to be good acoustic absorbers, especially in medium-low frequencies between *250 Hz*. and *2 kHz*. (Kumar & Lee, 2019).

However, it is common for reflective materials to be found on urban surfaces, causing an increase in the acoustic energy present in an environment (Davis et al., 2017; Jang, Lee, et al., 2015b; Mijić & Šumarac Pavlović, 2012). This phenomenon occurs because the sound from different noise sources collides with reflective surfaces when moving and repeatedly bounces off different surfaces (Alonso Montolio & Crespo Cabillo, 2019; Everest & Shaw, 2001; Howard & Angus, 2013). In this way, the energy produced by the noise remains for a greater amount of time in some areas. This phenomenon is common in urban street canyons, environments where a street is limited on both sides by different buildings, in which there are well-marked characteristics such as: width of the road, height of the buildings, uniformity, constitution, location, among others (Addepalli & Pardyjak, 2013; Kastner-Klein et al., 2001; Kim & Baik, 1999). This is because the facades of buildings are commonly constructed of materials such as glass, metal, stone, ceramics, cement and other materials that, due to their constitution and shape, are highly reflective (Krimm, 2018; Thota & Wang, 2017; W. Yang & Jeon, 2020). In addition, given the characteristics of an urban street canyon since the facades of the buildings are one in front of the other. The parallelism of these surfaces helps the noise caused by the various sources in an environment to persist (Bort & Beckers, 2021; Iu & Li, 2002; Van Renterghem et al., 2015).

It has been decided to implement different materials and shapes on the surfaces on which the noise sources affect to reduce noise reflections in urban street canyons. Some elements include absorbent materials and protuberances, the former acting on the reduction of the reverberation time and the latter acting on the diffusion of the sound field (Badino et al., 2019; Tian et al., 2014; Van Renterghem, 2019; Van Renterghem et al., 2013). Different urban designs are also contemplated that can redirect or avoid parallelisms in urban street canyons (Ariza-Villaverde et al., 2014; Echevarria Sanchez et al., 2016; Guedes et al., 2011; Han et al., 2018). It is also important to mention the use of adaptive facades, which can become a very good option to avoid this type of reflection (Monika & Boris, 2018; Tabadkani et al., 2021; Techen et al., 2018).

Among some of the elements that act on the diffusion and absorption of sound, emphasis is placed on the balconies. Balconies are considered elements of the facade that help mitigate environmental noise levels due to their shape and the absorbent material that can be adjusted to their surface (Badino et al., 2019; P. J. Lee et al., 2007; Tang, 2010). The main advantage is that the balcony itself is a common part of buildings, especially residential ones. And in some part of its structure (glider, roof, or floor) it can offer the possibility of housing either absorption or diffusion. On the other hand, balconies with surfaces oblique to the sources and other facades can help redirect noise and avoid reflections (Echevarria Sanchez et al., 2016; Hossam El Dien & Woloszyn, 2004; Ishizuka & Fujiwara, 2004; Magrini & Lisot, 2015).

In Colombia, it is common for stone materials to be used on facades, which commonly have low absorption and, depending on the roughness of the surface, may have little diffusion (Serrano, 2020). However, current facades tend to be sustainable, trying to reduce energy consumption. In this sense, tropical countries with a temperate or warm climate must migrate to facades that reduce the temperature caused by solar radiation towards the interior of the building (Halawa et al., 2018; C. Li et al., 2019; Ruiz-Valero et al., 2021). And the mitigation of environmental noise in urban street canyons can benefit from this situation. Since commonly the materials used for thermal insulation are good at absorbing sound (including green facades) (Attal et al., 2019; Chen et al., 2020; Jia et al., 2020; Oquendo-Di Cosola et al., 2022; Santoni et al., 2019).

In the past, some studies evidenced the use that could be given to scale models to adequately represent environmental noise in an urban areas (Delany et al., 1978; Horoshenkov et al., 1999; Ismail & Oldham, 2005). It is highlighted as advantages that this type of scale models that adequately represent the behavior of reflections, diffraction and diffusion (Jang, Kim, et al., 2015b). Although they present some limitations, especially given by the characterization of high frequencies. This is due to the fact that it is complex to obtain information on the sound absorption coefficient of the materials to be used in the scale model for frequencies scaled above *5 kHz* in impedance tubes (Corredor-Bedoya et al., 2021; Doutres et al., 2010; Koruk, 2014). However, scale models are a great tool to show the propagation of noise in an urban street canyon. And at the same time they serve to know how this contaminant can be managed appropriately (Baruch et al., 2018; Hornikx & Forssén, 2009).

The following work seeks to explore materials that can be used for noise control in urban canyons using 4 materials that due to their characteristics can be adapted to the facade of a building. Although several works have been carried out that investigate sound-absorbing materials placed on facades to control environmental noise, there are few investigations that use materials that manage to accommodate the external conditions that a facade must resist. For this, information on the dimensions and qualities of the urban street canyons in the Aburrá Valley is used, a *1:10* scale model of a street that represents the conditions of these urban street canyons, and an impedance tube that provides information on the coefficient sound absorption of materials. In this way, it is expected to investigate materials that, due to their acoustic characteristics, serve to manage environmental noise in cities.

10.2. Methodology

In the first place, a study was carried out based on GIS tools to analyze the different urban configurations of canyons present in the Aburrá Valley. Representative samples were taken from each of the townships that make up this urban area. For this, the width, length, and size of the platform were considered. However, the greater urban extension of Medellín was considered to assign *3* sectors of this city. In total, *3* samples were taken randomly in each of the 9 townships that are part of the Aburrá Valley: Barbosa, Girardota, Copacabana, Bello, Envigado, Itagüí, Sabaneta, La Estrella, and Caldas. And *3* random samples were taken in the Prado Centro, Laureles, and El Poblado neighborhoods of Medellín city. All these samples were carried out on residential sectors of a large area and representative of each municipality.

A field visit was made to consider the number of floors of each of the buildings in each urban street canyon and the shape and size of the balconies were also evaluated. Other variables such as width of the roads, width of the facades, length of the canyon was measured with GIS tools. From the average of each of the variables found, an urban street canyon pattern was designed for the Aburrá Valley metropolitan area.

Understanding that one of the main sources of noise in the Aburrá Valley and in other cities are road traffic. It was decided to make a linear source in the model with sound radiation characteristics like those of a road with cars. Thus, to represent a linear noise source in the scale model, the studies carried out by Piippo and Tang (2011). In this work, a prototype of a linear array for scale experiments was built. The array consisted of *46 BN83-0.35* loudspeakers, full range at *8 Ohms* and dimensions of *1-3/4" x 5", 10 w*, with a paper cone, a paper moving coil former, a fabric frame, neodymium motor, and *3/4 "* deep foam front gasket. For the connection of the speakers, a series-parallel connection was used to accommodate the impedance of the amplifier. This line array of speakers was placed in a wooden box *1.2 cm* thick with the shape of a right triangular prism with a base of *19.0 cm*, and lateral faces of *12.0 cm*, both lateral faces ended in a cusp with an opening of *2.0 cm*. To amplify the linear arrangement of the speakers, a *200 w* amplifier was used with toroidal transformer, a frequency range of *10 Hz* to *40 kHz* within *1 dB*, total harmonic distortion (THD) *<0.05 %* (typ), rate response > 20 V/uS, damping factor >100 and *CMRR > 60 dB* (typical at *1 kHz*).

Subsequently, an impedance tube based on the ISO 10534-1 "standing wave method" was constructed (Bujoreanu et al., 2017; Rendón et al., 2023). The tube made of Polyvinyl Chloride (PVC) had an internal diameter of *4 cm* to cover the highest working frequency *5000 Hz*, and an average length of *2 m* to cover the lowest working frequency *125 Hz*. The calibration of the entire chain for the impedance tube was carried out considering Annex B of the ISO 10534-1 standard, where continuous minimums were measured for each of the frequencies without a sample. Where it was confirmed that the consecutive levels had a monotonous or horizontal decrease. This for each of the minimum levels found when the microphone was moved towards the speaker position. The impedance tube was made up of the following elements: an electret measurement microphone, a *10 w* 8 Ohm class *D12 v* stereo audio amplifier, a *1-1/2"* full range speaker with dual aluminum 8 Ohm cone magneto, an audio interface with 48v phantom power to power the measurement microphone, a *3 m* XLR cable, an aluminum cylinder with 4 cm of diameter and 2 cm thick in the sample holder. Half an elbow of *1* and *1/2"*, pine board *1.2 cm* thick and *2 m* long as base and two aluminum handles, *200 Hz, 250 Hz, 315 Hz*, *400 Hz* and *500 Hz*.

