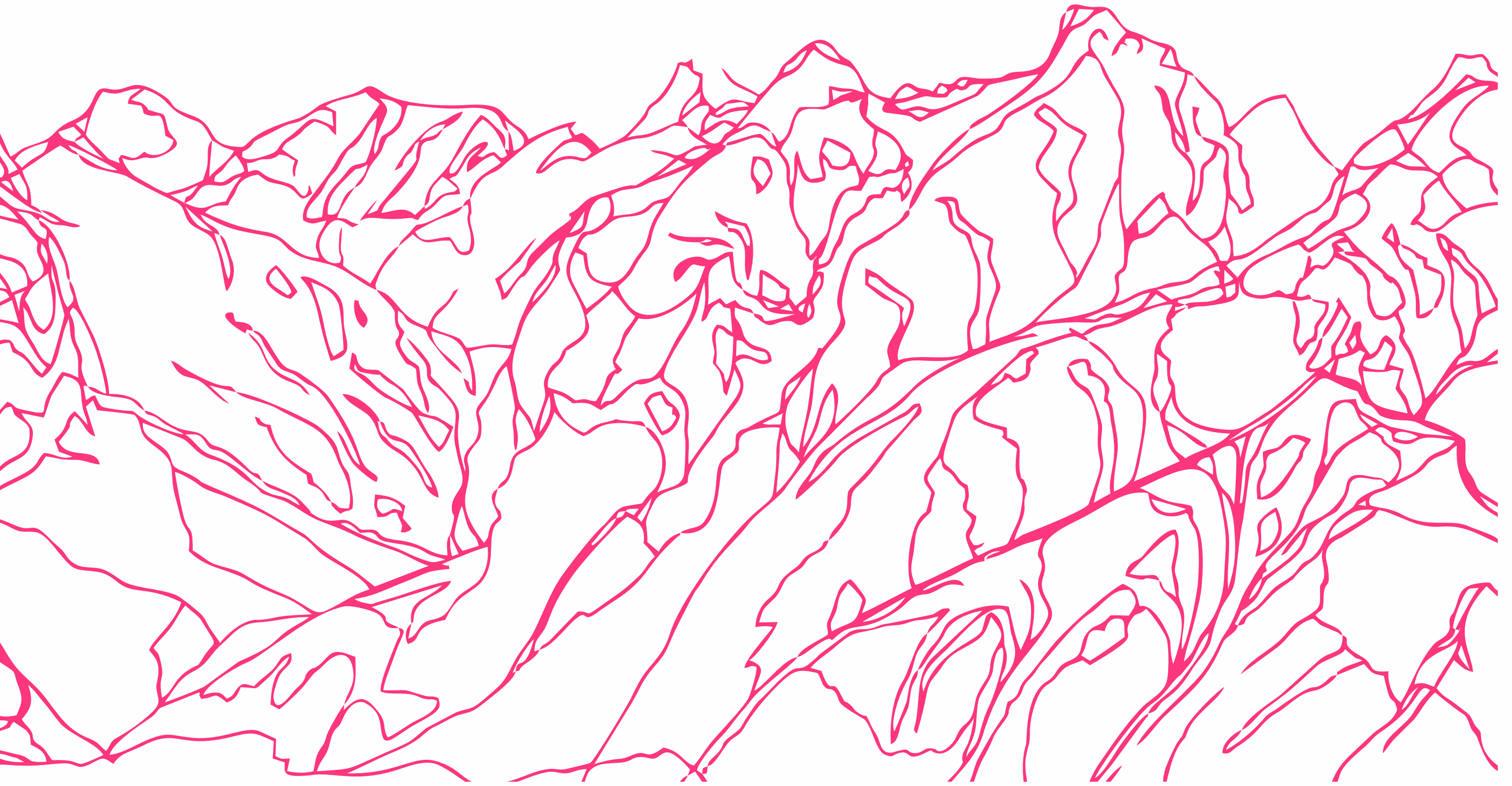
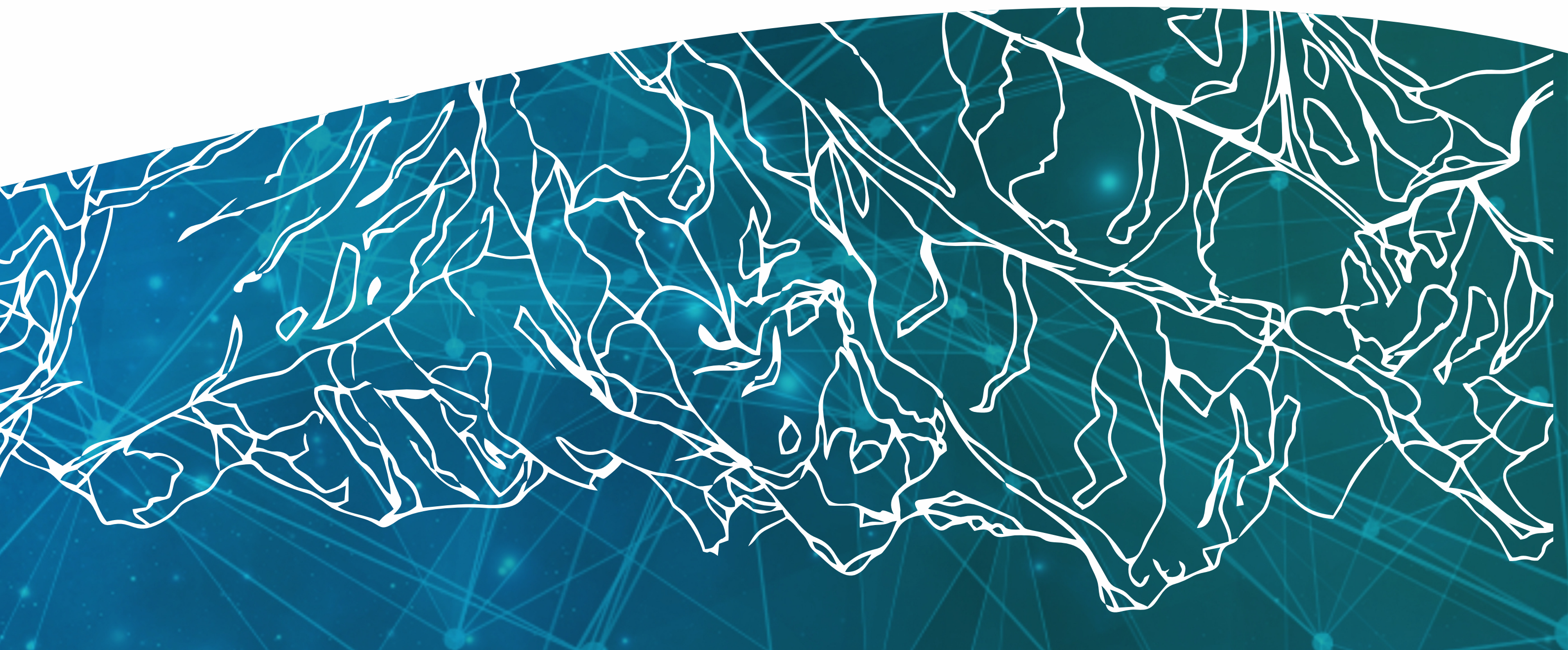
Book of Extended Abstracts ACOUSTICS 2024