Before experimenting with various materials, different bibliographic sources were used to find out the acoustic absorption coefficients of some materials that, given their frequency scaling, would fit the model. This considering the limitations of the designed impedance tube whose maximum measurement frequency is *5000 Hz* and whose minimum measurement frequency is *125 Hz*. For this reason, for the model it was only possible to quantify the behavior of the materials at the frequencies of *1250 Hz, 1600 Hz, 2000 Hz, 2500 Hz, 3150 Hz, 4000 Hz* and *5000 Hz*. Which would represent the scale conditions of the acoustic absorption coefficient for the materials that were measured in the impedance tube at frequencies of *125 Hz, 160 Hz, 200 Hz, 250 Hz, 315 Hz, 400 Hz* and *500 Hz*. It is also noteworthy that a test was carried out on the model with two special conditions, one without absorbent material and the other with an ideal material (rock wool) that represents a material with high absorption in all the frequency bands studied.

Subsequently, in the impedance tube, the different materials that best represent the conditions of the urban street canyon in the model are identified. Considering that during the field visit many facades finished with a mortar mixture were related and that the pedestrian walkways are built with a similar material. Materials were sought that simulate a similar acoustic absorption coefficient in the model for the facades, pedestrian walkways, and asphalt of the roads. For this, a sample of masonry cement mixture and graded sand (mortar) was made that complied with the ASTM C 270 standard in terms of sample quantities and was compared with feasible materials for the construction of a scale model. Furthermore, considering that asphalt has a sound absorption coefficient between *0.1* and *0.2* for the *125 Hz* and *500 Hz* bands (Knabben et al., 2016) and mortar between *0.0* and *0.1* for these same frequency bands (Bozkurt & Yılmaz Demirkale, 2020). A material was sought that met these characteristics in the model. Afterward, the identification of the materials that represent in the model the absorbent materials to be used in the facades was also carried out to achieve the purpose of mitigating the environmental noise in the pedestrian walkways.

Based on this, construction of a model consisting of a steel structure. The steel bases were attached with a *1/2"* steel screw. The plates were attached to the steel sheets with a *1/2"* self-drilling screw. The joints between the plates and the exposed screw heads were sealed with *70 % +/- 1.3 %* solids by weight Gyplac mastic which complies with the standard NTC 6224.

Once the model was finished and knowing the absorption coefficient of the materials in the frequency bands of interest, the absorbent material was placed on the facade of the buildings and the balconies of the model. To know the mitigation that the absorbent material managed to give in the facade, the insertion loss was used. This magnitude is the difference between the equivalent continuous level measured in the urban street canyon without any type of insulation and the equivalent continuous level in the urban street canyon with some of the configurations of the facade proposed in this research. The measurements of the equivalent continuous levels were performed in accordance with the provisions of ISO 1996-2 (Barrigón Morillas et al., 2016) using a Sound level meter *Type 1*, equipped with a *1/2"* Class 1 microphone, with a sensitivity of *50 mV/Pa*, configured for measurement by 1/3 octave, Z frequency response and fast impulse response. Before carrying out each measurement, a calibration procedure was carried out with a calibrator with an output of *114 dB* at *1000 Hz*. Five measurements were taken from each point, which in total were uniformly distributed throughout the scale model. The microphone measurement points were located on the platforms in the pedestrian reception area and at a height of *1.51 cm*, which represents on a *1:10* scale the approximate height of the average ear of a Colombian people (1.51m) (Chacón Orduz, 2021). To ensure that there was no interference from background noise, measurements were made with the line array turned off and then on at each of the five measurement points. In this way it was possible to corroborate that the sound of the linear source was always *10 dB* above the background noise. All measurements were made outdoors in an open country space with no nearby obstacles. On a piece of land that was far from sources of urban noise. During each measurement, meteorological data of wind speed, temperature, atmospheric pressure, and relative humidity were taken during each measurement interval. Taking special care that the wind speed inside the scale model never exceeds 3 m/s, since the microphone did not have a screen against the wind.

The linear array of speakers was successful with pink noise which has the same sound energy level in all octave bands. For this, the free software Audacity V 3.0.3, open source and multi-platform was used for sound recording and editing. And an audio cable with one end with a stereo *1/8"* Jack connector to two monophonic *1/4"* Jack connectors. The stereo connector was connected to the output of a laptop and the other ends to the inputs of the amplifier.

The different configurations of the absorbent materials and the balconies in the scale model are placed continuously and alternately. For the location of the absorbent material, a strip is used on the facade that goes from the base of the second floor to the opening of the windows. To fix the absorbent material, industrial glue without toluene was used. This strip covers *1.2 m* in height along the *6.0 m* of the scale model, which corresponds to *8.3 %* of the facade in the alternating pattern configuration and *16.7 %* of the facade in the continuous configuration. In this same strip, and as could be seen during the field visit, balconies are commonly located. The balconies presented measurements in which absorbent material was included on the floor at the bottom and without absorbent material in this place. Also, as observed during the field visit, it is common for balconies to project from the base of the second floor towards the platform where pedestrians walk. Since several of the residential buildings in the Aburrá Valley do not have a front garden.

10.3. Results

The urban street canyons of the Aburrá Valley are on average of *6.0 m* long, while the width is 7.5 m, including the pedestrian walkway Tab. 4. It was also possible to appreciate that on average the linear dimension of the front of each house was *7.5 m*. In general, the longest canyons were observed in Medellín and the shortest in Barbosa, Girardota, Copacabana and Sabaneta. Tab. 4 also show some other characteristics of the urban street canyons in the Aburrá Valley. It stands out in this table that the facades of the buildings were *76 %* cement and sand plaster or *24 %* baked brick, and *100 %* of the entire street surface was asphalt. It is also possible to see how *46 %* of the buildings in the measured urban canyons had *2* floors in buildings in residential areas. In addition to this table, it can also be seen that there was *25 %* for buildings with 3 floors, *15 %* for buildings with 1 floor, *12 %* for buildings with four floors or more, and *2 %* for spaces in which there were no buildings. Fig. 37 Example of street in residential buildings of the Aburrá Valley. In the photo 18 Av. between 6 and 7 ST in Barbosa township. shows how the balconies of these facades are projected onto the pedestrian walkway.

Town	**Road**	**Floors**					**Width**	**Lenght**	**Facade**	**Street**
		0	**1**	**2**	**3**	**4**	**(m)**	**(m)**	**M.**	**M.**
Barbosa	c9(k15-17)	1	3	8	2	3	5.5	67.2	cement	asphalt
	c16(k11-13)	0	9	2	6	3	4.2	50	cement	asphalt
	k19(c17-19)	0	2	8	3	1	8.7	20	cement	asphalt
Girardota	k18(c6-7)	0	5	5	8	2	6.1	76	cement	asphalt
	k12(c5aa-5b)	0	0	5	2	0	6.2	32.6	brick	asphalt
	c4(k14a-14)	0	1	2	3	0	6.8	28.5	brick	asphalt
Copacabana	c48(k46b-46c)	0	2	0	9	1	6.2	20	brick	asphalt
	k49(c49-48)	0	7	3	1	0	6.8	69.1	cement	asphalt
	c50a(k51-50a)	0	1	4	6	3	5.2	56.4	cement	asphalt
Bello	c53(k47-48)	0	8	8	13	2	6.4	50	brick	asphalt
	a45(d58-59)	0	7	2	4	4	7.6	70	cement	asphalt
	k56a(c52-51)	0	0	4	11	3	8.1	74	cement	asphalt
Envigado	c38as(k34-33)	0	5	1	1	5	11	56.5	brick	asphalt
	k41(c38as-39s)	1	4	5	3	2	9.3	69.7	cement	asphalt

	k39c(c46es-46ds)	0	0	16	1	0	7.4	64.7	cement	asphalt
Itagüí	c48(k47-46)	0	1	4	7	0	6.5	48.2	cement	asphalt
	k52(c53-53a)	0	0	3	2	3	6.7	34	brick	asphalt
	c43(k48-47)	1	2	7	3	2	5.9	83.2	cement	asphalt
Sabaneta	k46a(c72s-73s)	0	0	6	6	4	7.5	66.2	cement	asphalt
	c64bs(k45-46)	0	2	3	3	0	3.9	22.6	cement	asphalt
	k43b(c71s-70s)	0	2	3	6	6	9.2	54.9	brick	asphalt
La Estrella	c81s(k59-59b)	0	3	9	4	3	5.8	66.2	cement	asphalt
	c80s(k63-62)	2	7	4	8	1	5.9	58.4	cement	asphalt
	k56e(c76s-76bs)	1	1	13	4	1	6	63.3	cement	asphalt
Caldas	k49(c131s-132s)	0	6	2	2	7	6.4	83.3	cement	asphalt
	c127s(k48-48a)	0	1	3	4	1	5.9	40.5	cement	asphalt
	c124s(k52-51)	0	1	4	6	0	6.5	39.4	cement	asphalt
M. Prado c.	k48(63a-63)	0	2	8	3	0	11	73	cement	asphalt
	k50a(c66-65)	0	5	15	7	0	8	97	cement	asphalt
	c60(k48-47)	0	2	3	1	4	6.6	60.1	cement	asphalt
M. Laureles	k69(c46b-47)	0	0	14	1	1	8	68.6	cement	asphalt
	k76(c45d-45c)	0	0	24	5	0	14	110	cement	asphalt
	k72(c44-43)	1	1	1	3	2	13	60	cement	asphalt
M. Poblado	c10a(k40-38)	0	2	2	4	0	10.7	55.2	cement	asphalt
	k43c(c7d-8)	0	4	8	0	0	9.5	76.9	cement	asphalt
	c12(k43b-43d)	0	1	6	4	0	9.2	93	cement	asphalt

Tab. 4 Characteristics of urban street canyons in the Aburrá Valley. Number of floors in each building (Floors). Facade material (Facade M.). Street material (Street M.). (Taken from own source).

Fig. 37 Example of street in residential buildings of the Aburrá Valley. In the photo 18 Av. between 6 and 7 ST in Barbosa township.

Then, using the impedance tube, the materials that represented in the model those found in urban street canyons were identified. A total of *4* materials were tested that could be coupled with the acoustic absorption conditions of cement and asphalt and that at the same time were feasible for the construction of the model. Thus, *1.1 cm* thick MDF chipboard, drywall plasterboard, porcelain polymer, and fiber cement board were tested. Fig. 38 shows the absorption coefficient of the mortar mixture in comparison with the replacement materials in the scale model. The lowest difference can be seen between the mortar mixture and the fiber cement with an average difference of *0.087*, the other materials presented differences of *0.115*, *0.273*, and *0.370* for the respective samples of drywall, porcelain polymer, and MDF.

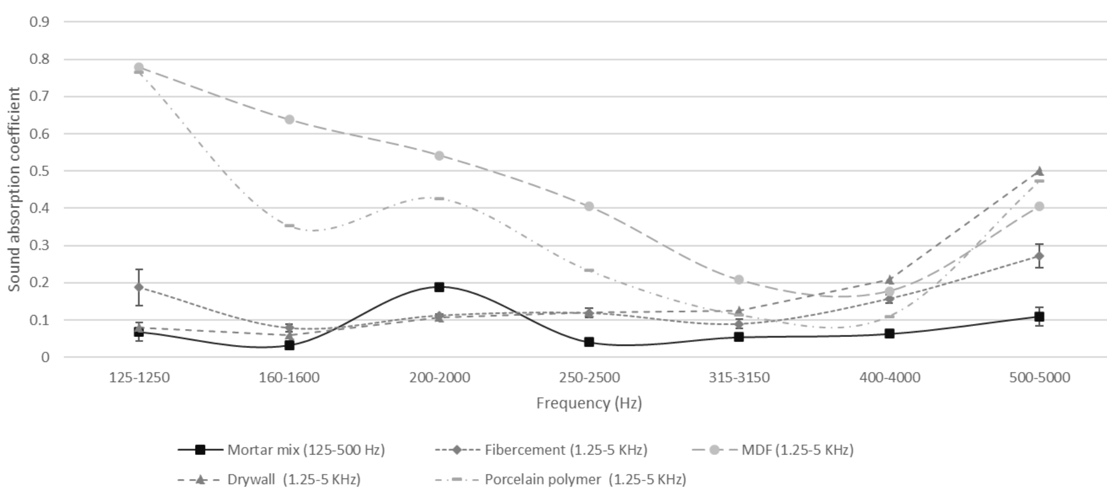

Fig. 38 Comparison of different materials to represent mortar mix in scale model. (Taken from own source).

Based on the results of the GIS tools and the field visits, the model of Fig. 39 is made. In which different configurations can be observed from numeral A to G. In this figure the following acronyms are described: WOAB (Without Absorbent or Balconies), AC WOB (Absorbent-Continuous and Without Balconies), AA WOB (Alternate-Absorbent material and Without Balconies), BA WOA (Balconies-Alternate and Without Absorbent), AA & AB (Alternate Absorbent and Alternate Balconies), BC WOA (Balconies-Continuous and Without Absorbent), and AC & BC (Absorbent-Continuous and Balconies Continuous), AAAF & AB (Alternate Absorbent on All Faces and Alternate-Balconies), ACAF & BC (Absorbent-Continuous on All Faces and Balconies-Continuous). Fig. 52 shows the scale model *1:10* in AC WOB configurations with hard foam (0.9 cm), the line array source, and the measurement microphone.

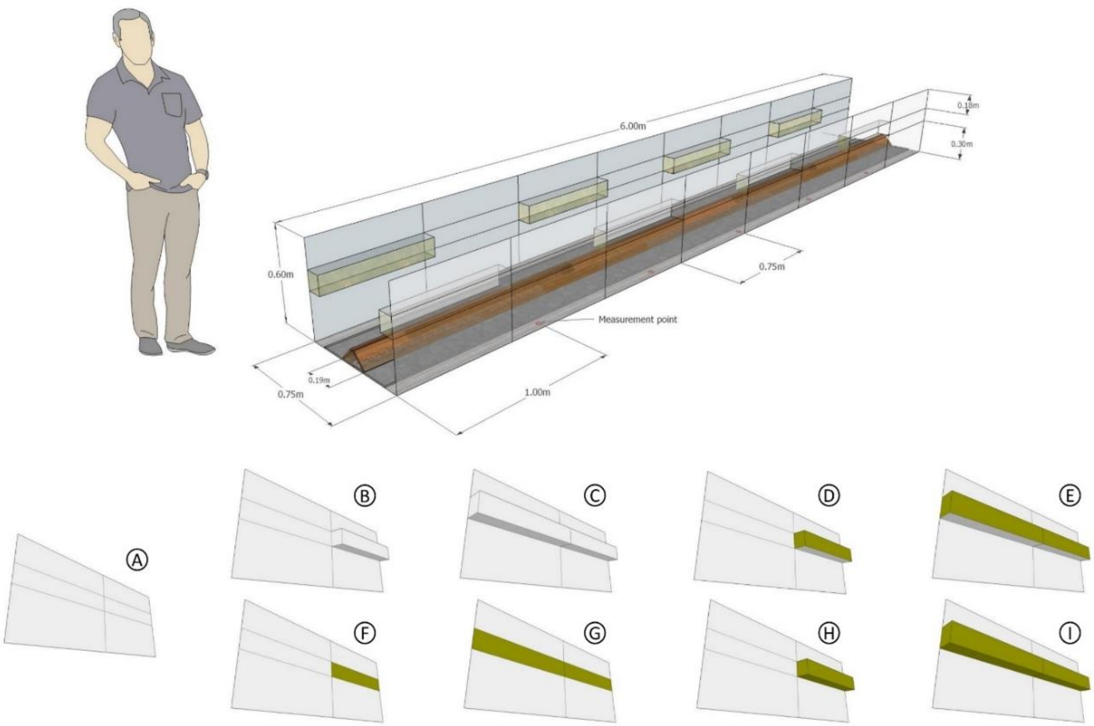

Fig. 39 Design of scale model and different configurations with alternate patterns of sound absorbing material and balconies. A. WOAB. B. BA WOA. C. BC WOA. D. AA & AB. E. AC & BC. F. AA WOB. G. AC WOB. H. AAAF & AB. I. ACAF & BC. (Taken from own source).

Fig. 40 Speaker connection. (Taken from own source).

Fig. 41 Assembly of structure for the baffle. (Taken from own source).

Fig. 42 Speaker assembly inside the baffle. (Taken from own source).

Fig. 43 Baffle with opening at the top for sound radiation. (Taken from own source).

Fig. 44 Detail of the sound level meter used for the measurement. (Taken from own source).

Fig. 45. Positioning of the microphone for its location in the model. (Taken from own source).

Fig. 46 Measurement microphone on the scale model. (Taken from own source).

Fig. 47 Absorbent material interleaved without balconies. (Taken from own source).

Fig. 48 Interspersed balconies. (Taken from own source).

Fig. 49 Continuous balcony. (Taken from own source).

Fig. 50 Continuous balcony configuration with sound absorbing material on all sides. (Taken from own source).

Fig. 51 Configuration balconies interspersed with absorbent material. (Taken from own source).