Martin Čulík – Vojtech Chmelík

ACOUSTICS 2024 High Tatras

JUNE 12-14, 2024 / ŠTRBSKÉ PLESO, VYSOKÉ TATRY, SLOVAKIA



Technical University in Zvolen – Slovak University of Technology in Bratislava
2024

BOOK OF EXTENDED ABSTRACTS ACOUSTICS 2024

"ACOUSTICS 2024 High Tatras"

June 12-14, 2024 / Štrbské Pleso, Vysoké Tatry, Slovakia

Editors: Martin Čulík, Vojtech Chmelík

Technical University in Zvolen
Slovak University of Technology in Bratislava

2024

The main aim of the (36th) International Conference „ACOUSTICS 2024 High Tatras" is to exchange theoretical and practical knowledge from various fields of acoustics focusing mainly on the properties of special wood products, building materials and the current issues connected with noise and vibrations and their impact on humans as well as on the environment. Participants will get information concerning the current state of the art in the field in question and information about proposed or implemented solutions to problems emerging from practice in above mentioned fields. As the participants are university teachers, scientists and representatives of practice obtained knowledge will be implemented into the teaching process and will find its application while solving research problems or will be used in the practice. The international aspect of the conference is a good presumption for establishing closer cooperation in science and research.

Keynote Lectures

KRISTIAN JAMBROŠIĆ – Overcoming Acoustic Design Challenges of Historical and Modern Spaces

LOUENA SHTREPI – From real to virtual: Acoustic materials in Architectural Acoustics

KONCA ŞAHER - Elevating Acoustic Consultancy Through Auralization Experiences

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- Progressive research of performance properties of wood-based materials and products (LignoPro), ITMS: 313011T720, supported by the Operational Programme Integrated Infrastructure (OPII) funded by the ERDF (Technical University in Zvolen, Slovakia)
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- HORIZON – MSCA – 2021 – DN, No. 101072598 – Acoustic and Thermal Retrofit of Office Building Stock in EU (Department of Materials Engineering and Physics, Faculty of Civil Engineering, STU in Bratislava, Slovakia)
- VEGA 1/0205/22 and KEGA 033STU-4/2024 (Department of Materials Engineering and Physics, Faculty of Civil Engineering, STU in Bratislava, Slovakia)

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Topics

Acoustic comfort
Acoustic properties of wood
Acoustics and physics in education
Acoustics of musical instruments
Economics and management of processes in the production of musical instruments
Environmental acoustics and Soundscapes
Noise and health
Musical acoustics
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Smart building façade techniques
Fire protection
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Hotel Panorama ****
Štrbské Pleso, Vysoké Tatry, Slovakia

Slovak Young Acousticians Network event

Pitch talks, team building and workshop
Date: 12th June 2024
Chair: Dominika Húdoková

Program of SlovakYAN event

14:00~14:15 – Opening of the SlovakYAN event
14:15~15:00 – Elevator pitch
15:00~16:00 – Late lunch
16:00~18:00 – Workshop
18:00~∞ – Team building activities

YAN EAA Young Acousticians Network

FOREWORD

The International Conference „ACOUSTICS 2024 High Tatras“ is a joint event of two conferences organized by the Slovak Acoustical Society (SKAS) – „MAP, Zvolen“ a „MAK, Kočovce“. The event is the continuation of successful Czechoslovak and later Slovak international acoustic conferences in the past. This conference took place in the beautiful environment of High Tatras – Štrbské Pleso on 12th – 14th June 2024 in Hotel Panorama.