Fig. 52 Scale model (1:10) with continuous absorbing hard foam, alloy steel structure, fiber-cement plates, line array of tweeters with acoustic box, and measurement microphone. (Taken from own source).

The previous figures Fig. 40, Fig. 41, Fig. 42, Fig. 43, Fig. 44, Fig. 45, Fig. 46, Fig. 47, Fig. 48, Fig. 49, Fig. 50, Fig. 51, and Fig. 52 show the entire assembly carried out on the 1:10 scale model. Showing from the stage of elaboration of the linear source of sound radiation, the assembly of the speakers used for its construction, the positioning of the microphone, and the use of the different configurations with and without absorbent material, and with and without balconies.

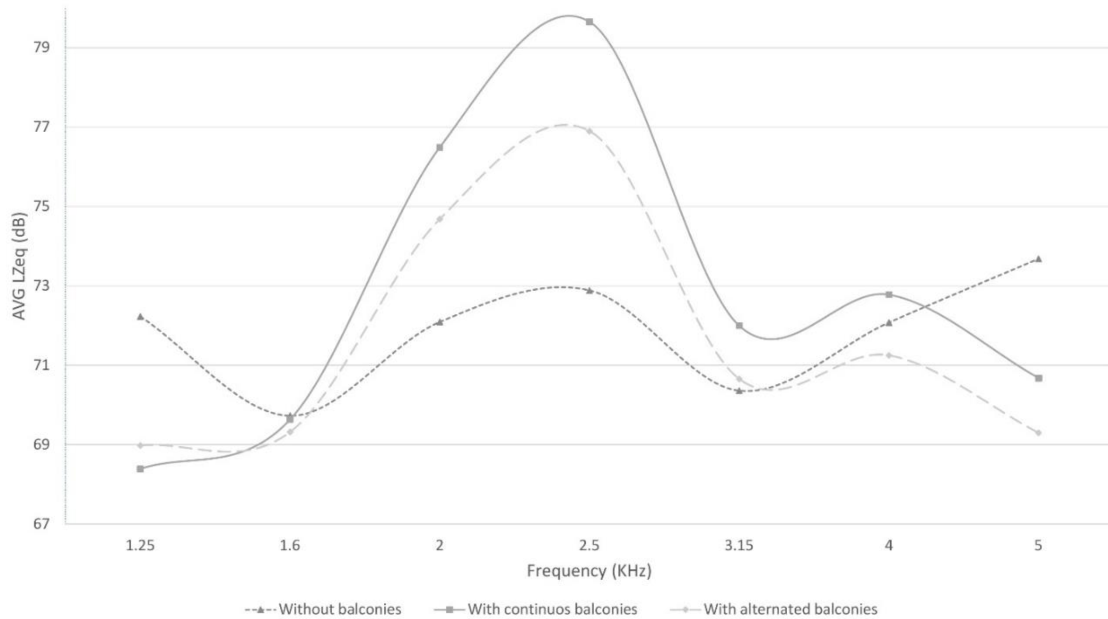

Fig. 53 Comparison of scale model without absorbent material and different balconies configurations. (Taken from own source).

The behavior of the urban street canyon without absorbing materials can be seen in Fig. 53. Balconies can slightly reduce the noise from motor vehicles at the frequencies of *125 Hz* and *500 Hz*. However, the noise produced by vehicles on pedestrian walkways tends to increase with the presence of balconies by even *5 dB* at some frequencies. As can be seen in this graph balconies, as they are built in the Aburrá Valley, tend to increase noise levels for pedestrians walking on the walkway.

Freq. (Hz)	**Steel wool**	**S. D.**	**Stainless steel**	**S. D.**	**F/C perfored + A.G.**	**S. D.**	**Cork**	**S. D.**	**Pumice**	**S. D.**	**Nylon & Polyester**	**S. D.**	**Refractory brick**	**S. D.**	**Foamy**
125	0.12	0.01	0.09	0.02	0.09	0.01	0.10	0.01	0.14	0.00	0.07	0.00	0.06	0.02	0.09
160	0.09	0.04	0.05	0.10	0.07	0.03	0.06	0.02	0.10	0.00	0.06	0.00	0.04	0.01	0.05
200	0.19	0.03	0.13	0.02	0.12	0.02	0.18	0.07	0.21	0.00	0.17	0.04	0.17	0.04	0.20
250	0.14	0.04	0.05	0.03	0.05	0.08	0.12	0.06	0.25	0.01	0.11	0.00	0.32	0.07	0.10
315	0.23	0.07	0.08	0.09	0.05	0.18	0.20	0.08	0.41	0.01	0.19	0.02	0.31	0.06	0.08
400	0.22	0.12	0.06	0.09	0.05	0.16	0.28	0.14	0.76	0.02	0.12	0.03	0.50	0.12	0.10

500	0.34	0.14	0.09	0.12	0.07	0.19	0.50	0.22	0.84	0.01	0.18	0.00	0.72	0.20	0.09

Tab. 5 Average sound absorption coefficient of materials in facade. Fiber-cement performed with Air Gap (F/C performed + A.G.). Standard deviation (S.D.). (Taken from own source).

After carrying out a bibliographical study of several materials in accordance with the purposes of this work, some materials were chosen that, given their characteristics of presumed resistance to humidity and solar radiation, could have a good performance outdoors and at the same time possess acoustic absorption qualities. These materials were: porous refractory brick, pumice stone, cork wood, foamy, nylon and polyester compounds, stainless steel sponge, steel wool with thickness of *3.5 cm*, and perforated fiber-cement with thickness of *0.8 cm* and *2.2 cm* air gap. Tab. 5 shows the sound absorption characteristics of these materials. In general, between the bands of *125 Hz*, *160 Hz* and *200 Hz*, all the materials behave in a similar way and the absorption coefficient that can be observed is low. However, from *250 Hz* considerable differences begin to be observed. The material that presented the best conditions was pumice stone followed by porous refractory brick, cork wood and finally iron wool. The other compounds did not actually show significant sound absorptions.

Fig. 54 Pumice stone sample (3.5 cm high and 4 cm in diameter). (Taken from own source).

An example of the pumice stone used in the measurements of the impedance tube, *3.5 cm* high and *4.0 cm* in diameter can be seen in Fig. 54, this material presented the best sound absorption performance. Subsequently, comparisons of these chosen materials were made with others that could be represented in the scale model at the frequencies of *1250 Hz, 1600 Hz, 2000 Hz, 2500 Hz, 3150 Hz, 4000 Hz* and *5000 Hz*. Different types of materials were tested such as: paper, different types of cardboard, foams, rugs, and felts.

Freq. (Hz)	**Cork**	**S.D.**	**Dif.**	**Steel wool**	**S.D.**	**Dif.**	**Freq. (Hz)**	**Cardboard**	**S.D.**
125	0.10	0.01	0.09	0.12	0.01	0.11	1250	0.18	0.10
160	0.06	0.02	0.04	0.09	0.04	0.05	1600	0.15	0.04
200	0.18	0.07	0.11	0.19	0.03	0.16	2000	0.25	0.06
250	0.12	0.06	0.06	0.14	0.04	0.10	2500	0.27	0.01
315	0.20	0.08	0.12	0.23	0.07	0.16	3150	0.24	0.04
400	0.28	0.14	0.14	0.22	0.12	0.10	4000	0.33	0.05
500	0.50	0.22	0.28	0.34	0.14	0.20	5000	0.58	0.13

Tab. 6 Sound absorption coefficient comparison between cork wood and steel wool with cardboard. Standard Deviation (S.D.). Difference between material and representation in scale model (Dif.). (Taken from own source).

The material that best adjusts to those proposed for cork and metal wool is *0.4 cm* corrugated cardboard, which is shown in Tab. 6. Between corrugated cardboard and cork wood there is an average difference of *0.079* in the sound absorption coefficient. And between corrugated cardboard and metal wool there is an average difference of *0.097* in the sound absorption coefficient.

Freq. (Hz)	**Pumice**	**S.D.**	**Dif.**	**Refractory B.**	**S.D.**	**Dif.**	**Freq. (Hz)**	**Hard Foam**	**S.D.**
125	0.14	0.00	0.17	0.06	0.02	0.25	1250	0.31	0.13
160	0.10	0.00	0.26	0.04	0.01	0.33	1600	0.37	0.17
200	0.21	0.00	0.10	0.17	0.04	0.14	2000	0.30	0.09
250	0.25	0.01	0.03	0.32	0.07	0.04	2500	0.28	0.06
315	0.41	0.01	0.06	0.31	0.06	0.04	3150	0.35	0.06
400	0.76	0.02	0.00	0.50	0.12	0.26	4000	0.76	0.09
500	0.84	0.01	0.01	0.72	0.20	0.11	5000	0.82	0.07

Tab. 7 Sound absorption coefficient comparison between pumice stone and refractory brick with hard foam. Standard Deviation (S.D.). Difference between material and representation in scale model (Dif.). (Taken from own source).