The nowadays methodological trend in science is characterized by an increasing degree of specialization, which on one hand leads to improved focussing of efforts, but on the other hand to fragmentation of know-how and loss of overview. Interdisciplinary activities, as demonstrated in this conference, are an efficient way to connect different scientific fields, and exploit opportunities for synergy.

One of the main goals of this conference was to allow experts from different disciplines in acoustics, building engineering and architecture to regain overview, to seed new collaborations, and to bring experience theory and practice together.

The conference „ACOUSTICS 2024 High Tatras“, hosted three keynote speakers – Kristian Jambrošić, Louena Shtrepi and Konca Şaher. Many interesting presentations were presented and discussed.

Conference Chairs

CONTENTS

KEYNOTE LECTURES

KRISTIAN JAMBROŠIĆ
Faculty of Electrical Engineering and Computing, University of Zagreb, Croatia

LOUENA SHTREPI
Applied Acoustics Group, Department of Energy “Galileo Ferraris”, Politecnico di Torino, Italy

KONCA ŞAHER
Interior Arch. & Environmental Design, Kadir Has University, İstanbul, Turkey

OVERCOMING ACOUSTIC DESIGN CHALLENGES OF HISTORICAL AND MODERN SPACES

Kristian Jambrošić
Faculty of Electrical Engineering and Computing, University of Zagreb, Croatia
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KEYNOTE LECTURE

What are our expectations of acoustics in historical/heritage spaces compared to modern spaces?

How did the development of modern construction technology of buildings change the underlaying acoustics of spaces?

What are the typical design flaws encountered in acoustic design projects?

Is the use of changeable acoustics an universal solution for the acoustical design of multipurpose halls?

What about auralization as a helping tool in the acoustic design process?

FROM REAL TO VIRTUAL: ACOUSTIC MATERIALS IN ARCHITECTURAL ACOUSTICS

Louena Shtrepi
Applied Acoustics Group, Department of Energy "Galileo Ferraris",
Politecnico di Torino, Italy
louena.shtrepi@polito.it

KEYNOTE LECTURE

Which acoustic materials should we choose? What are the effects of acoustic materials in spaces for different uses?

How did the development of new materials and fabrication techniques change the aesthetics of spaces?

Should we choose sound absorptive or sound diffusive materials? Can we hear their effects?

Is the new frontier of metamaterials applicable to the acoustic performance in more broad building sector context?

ELEVATING ACOUSTIC CONSULTANCY THROUGH AURALIZATION EXPERIENCES

Konca Şaher
Interior Arch. & Environmental Design, Kadir Has University, İstanbul, Turkey
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KEYNOTE LECTURE

In the realm of acoustic consultancy, the challenge often lies in effectively communicating complex theoretical concepts, acoustic indicators and proposed solutions to clients who may lack technical expertise. Traditional methods such as charts, graphs, and numerical data, while valuable, can sometimes fall short in conveying the experiential aspect of proposed acoustic interventions.

This speech proposes the integration of auralizations in acoustic consultancy practices as a powerful tool for bridging the gap between theory and experience. Auralizations have the potential to enhance client engagement, facilitate decision-making processes, and ultimately lead to more effective acoustic solutions. Through case studies and real-world examples, this speech will showcase the practical benefits of integrating auralizations into acoustic consultancy workflows. It will also discuss potential mishandling, how widely it’s being adopted, how reliable it is, whether it’s worth the cost for smaller companies, and what the future might holds for the auralizations.

LONG-TERM TRENDS IN TRAFFIC NOISE ANNOYANCE: BRATISLAVA STUDY

Lubica Argalasova; Alexandra Filova; Barbora Chovancova; Katarina Hirosova; Jana Jurkovicova
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Abstract

The present study's primary objective was to conduct a longitudinal investigation of trends in noise annoyance associated with road traffic within Bratislava's continuously monitored neighborhoods. This assessment employed a 30-year timeframe, with data collected at 10-year intervals. A particular emphasis was placed on evaluating the impact of the global COVID-19 pandemic on both objective noise levels and subjective annoyance experienced by residents- young healthy individuals. Traffic noise burden (L_{Aeq}) and annoyance significantly increased in exposed areas during the first decade (1989-1999). A slight decrease in noise levels and annoyance was observed by 2019. During COVID-19 lockdowns, a more substantial decrease in noise levels (L_{Aeq}) and annoyance occurred in both exposed and control areas. Despite a recent downward trend, road traffic noise annoyance remains a significant issue. The study highlights the need for implementing noise mitigation strategies and developing sound-sensitive urban transport systems.

Keywords: Environmental noise, noise annoyance, young healthy individuals, trends

Acknowledgements

This work was supported in part by the grant KEGA 015UK-4/2022, Innovation of education in the field of health protection and promotion with an emphasis on e-learning and implementation of multimedia technologies.

INTRODUCTION

Previously considered a minor health concern,environmental noise exposure is now recognized as a significant public health issue. Unlike readily identifiable hazardous substances, noise's indirect health effects (e.g., cardiovascular issues, sleep disruption) were likely underestimated (BASNER et al., 2014, ZIARAN, 2016, EEA,2020). This study investigates long-term trends in noise annoyance within Bratislava using decade-long intervals (10, 20, and 30 years) incorporating the potential influence of COVID-19.

METHODS

Our study investigated the connection between noise annoyance and psychosocial well-being in young, healthy individuals (ARGALASOVA et al., 2014, PERIS and FENECH, 2020). We recruited a homogeneous sample of 3,197 Comenius University in Bratislava students living in either exposed (n=1,294) or control locations - dormitories (n=1,903) in the Bratislava city for more than 4 years. To assess these factors, we employed a validated subjective methodology (noise annoyance questionnaire) and direct sound level measurements. A noisy dormitory near major roads and trams served as the exposed location, while a quiet dormitory in a pedestrian zone acted as the control one. Noise measurements and strategic noise maps (L_{DEN}) helped to categorize participants based on noise levels for epidemiological research. The study used statistical methods (bivariate and stratified analysis) to assess community noise annoyance risks from various sources. The risks were followed at time intervals of 10, 20, and 30 years and the time trends were assessed. Major analytical tools were Epi Info™, different versions during decades, the latest version EPI-INFO 7.2.5.21, and IBM SPSS Statistics 25.0 (International Business Machines Corp., New Orchard Road, Armonk, NY, USA).

FINDINGS AND ARGUMENT

Traffic noise in the exposed area steadily increased over 10, 15, and 20 years, exceeding the health risk zone of 60 dB (L_{Aeq}). The highest levels (67.5 dB L_{Aeq}) likely occurred between 1999 and 2009 (SOBOTOVA et al, 2001) (Figure 1).

There was a slight decrease after 2014 when the measured values fell to L_{Aeq} = 65.7 dB and in 2019 to L_{Aeq} = 63.9 dB (ARGALASOVA et al., 2014). In 2020, during lockdown due to the COVID-19 pandemic, they dropped to L_{Aeq} =62.5 dB. However, they still reach higher values than allowed in residential areas and around school facilities. In 2023, after the COVID-19 pandemic, the measured values increased in the exposed and in the control location by 1 dB (Figure 1).

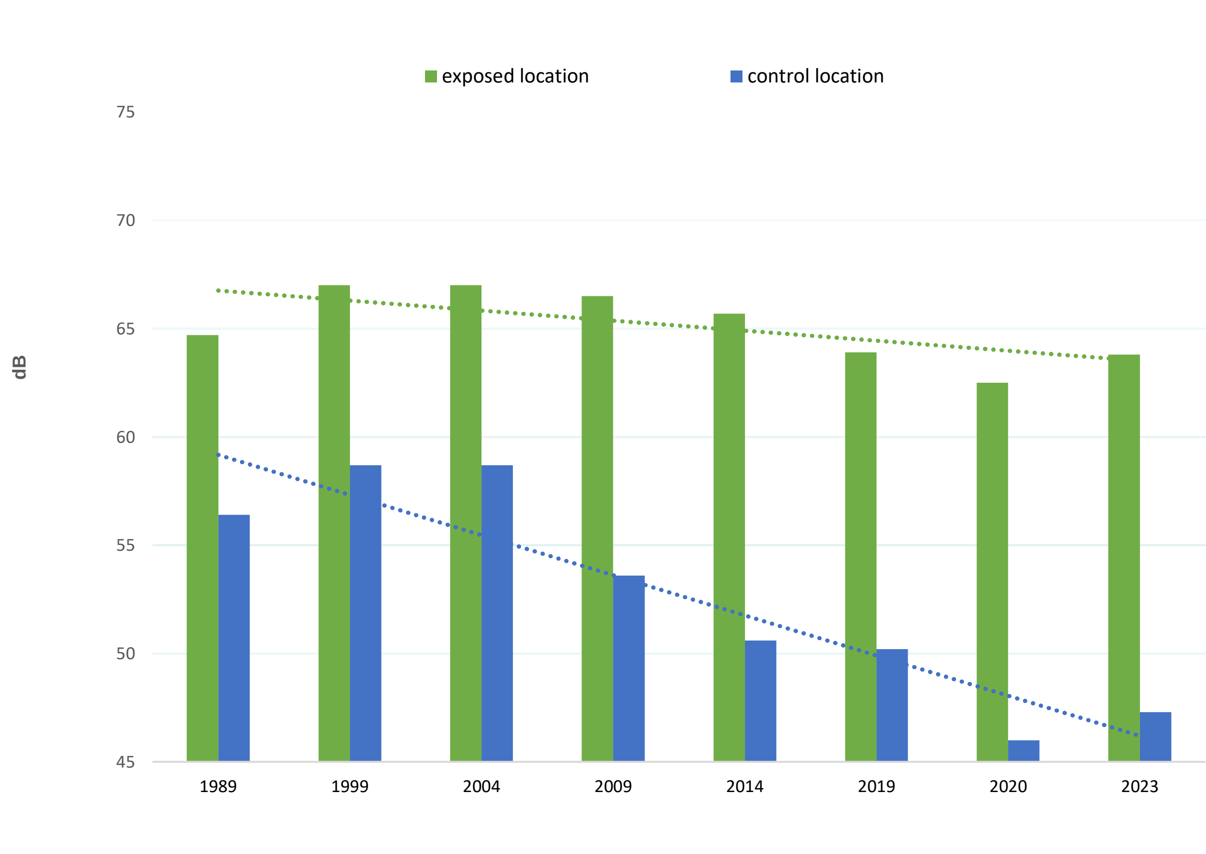

Figure 1. The development of noise levels in the observed areas during 1989-2023.