On the other hand, the material that best adjusted to the pumice stone and the porous refractory brick was the *0.9 cm* hard foam Tab. 7. Between the hard foam and the pumice stone there is an average difference of *0.069* in the acoustic absorption coefficient. Between hard foam and pumice there is an average difference of *0.156* in the sound absorption coefficient. The latter does not show a completely adjusted relationship, however, of the materials compared, it was the one that presented a more approximate condition.

Component numbers	**Eigenvalue**	**Percent variance**	**Accumulated percentage**
1	5.25495	52.550	52.550
2	3.41525	34.153	86.702
3	0.862675	8.627	95.329
4	0.467123	4.671	100.000
5	2.96975E-16	0.000	100.000
6	2.18773E-16	0.000	100.000
7	1.84002E-16	0.000	100.000
8	0.0	0.000	100.000
9	0.0	0.000	100.000
10	0.0	0.000	100.000

Tab. 8 Component Weight Chart. (Taken from own source).

In the previous Tab. 8 with 2 components the behavior of all the variables can be explained since 2 components had eigenvalues greater than or equal to 1.0. Together they explain 86.8798% of the variability in the original data.

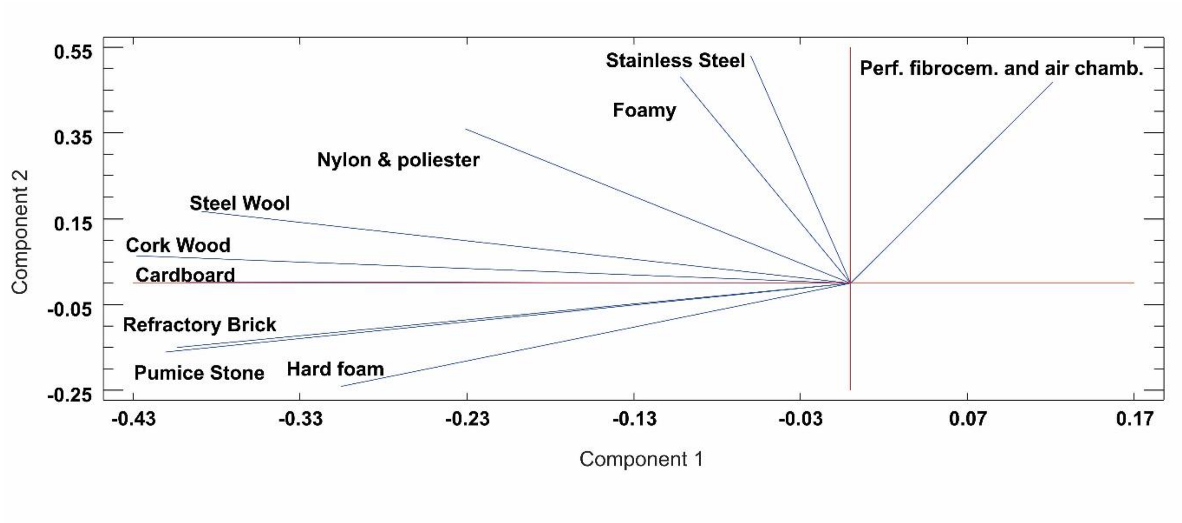

Fig. 55 Component Weight Chart. (Taken from own source).

As can be seen in the previous Fig. 55, component 1 represents most of the materials evaluated except for Foamy, Stainless Steel and perforated fiber cement with an air chamber. It is also possible to appreciate that there is a strong relationship between refractory brick and pumice stone with hard foam and cork wood and metal wool with cardboard.

Configuration	Frequency (Hz)	Hard Foam	Cardboard	Rock Wool
AC WOB	1250	3.0	3.7	3.9
	1600	3.1	3.0	1.6
	2000	0.1	-2.0	-3.3
	2500	-0.2	-2.7	-2.2
	3150	1.1	0.1	-0.9
	4000	1.6	1.5	-1.3
	5000	5.1	3.9	4.0
AA WOB	1250	3.6	3.3	3.2
	1600	3.2	3.3	1.6
	2000	-0.2	-1.6	-2.3
	2500	0.0	-2.1	-2.1
	3150	0.8	0.2	0.2
	4000	0.7	0.8	2.8
	5000	4.9	3.9	4.5

AC & BC	1250	-0.4	-1.1	2.4
	1600	-4.7	-3.6	0.8
	2000	-2.7	-3.0	1.8
	2500	-1.9	-1.0	3.7
	3150	-0.3	-0.2	2.4
	4000	0.7	1.6	2.1
	5000	-1.2	0.1	1.8
ACAF & BC	1250	-0.1	3.1	3.0
	1600	1.8	0.4	2.1
	2000	0.5	0.7	1.4
	2500	-0.2	3.5	3.7
	3150	0.4	1.9	1.4
	4000	0.1	1.3	1.5
	5000	-2.2	0.1	2.9
AA & AB	1250	2.1	2.0	3.7
	1600	-1.0	-0.6	-1.2
	2000	-2.3	-1.8	-0.1
	2500	-0.7	-0.5	3.9
	3150	-1.1	-0.6	3.0
	4000	-0.7	-0.3	4.6
	5000	-0.9	-1.2	1.2
AAAF & AB	1250	3.2	0.5	3.1
	1600	-1.6	-1.9	0.8
	2000	-2.9	-3.2	-2.3
	2500	-0.5	-1.4	-0.3
	3150	-0.4	-2.7	-1.0
	4000	0.6	-0.7	-0.1
	5000	-1.3	-0.8	-0.6

Tab. 9 Insertion Loss in all configurations for the different materials. (Taken from own source).

The insertion loss of the different configurations of the scale model can be seen in Tab. 9. It can be seen how the hard foam manages to mitigate the noise in the barrel for several frequencies except *2500 Hz*. In general, it can be seen how the balconies prevent the absorbent material from achieving its goal. It is also noted from this table that when the continuous balcony does not have absorbent material on the lower external part, the noise tends to increase. As for the alternate balconies, they also make noise mitigation somewhat difficult by the hard foam. Cardboard also shows the low absorption at the frequency of *2500 Hz*. This except for the configuration that had a continuous balcony with all sides lined with this material. Which is the only configuration that shows a significant reduction in noise with the use of the balcony. Otherwise, the configurations with balcony do not present relevant noise attenuation. On the contrary, they increase the noise levels for the pedestrian reception point. Finally, rock wool presents an ideal case in which a highly absorbent material was placed. It is possible to see a very uniform absorption in the different combinations of this material. In this graph you can see a good performance of the balconies in which the greatest amount of absorption was presented for the configurations they had. However, frequencies near *250 Hz* are again not favored.

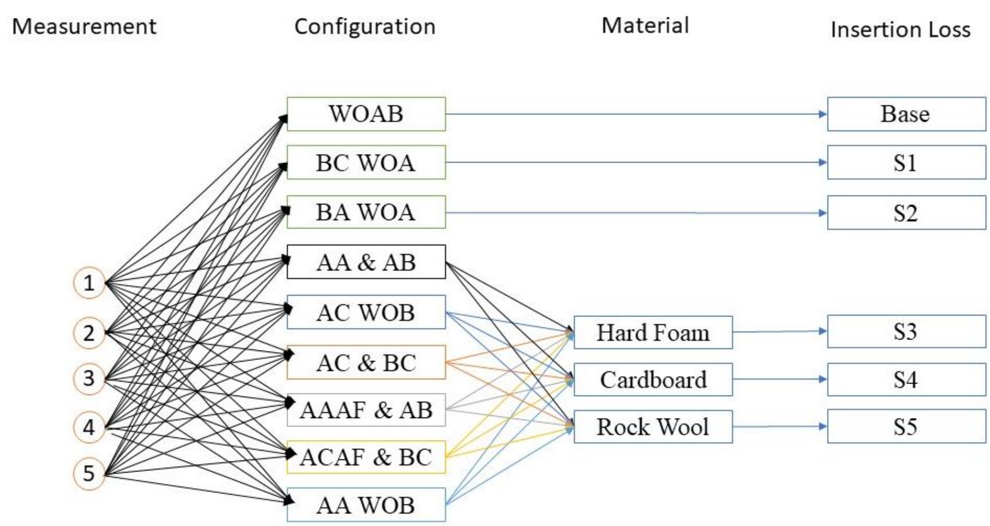

Fig. 56 Summary of the experimental design corresponding to a mix factorial, with variables and factors. (Taken from own source).