Traffic noise emerged as the dominant source of annoyance in the exposed area, followed by noise from entertainment facilities. Residents reported a significant increase in traffic noise annoyance over a decade (OR_{MH}: 2.56 in 1989 to 6.01 in 1999, 95% CI [1.93-3.42, 4.97-7.95]. Annoyance from trams (OR_{MH}: 3.05, 95% CI [1.93-4.82] in 2019) and neighborhood noise (OR_{MH}: 2.81, 95% CI [2.12-3.74] in 2023) also showed upward trends, with entertainment facilities reaching their peak annoyance level in 2023 (OR_{MH}: 4.31, 95% CI [3.25-5.72]). Traffic noise annoyance risks showed a slight decrease between 2020-2021 (OR_{MH}: 4.37, 95 % CI [2.98–6.40] and 2023 (OR_{MH}: 3.26, 95% CI [2.19–4.90], but still remains a concern.

CONCLUSIONS

This 30-year study investigated the link between environmental noise and annoyance, focusing on a specific situation during the COVID-19 pandemic. The first decade revealed a substantial rise in road traffic noise annoyance, potentially due to the country's development and traffic management changes. While a slight decrease in traffic noise annoyance was observed recently, it remains a significant concern. Annoyance from entertainment facilities also increased. The experience and lessons from the pandemic can guide the development of sustainable urban transport and the implementation of noise reduction strategies. Our findings highlight the need for preventive measures to minimize environmental noise exposure in residential areas.

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SOUND TRANSMISSION LOSS OF A POROUS MEDIA IMPREGNATED WITH PHASE CHANGE MATERIAL

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Abstract

Incorporating Phase Change Materials (PCMs) in building components is designed to improve the thermal comfort of those who inhabit these spaces. However, the incorporation of PCM in façades components can influence the acoustic performance of the envelope, leading to improved indoor acoustic comfort. This research aims to characterise the sound transmission loss (STL) of different porous media following the ASTM 2611-09 transfer matrix method. In particular, a rigid mineral-based board was saturated with 55 by weight (wt%) of paraffin-based PCM and the results were compared with a panel without PCM and a mineral wool sample. Results show that the incorporation of PCM increases the insulation capacities of the calcium silicate over the entire frequency range examined, from a minimum of 4 dB at 250 Hz to a maximum of 17 dB at 800 Hz. However, the dispersion of the results obtained indicates possible limitations in the measurement technique to reliably characterise only non-rigid materials.

Keywords: Sound Transmission Loss, Composite Materials, Porous Media, Phase Change Material, PCM-impregnation

Acknowledgements

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INTRODUCTION

A promising strategy to improve buildings' indoor thermal comfort and energy efficiency is the application of Phase Change Materials (PCMs). These materials can store and release thermal energy during the phase transition from solid to liquid state and vice versa, utilising both sensible and latent heat. However, in addition to thermal, visual and air quality comfort, the integrated design of spaces with adequate acoustic performance is crucial to ensure an appropriate level of acoustic comfort, contributing to an overall improvement in the well-being and quality of life of end users without having to prioritise (TORRESIN et al., 2020).
Although the literature on the thermal storage properties of PCMs is extensive, that on the acoustic performance of building components with embedded PCMs is limited. CHOI et al. (2022) investigated the sound absorption coefficient (α) of a shape-stabilised BioPCM in coffee waste particles using the transfer matrix impedance tube method. The authors developed porous samples with mixtures of

coffee waste and 0, 3, 5, and 10 by weight (wt.%) of BioPCM. PCM impregnation increased sound absorption at medium frequencies, reaching values between 0.7 and 0.8 at around 800 Hz regardless of the amount of PCM incorporated. However, the impregnation caused a decrease in *a* values at high frequencies, resulting in variations of 0.1-0.15 for all samples analysed. BARRENECHE et al. (2016) measured the difference between normalised levels (D_{nT}) of a shape-stabilised paraffin-based PCM (12 wt.% of RT21) in a polymer matrix and electrical furnace dust. Measurements were performed in full-scale twin chambers to compare the sample with a reference without PCM and found an increase in sound insulation of approximately 4 dB. UTHAICHOTIRAT et al. (2020) evaluated the Sound Transmission Loss (STL) of a concrete component containing 25 wt.% of paraffin-based PCM lightweight aggregates following the ASTM E90 standard. The authors pointed out that the STL decreases with increasing PCM content due to the reduction in porosity, and there is a difference of about 5 dB below 500 Hz and 10-16 dB from 500 Hz onwards.

These studies highlight how integrating PCMs into building materials can affect acoustic performance. However, it is necessary to understand the extent of this influence depending on the application in spaces or the building envelope. This study aims to fill this gap by evaluating the STL of a highly porous calcium silicate-based material impregnated with PCMs with a high application potential for thermal control and storage. The STL of the PCM-impregnated porous media was assessed using the impedance tube method, a traditional and cost-effective methodology, according to the ASTM E2611 (2019) standard. The results were compared against samples without PCM and a soft sound-absorbing material.

By analysing acoustic properties this study seeks to contribute to developing advanced building materials that improve thermal regulation, energy efficiency, and acoustic comfort. This is in line with the principles of sustainability and retrofitting in the building sector, to raise the quality and overall performance of buildings.

METHODS

For sound transmission loss (STL) measurements, an extension was added to the impedance tube used for sound absorption measurements, equipped with three microphone holders placed at a 31 mm and 171 mm spacing (see Figure 1). As stated in ASTM E2611, a transfer matrix method is used to determine the STL at normal incidence based on a measurement with a single termination, such as the anechoic, and the single microphone moves procedure was followed. To ensure that no non-plane waves are generated inside the tube, the upper and lower limit frequencies were calculated as a function of the tube's internal diameter of 40 mm and the chosen distance between the two microphones of 31 mm. The frequency range within which the measurement at normal incidence is valid is $117 < f < 4973$ Hz. The input data of temperature and atmospheric pressure influence the STL. A monitoring sensor was placed inside the laboratory to account for any changes that could occur to these factors during the test, registering an average temperature and pressure of approximately 25°C and 99 kPa.

Figure 1. Impedance tube used for the measurements.

For the measurements in the impedance tube, three samples of each material type were cut with the same tube diameter (see Figure 2). The calcium silicate samples without embedded PCM (GS1_T, GS2_T, GS3_T) showed an average density of 252 kg/m^3, PCM-impregnated samples with a melting temperature of 27°C (PCM1, PCM2, PCM3) reached a PCM content of about 55 wt%, and an average density of 593 kg/m^3, about 2.4 times higher than the sample without PCM. Finally, three mineral wool samples (MW1, MW2, MW3) with an average density of 96 kg/m^3, were considered as a reference in comparison with the rigid materials subject of this study. All samples have a thickness of 32 mm for a direct comparison of the results obtained, and the rigid ones were sealed around with the same amount of plasticine to avoid a high impact in the measurement, as suggested by the standard.

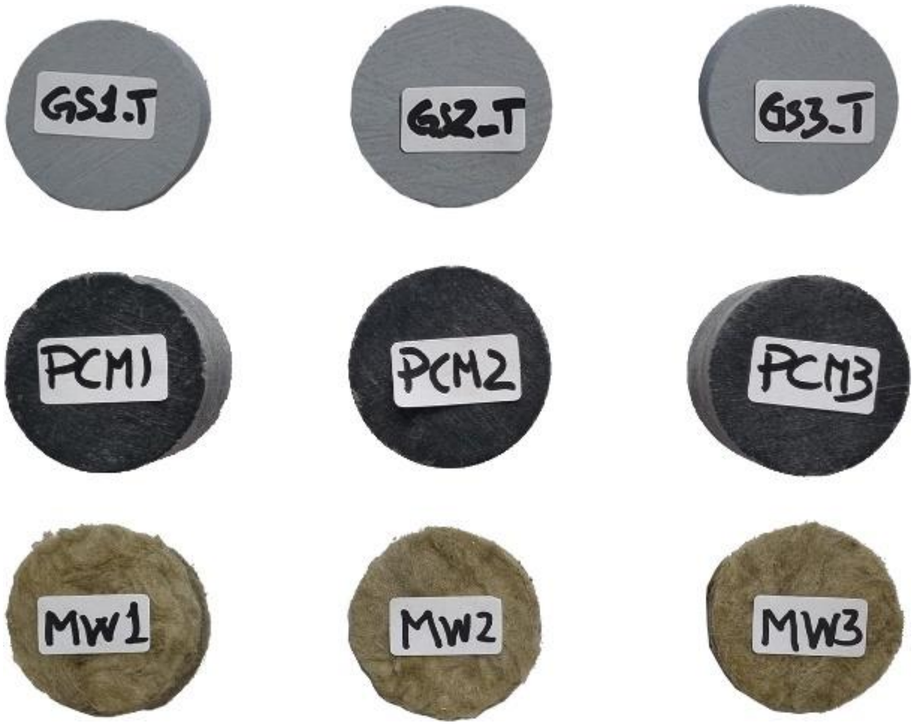

Figure 2. Samples used for the impedance tube measurements.

FINDINGS AND ARGUMENT

The normal Sound Transmission Loss (nSTL) measurements were performed on three samples for each type of material. Figure 2 shows the average nSTL values for the different characterised samples: mineral wool (MW_Av), calcium silicate with PCM (PCM_Av), and calcium silicate without PCM (GS_T_Av). The incorporation of PCM in the calcium silicate samples increases the insulation performance across the entire frequency range. Specifically, there is a minimum increase of 4 dB at 250 Hz and a maximum increase of 17 dB at 800 Hz. As expected, according to the mass law, incorporating PCM in porous materials improves the sound transmission loss, as the density of the material will increase without negatively affecting its Young's modulus, or even improve it when the pores are filled with a material that has higher resistance to stress than voids. In particular, with a 2.4-times increase in surface mass of PCM samples, the sound reduction index was expected to rise by 7.6 dB, knowing that doubling the frequency and/or mass per unit area leads to a 6 dB increase in sound reduction (VIGRAN, 2008). However, the measurements exhibit high variability, as indicated by the shaded areas around each curve representing the standard deviation.