The experimental design includes *5* measurements for each scenario Fig. 56. In total there were *9* scenarios, *3* on which no sound absorbing material was applied and *6* on which *3* types of materials Hard Foam, Cardboar, and Rock Wool were placed. In total, *5* Scenarios were found in which the Insertion Loss was identified, including a scenario that was taken as a base, without absorbent material or balcony, to make the comparisons between with and without a balcony and between with and without absorbent materials.

10.4. Discussion

According to the results stated in the previous chapter, the first element to be discussed is the tendency for noise to increase in the presence of balconies. This can be due to the additional boundary that is placed on the path of the acoustic wave generated by the linear source that affects the facade and the pedestrian walkway. As a new boundary is presented, the sound tends to remain in the space of the pedestrian walkway for a longer time. This increases the presence of noise in this space and therefore harms the conditions of noise pollution in pedestrians. According to acoustic theory, the limits increase the sound energy of a wave by *3 dB* (Howard & Angus, 2013) and this seems to occur in this case. Because the waves generated by car traffic bounce off the external bottom of the balconies.

On the other hand, works such as the one carried out by Lee et al. (2007) and Naish et al. (2013) show how balconies can reduce outside noise. However, this type of research locates the receptor in the space generated by the balcony itself. And these receptors are measured at different levels of a building. Other research's point to making modifications to the balconies located at different heights of a building that can either redirect the waves produced by noise sources or modify their surface to serve as diffusing elements (W. Yang & Jeon, 2020). Working on different variables of the balcony such as width, absorption and shape of the sky, shape, height, material and inclination of the parapet, parasols on the roof, among others.

It is important to highlight some complementary research that allows the materials used in this work to become usable elements in the facades. For example, in the case of cork, the works carried out by (Malanho et al., 2021; Marques & Eloy, 2013; Papadikis et al., 2020; Roseta & dos Santos, 2014) are mentioned. Those works show how cork agglomerate sheets can become a good thermal insulating material in the facades of buildings in a subtropical climate. In addition, benefits such as its durability, resistance to humidity, low cost and reuse are considered, demonstrating great conditions for its use.

Pumice stone is little referenced as a facade material, it is only mentioned in some works such as Al-Hafiz et al. (2015), Grasser and Minke (1990), and Mintorogo et al. (2022). Among some of the advantages that this material presents is its low cost, its capacity as thermal material, its ease of work, and its resistance to pests. And among some of the disadvantages are its lack of frost resistance when wet, wear tendencies, and poor compressive strength compared to concrete.

Refractory brick is treated in some publications as Ahmadi and Reisi (2020), where it is possible to demonstrate the compressive strength of refractory bricks, which is *40-66 %* of that of concrete. As for the compressive strength when exposed to moisture, it has values equal to those of concrete. However, it does not have the same resistance to freezing and thawing. As for steel wool, there is no precedent for the use of this material on facades, so future research is recommended in which both this material and the others that have been proposed are subjected to weather resistance tests. It is emphasized that this type of wool must be made of stainless metals that are resistant to humidity. Likewise, it would be important to carry out more in-depth work that deals with the issue of facade design for the mitigation of environmental noise, since from what is known from the existing bibliography there are few that are available and do not properly address this issue (Echevarria Sanchez et al., 2016; Eggenschwiler et al., 2022; Kang, 2002).

10.5. Conclusions

A good behavior of the absorbent materials can be interpreted in the tests carried out on the scale model to mitigate environmental noise on the pedestrian walkway. The greatest mitigation was provided by pumice stone and fire brick up to *5.1 dB* at the *500 Hz* frequency and cork wood and metal wool up to *3.9 dB* also at the *500 Hz* frequency. These noise mitigation results were achieved especially for the configurations that did not have a balcony.

However, the measurements made to this model also show how the specific building characteristics found in the Aburrá Valley are counterproductive in noise control, since the projection of the balconies on the second floors towards the pedestrian road increases the noise due to the accumulation of reflections from the noise source by car traffic. The only balcony configuration that managed to mitigate noise at all frequencies with the different materials was ACAF & BC (Absorbent-Continuous on all sides and Balconies-Continuous) when the continuous balcony was presented with absorbent material on the parapet and on the roof that forms the floor of the balcony over the pedestrian walkway.

It seems that the presence of balconies to mitigate noise on the pedestrian walkway is not relevant in the case of an ideal absorbent material located on the facades.

11. URBAN NOISE MITIGATION STRATEGIES IN THE ABURRÁ VALLEY (Research component related to specific objective 3).

According to the latest report from the Medellín 2021 Citizen Perception Survey (Medellín Como Vamos, 2021), noise is the pollutant with the lowest degree of acceptance by the population. Since the 2018 – 2020 survey (Medellín Como Vamos, 2018, 2020) it ranked second in dissatisfaction only below air pollution, now it goes to first place with only *20 %* acceptance by the population. This is not unrelated to the rest of the metropolitan area near Medellín, where in different evaluations it is possible to see the high levels of noise to which the inhabitants of the urban areas of this valley are exposed. This can be seen in the first noise maps made in 2006 for all the nine municipalities that make up the Aburrá Valley, and the subsequent updates in 2010 and 2014 for Medellín, Itagüí and Bello (Barreto & Bañuelos, 2015). The latest noise maps developed in 2018, which again include the *9* municipalities of the jurisdiction, claim that automotive noise is the main cause of poor acoustic quality (Tafur et al., 2019). According to the results shown in these maps, a large part of the areas evaluated exceed *55 dB* at night, this being the maximum level of environmental noise allowed for residential areas according to resolution 0627 of 2006 (Ministry of environment, housing, and territorial development, 2006), hours in which the inhabitants expect to have favorable environments for rest. There is also evidence that in the vicinity of highly traveled roads, levels of up to *80 dB* can be reached, which the World Health Organization warns can cause hearing impairment, mental disorders, stress, and aggressive behavior on people exposed to these levels (Berglund et al., 1999).

Currently, the large percentage of automotive noise is generated in the interaction that occurs between the tire and the ground by: hitting, vibrating, rubbing, sucking and expelling air against the asphalt (Ling et al., 2021), since other sources of noise such as Engine combustion and turbulence from wind impact against the vehicle have been largely controlled for several years (Gibbs et al., 2005). Thus, the development of elements with sound-absorbing qualities in the vicinity of this source of noise emission is one of the issues in which more effort has been made by the scientific community worldwide to mitigate noise in urban areas (Ling et al., 2021; Meiarashi et al., 1996; W. Yang & Jeon, 2020). Although, environmental variables such as weather conditions, vehicle fleet, slope on the roads, types of tires, rolling speeds, among others, are of great importance when implementing noise control (Cho & Mun, 2008). There are other variables that, as already explained, are generated by the reverberant field of urban canyons. And the latter have been less addressed in the literature, since for the former there is an important bibliographical production about sound-absorbing asphalts, granular compounds that, although they manage to have good acoustic absorption, quickly lose their absorbent features due to obstruction of the exposed ducts towards the pathway (Kehagia & Mavridou, 2014).

So, sound-absorbing materials located on the facades of urban canyons can be a good option, mitigating an average of *7.2 dB* and having maximum reductions of up to approximately *12 dB* (W. Yang & Jeon, 2020). These types of reductions could be of great help to reduce the noise suffered by this urban area, especially in residential areas. From the conflict maps generated in 2018 for the Aburrá Valley, *9.1 %* of the urban population is affected by noise above the maximum levels allowed in Resolution 0627. Thus, with the purpose of to improve the sound environment, one of the priority actions that must be undertaken to mitigate environmental noise is the implementation of strategies that can cooperate widely to reduce the affected population of the Aburrá Valley by *5.6 %* in the short term and medium term. Therefore, four strategies are proposed that are glimpsed considering the results obtained in this investigation.

11.1. Strategy 1 (Expansion of the noise monitoring network)

Fixed noise monitoring networks are a great ally in the evaluation of environmental noise that occurs in an urban environment, as could be demonstrate in the development of specific objective 1. However, while these stations may give us the possibility of having a wide temporal window, it is important that each of them more effectively represents the spatiality of the urban area. In the articles reviewed, monitoring networks could be observed that were made up of *75* stations such as in Gdansk, Poland with $262\ km^2$ and *582205* inhabitants (Przysucha et al., 2020), *28* stations in Dublin, Ireland with $117.8\ km^2$ and *544107* inhabitants(Geraghty & O'Mahony, 2016), *14* stations in Barcelona, Spain with $102.2\ km^2$ and *1600000* inhabitants. These data contrast with the Aburrá Valley, where there are *7* stations in $1157\ km^2$ and *3931447* inhabitants (Rendón et al., 2022). However, knowing the budget limitations that this type of infrastructure may have, it is important to identify the main sources of noise in each of the urban areas that make up this Valley. To do this, you can resort to the current *7* noise monitoring sources installed by SIATA, the noise maps and action plans that have been developed by the AMVA, the reports and surveys developed by the health departments of the different municipalities that make up this urban area and other similar reports. In this way, common sources that have similar characteristics could be addressed and have an estimate of fixed monitoring stations that can be implemented depending on the noise sources, locating 3 stations for each source in:

- High traffic flow routes
- Pink areas
- Areas with permitted industrial uses
- Centralities of the municipalities with permitted commercial uses
- Stadiums and/or sports celebrations

And depending on the land uses and receivers:

- Service areas such as: hospitals, libraries, nurseries, sanatoriums, nursing homes.
- Service areas such as: Universities, colleges, schools, study, and research centers.
- Residential and hotel areas.
- Recreation and rest parks.

The tactic of placing three stations per source and receiver (a total of 27) guarantees that after 4 years of measurement the information from each of the stations can be contrasted and averages, errors and deviations can be obtained from the information. Later they would be relocated to other similar sectors of the city to later make comparisons between four years periods. With these data and according to the tools proposed in the publication (Rendón et al., 2022) an adequate representation of noise in the Aburrá Valley could be obtained and thus improve its management.

11.2. Strategy 2 (Implementation of complementary tools for the annual noise evaluation)

The installation of the different noise stations proposed in strategy *1* allows a greater resolution for temporality and spatiality, to which, as noted, a more detailed study can be carried out, implementing analysis of hours throughout the days of operation. the week during each year to know the cycle of automotive noise or leisure activities; comparisons between days throughout the year to know the influence of festivities, celebrations, and special events; comparisons between hours of different days of the week throughout the months and year to know noise disturbances due to soccer celebrations; or comparisons between years to know long-term eventualities. All this with the aim of achieving better noise management in the Aburrá Valley. For the development of this strategy, the methodologies are explained in detail in the article (Rendón et al., 2022). Its implementation has already been shown with the data of the current *7* stations installed by SIATA.

11.3. Strategy 3 (Control over construction projections towards the pedestrian platform)

One of the main conclusions that the noise modeling in the scale model left us is that the balconies increase the level of noise at the pedestrian level on the platform. For this reason, one of the strategies that could be considered to reduce the levels of environmental noise in urban canyons occurs with the regulation of this type of facade elements by the planning departments in all municipalities of the Aburrá Valley. For this, regulations should be implemented that do not allow the projection of balconies towards the pedestrian platform. Other variables that can be contemplated in the urban planning of urban canyons would include front gardens, extensions, retreats, and any other type of urban measure that avoids the projection of elements on the facade of buildings towards the public space.

11.4. Strategy 4 (Implementation of sound-absorbing material on urban canyon facades)

Among the main materials that can be located on the facade of buildings, pumice stone stands out. This material is easy to acquire, cheap, has good sound-absorbing characteristics and is resistant to weathering and fire. It can even improve its performance at low frequencies if a 1 cm air chamber is used on the back. Therefore, among all the materials studied, this presents the best conditions to control noise in urban canyons. For the case study carried out, it is known that by covering *16.7 %* of the facade you can obtain mitigations of up to *5.1 dB* in the *500 Hz* band. You can also achieve reductions in reverberation time of up to *0.17 s* in this same frequency for coverages in *90 %* facade.

11.5. Strategy 5 (Strict control of commercial properties with medium and high-power sound system and small workshops)

Since it was possible to appreciate that a large part of the problem is caused by commercial properties open to the public with a high-power sound system and workshop. The possibility of creating local regulations that regulate the operation of this type of establishment is raised. In general terms, the commercial properties and workshop seen in field visits have multiple openings for the entry of people and environmental elements that provide comfort, such as lighting and ventilation. That is why it is proposed as a first measure, in this strategy, to perform acoustic insulation by sealing this type of opening. The accesses for people must have a configuration such that they are compatible with the entry and exit of people and at the same time manage to control noise. For this, entrances with double doors at different points of the entrance, return system, and acoustic vestibules can be used. This type of control must include commercial properties such as: bars, discos, pubs, gyms, canteens, centers for religious celebrations, joinery, carpentry workshops, metalworking, aluminum cutting and assembly, car repair, and similar.

12. CONCLUSIONS

In the Metropolitan area of Aburrá Valley, a high incidence of leisure activities was observed on weekends (Friday, Saturday, and Sunday, even some Thursdays) until *2:00 a.m*. Likewise, the different celebrations during Holy Week, the Flower Fest, football matches, and especially on December *1* and *7* present important periods of noise every year. There is also a high incidence of road traffic during work and rest periods, which means that the levels recommended by the World Health Organization are continuously exceeded during the day and at night.

The typical configurations of the facades of the Aburrá Valley, where there are balconies with overhangs towards the pedestrian sidewalk, increase environmental noise due to the various reflections that accumulate due to the noise produced by road traffic. However, a good behavior of absorbent materials can be interpreted to mitigate environmental noise in pedestrian walkways. The greatest mitigation was provided by pumice stone and refractory brick up to *5.1 dB* at the *500 Hz* frequency, cork wood and metal wool up to *3.9 dB* also at the *500 Hz* frequency. An air gap of 1 cm in pumice stone it presents good results especially for frequencies in the medium and low range, since it can decrease the reverberation time by up to *0.17 s* for the same frequency band of *500 Hz.*

Regarding the compounds generated based on rice husk nanoparticles, the compound that presents the best conditions for the proposed mixture is Epoxy Resin/Rice Husk NPs in a *20/80* mass mixture. The first thing that this compound presents is a very homogeneous, resistant, compact surface, without cracks or wear. In addition, it achieves an average sound absorption coefficient of *0.39* between the *250* and *5000 Hz* bands and has a maximum sound absorption coefficient of *0.5* in the *5 kHz* band. If this mixture is compared with the initial *100/0* without rice husk nanoparticles, a percentage increase in the mean acoustic absorption coefficient of *167%* is observed between the *500 Hz* and *5 kHz* bands.

The strategies proposed in this work show some tasks that urgently need to be articulated to the action plans. It is mentioned that actions are required to control discos, bars, pubs, among others. Since these types of places have to their credit high-power sound systems that constantly disturb different sectors of the city. Joint work between different administrative departments of this urban environment is needed to control the so-called "pink zones".

Other actions within the action plans are also important, among which are mentioned: urban intervention in the buildings to avoid the protrusion of the balconies on the pedestrian promenade, the location of elements on the facade of buildings of urban street canyons with high reverberation time (such as pumice stone with an air chamber), use other tools that complement the noise maps (such as day cycle graphs, comparison of months and comparison between special days and celebrations and normal days), and finally it would be important to strengthen the noise monitoring network.

The methodology used in the paper *1* could be replicated in urban areas of countries with socioeconomic characteristics such as Colombia. And they would be of great help to focus action plans against noise pollution. This is because the literature currently focuses mainly on problems in developed countries that require different environmental management.

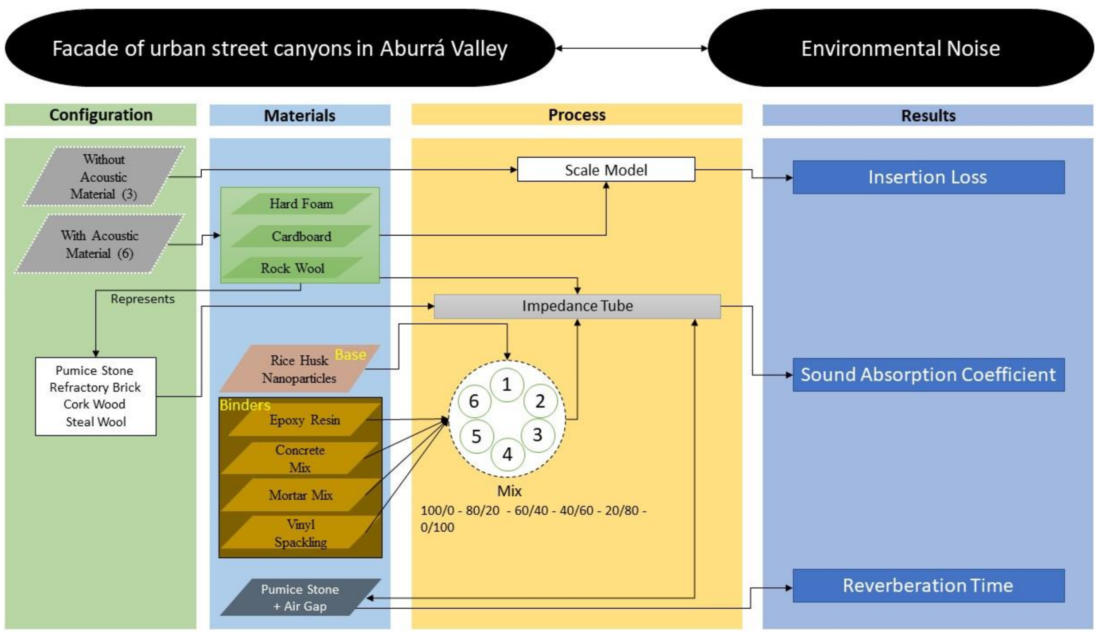

Fig. 57 Conclusion diagram (Taken from own source)