Concerning the mineral wool samples, it should be noted that the dispersion of the results is significantly lower compared with the calcium silicate samples. The higher variability in the GS_T_Av and PCM_Av samples compared to the MW_Av samples may indicate that the measurement technique is more suited to materials with a more flexible structure like mineral wool and less for rigid materials such as calcium silicate. The rigid nature of the calcium silicate and the mounting conditions could affect the consistency of measurements, and lead to resonance effects or non-perpendicular surfaces causing small shifts in the results obtained from standing wave theory.

The results show that PCM-impregnation in calcium silicate-based porous media enhances the sound insulation properties, particularly at mid to high frequencies, although it also introduces greater variability in the results.

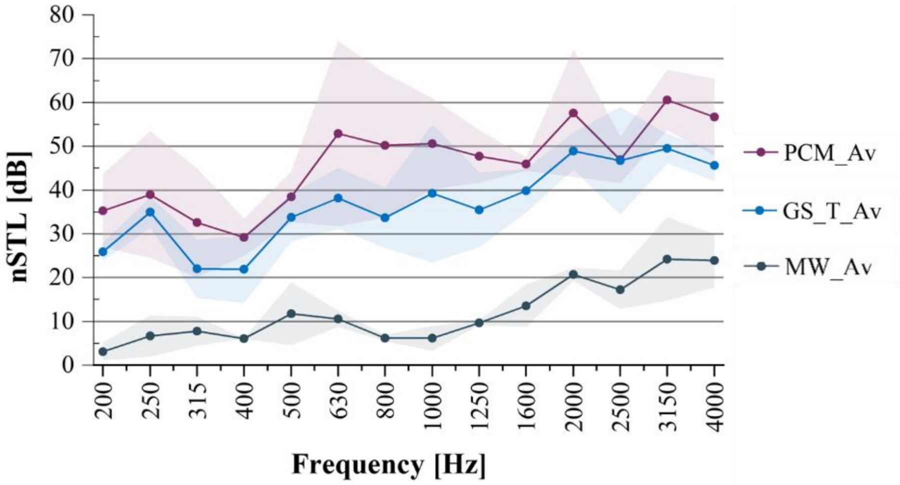

Figure 3. The normal Sound Transmission Loss (nSTL) obtained for the analysed samples, together with the standard deviations of the results.

CONCLUSIONS

This study demonstrated that incorporating PCMs into calcium silicate-based materials enhance sound insulation across a wide frequency range, aligning with theoretical expectations based on the mass law. Results showed variability with higher standard deviations observed in the rigid samples as GS_T and PCM-impregnated samples compared to mineral wool. Given this variability, future work should involve large sampling to determine whether the hypothesis that the PCM incorporated in porous media improves sound transmission loss can be conclusively supported. Further research is needed to optimise PCM content and explore other PCM-material combinations to improve thermal and acoustic properties. A higher PCM content shows an increase in the final density of the component and an increase in STL values. These findings underscore the importance of integrating PCM technology into building materials to address both acoustic and thermal performance. he building industry aims for higher standards of occupant comfort and energy efficiency, making the development of multifunctional materials, like those studied here, critical. Understanding how PCMs enhance building performance can lead to more sustainable, comfortable, and energy-efficient living and working spaces.

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ASSESSMENT AND COMPARISON OF AIRBORNE SOUND INSULATION OF PARTITION WALL IN TWO WOODEN CONSTRUCTIONS

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Abstract

Acoustic comfort in an inhabited building is an important aspect from the point of view of a person's quality of life, especially in the hotels and the buildings for temporary accommodation. When evaluating the sound insulation of the partition walls, measurements carried out in buildings are decisive, which can confirm the suitability of the used material composition and correct application in the wooden constructions. The work deals evaluation the airborne sound insulation of the partition walls of a different thickness and material composition between the rooms of the two different residential houses. The results of the airborne sound insulation measurements showed that, even after considering the required spectrum adaptation terms, the requirements of the standard STN 73 0532:2013 were not met in the first building, but they were met in the second building.

Keywords: Building acoustics, Airborne sound insulation, Standardized level difference, wooden constructions

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INTRODUCTION

The building should be designed in such a way that the noise and vibrations affecting the users do not exceed the noise level that would endanger their health or make sleep and relaxation impossible. Investigating the acoustic characteristics of dividing structures from the point of view of sound insulation is a very topical topic in the 21st century already in the project preparation phase. During the approval of the wooden constructions, measurement of noise level, both inside and outside, as well as the sound isolation of the partition constructions is becoming very popular (ŠTEFKO ET AL., 2021).

Technical progress in the measurements and simulations currently allows not only a better assessment of existing structures, but also the prediction of their soundproofing properties at the design stage. Based on the prediction, it is possible to solve various details of the structures, identify the acoustic bridges and help in the development of acoustically composite constructures. Sound insulation cannot be ensured only by increasing the thickness of a certain material, but only by a conceptual solution (RYCHTÁRIKOVÁ ET AL., 2019).