13. ANEXOS

13.1. Publications

13.1.1. Publication 1

Colorado, H. A., Saldarriaga, L., Rendón, J., & Correa-Ochoa, M. A. (2022). Journal of Material Cycles and Waste Management, 24(2), 466-476. https://doi.org/10.1007/s10163-021-01330-4

• Journal: Journal of Material Cycles and Waste Management

• Year: *2022*

• Status: Published

• Impact factor: *3.67*

• Classification scimagojr: Q2

• Classification publindex: A2

13.1.2. Publication 2

Rendón, J., Murillo Gómez, D. M., & Colorado, H. A. (2022). Useful tools for integrating noise maps about noises other than those of transport, infrastructures, and industrial plants in developing countries: Casework of the Aburra Valley, Colombia. Journal of Environmental Management, 313, 114953. https://doi.org/10.1016/j.jenvman.2022.114953

• Journal: Journal of Environmental Management

• Year: *2022*

• Status: Published

• Impact factor: *8.63*

• Classification scimagojr: Q1

• Classification publindex: A1

13.1.3. Publication 3

Rendón, J., Giraldo, C. H. C., Monyake, K. C., Alagha, L., & Colorado, H. A. (2023). Experimental investigation on composites incorporating rice husk nanoparticles for environmental noise management. Journal of Environmental Management, 325, 116477. https://doi.org/10.1016/j.jenvman.2022.116477

• Journal: Journal of Environmental Management

• Year: *2023*

• Status: Published

• Impact factor: *8.63*

• Classification scimagojr: Q1

• Classification publindex: A1

13.1.4. Publication 4

Rendón, J., Giraldo, C. H. C., & Colorado, H. A. (2022). Insights and research in materials used to decrease noise pollution: Developments for Colombia. 1, 551. ISBN Digital: 978-628-95287-1-8

• Book: ENGINEERING FOR TRANSFORMATION

• Year: *2022*

• Status: Published

13.1.5 Publication 5

Rendón, J., & Colorado, H. A. (2023). Mitigation of Urban Noise Through the Implementation of Pumice with an Air Chamber on Building Facades. DOI: 10.1007/978-3-031-22524-6_121, pp 1258–1262.

• Book: TMS 2023: TMS 2023 152nd Annual Meeting & Exhibition Supplemental Proceedings.

• Year: *2023*

• Status: Published

13.2. Conferences and Posters

13.2.1. International conference 1

“Mitigation of Environmental Noise through the use of Composite Materials containing Nanoparticles of Rice Husk.”

• Congress: Pan American Ceramics Congress and ferroelectrics Meetings of Americas

• Date: July 24-28 of 2022

• Status: Presentation done

• Place: Hotel Hilton

• City: Panamá City

• Country: Panamá

13.2.2. International conference 2

“Insights and research in materials used to decrease noise pollution: developments for Colombia.”

• Congress: EXPOIngeniería 2022

• Date: October 27-29 of 2022

• Status: Presentation done

• Place: Pabellón Verde de Plaza Mayor

• City: Medellín

• Country: Colombia

13.2.3. International conference 3

“Mitigation of Urban Noise through the Implementation of Pumice with an Air Chamber on Building Facades”

• Congress: TMS 2023

• Date: 03/20/2023

• Status: Presentation done

• Place: SDCC - Exhibit Hall G

• City: San Diego, California

• Country: USA

13.2.4. International poster 1

"Mitigation of Urban Noise through the Implementation of Sound-absorbing Facade Skirting Boards Based on Epoxy Resin and Rice Husk Nanoparticles."

• Congress: TMS 2023

• Date: 03/22/2023

• Status: Presentation poster done

• Place: SDCC - 33B

• City: San Diego, California

• Country: USA

13.3. Glossary of terms

- Frequency: Physical magnitude that quantifies the number of oscillations per second of a wave.
- Amplitude: Maximum displacement generated by a wave from its equilibrium point.
- Noise: Qualitatively we can define it as a sound that is annoying for a receiver and that can even be harmful to their health.
- Sound: Mechanical propagation in the form of waves that occurs on matter and that is generated by a vibrating source.
- Acoustics: Branch of science that oversees the study of sound beyond its audible spectrum and the interaction that it has with different elements.
- Audible range: Amount of dB that can be perceived by the human ear (0-130 dB).
- Frequency spectrum: Quantity of Hz that can be perceived by the human ear (20-20000 Hz).
- Octave bands: Frequency division by international standards of the audible spectrum perceived by the human being.
- Sound level meter: Measuring equipment used to capture and analyze sound waves.
- Acoustic insulation: Set of techniques used to control the noise generated in a space so that it does not transcend its surroundings.
- Sound Landscape: It is the set of sound elements that are part of a geographical space.
- Acoustic screen: Element located between the emitter and the receiver that manages to mitigate the passage of noise in its transmission medium.
- Impedance tube: Device used, among other measurements, to determine the sound absorption coefficient of a material.

- Sound absorption coefficient: Amount of acoustic absorption that a material manages to have on an acoustic wave that impacts its surface.
- Insertion lost: It is the reduction of the noise level due to the acoustic conditioning that occurs in a certain place. It is calculated how an arithmetic difference given between an environment without and with acoustic treatment.
- Noise map: Cartographic representation that represents the spatial-temporal noise condition.
- Reverberation time: Time it takes for sound to decay one millionth of its initial energy.
- Reverberant field: Place in which the sound reflected by the limits is contained once a sound source is activated.
- Environmental noise: Noise produced by all sound sources that inhabit a given space.
- Stabilization time: the time it takes for the equivalent continuous level to fall within a given level range for example +1 and -1 dB.
- Pink Zones: Refers to the areas used for leisure activities where many commercial activities agglomerate such as: discos, pubs, bars, among others. These places are characterized by having high-powered sound systems.
- High power sound systems: Sound systems that can handle power of more than 100 w in closed spaces.
- Nanoparticle: Particle whose dimensions are less than 500 nm.

13.4. Measurement units

- Hertz: Hz
- Decibel: dB
- A-frequency-weighted decibel: dBA
- Centimeter: cm
- Meter: m
- Inch: "
- Percent: %
- Seconds: s
- Minutes: min
- Hour: h
- Total: T
- Post Meridiem: p.m.
- Ante Meridiam. a.m.
- Liters: l
- Grams: g
- Ohms: Ohms
- Watts: w
- Volts: v
- Pascal: pa

- Joules: J

13.5. Acronyms

- END: Environmental Noise Directive.
- POI: Points of Interest
- PVP: Polyvinylpyrrolidone
- PVC: Polyvinyl Chloride
- ISO: International Standard Organization.
- MED: Medellín
- SAB: Sabaneta
- GIR: Girardota
- ITA: Itagüí
- CEN: Centro
- CODI: Complex Ditaires
- SEMS: Department of Education of Sabaneta
- PLMA: Plaza Mayor
- BOTJ: Bótica Junín
- PJIC: Politécnico Jaime Izasa Cadavid
- SOSN: Comprehensive Risk Management System North
- SIATA: Medellin Early Warning System
- ZOOL: Medellín Zoo
- TRAF: Traffic
- ZS: Zetasizer
- DLS: Dynamic Light Scattering
- ASTM: American Society for Testing and Materials
- MDF: Medium Density Fiberboard
- GIS: Geographic Information System
- WOAB: Without Absorbent or Balconies
- AC WOB: Absorbent-Continuous and Without Balconies
- AA WOB: Alternate-Absorbent material and Without Balconies
- BA WOA: Balconies-Alternate and Without Absorbent
- AA & AB: Alternate Absorbent and Alternate Balconies
- BC WOA: Balconies-Continuous and Without Absorbent
- AC & BC: Absorbent-Continuous and Balconies Continuous
- AAAF & AB: Alternate Absorbent on All Faces and Alternate-Balconies
- ACAF & BC: Absorbent-Continuous on All Faces and Balconies-Continuous
- AMVA: Metropolitan Area of the Aburrá Valley

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