The acoustics of wooden constructions is affected by several factors. Soundproofing of partitions in wooden constructions can be affected by material layers, their properties, and the layer arrangement as well as the method of joining the partition with other elements of the wooden constructions.

A clear advantage of wooden constructions from this point of view is the possibility of the selecting materials with the required soundproofing providing a relatively lower wall thickness. However, acoustically multiple constructions of wooden buildings usually have a problem eliminating low-frequency noise due to the lower surface density of the materials compared to, for example, reinforced concrete constructions. The airborne sound insulation is affected mainly by sound transmission caused by leakages.

Standardized level difference parameter was chosen for evaluating the airborne sound insulation, measured according to STN EN ISO 16283-1:2014. This parameter provides a straightforward link to the subjective perception of noise level in buildings.

METHODS

The on-site measurements of airborne sound insulation between two rooms were carried out according to the standard STN EN ISO 16283-1:2014. A method for determining a single numerical value, i.e. the weighted value of the determining parameter of building acoustics, including spectrum adaptation terms, is specified by the standard STN EN ISO 717-1:2021. The standard ISO 717-1 is already inclined to the evaluation of parameters measured by A-weighting filter and also inclined to the extended evaluation of sound insulation in the frequency interval from 50 Hz to 5 kHz.

The measuring apparatus (Figure 1) consisted of the certified instruments, software for measurement and evaluating of the results from the Brüel & Kjær. The measurement system includes omnidirectional sound source with stand Type 4292-L; mechanism for simulating steps Type 3207; amplifier with wiring Type 2734-A; Hand-held analyzer Type 2270 with a license for measuring parameters of building acoustics; software Measurement Partner Suite BZ5503 and Building Acoustics Partner; laptop.

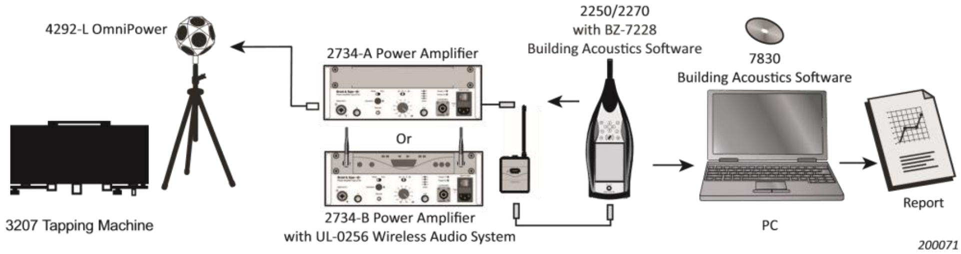


Figure 1. Schematic connection of equipment for measuring parameters of building acoustics from Brüel & Kjær (PRODUCT DATA: SOUND SOURCE AND IMPACT SOUND SOURCE FOR BUILDING ACOUSTICS, 2023).

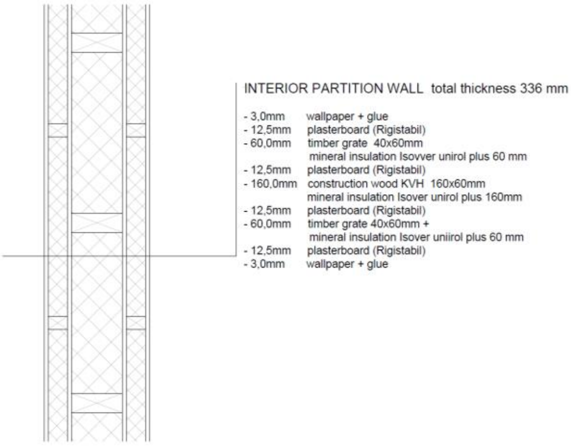
FINDINGS AND ARGUMENT

The airborne sound insulation of the partition walls between the mirror-oriented separate accommodation units was evaluated. In the first building, there are larger bedrooms, connected to the entrance corridor "L" without internal equipment and with an air conditioning unit. In the second building, there are smaller bedrooms of the same volume, along with interior furnishings and accessories. The composition and thickness of the wall layers in the assessed objects is shown in Figure 2.

The results of the evaluation of sound insulation between apartment partitions in the first building are in Table 1 and Figure 3. It turned out that according to the applicable standard, the partition does not meet the specified requirements. The reverberation time in the receiving room reached high values: at f = 63 Hz, T_{30} = 1.52 s; at f = 1 kHz, T_{30} = 1.57 s. A weighted sound reduction index with a value of 53 (-13; -22) dB was determined for this object using prediction software. When converted to the weighted apparent sound reduction index, it was evaluated at (45-49) dB, i.e. partition wall meets the requirements of the STN 73 0532:2013 standard to a minimum.

The results of the evaluation of airborne sound insulation between the apartment partition in the second building (Table 1 and Figure 3) showed that the partition wall meets the requirement stated in the standard STN 73 0532:2013. The reverberation time in the receiving room reached adequate values: at f = 63 Hz, T_{30} = 0.67 s; at f = 1000 Hz, T_{30} = 0.32 s.

1. building



2. building

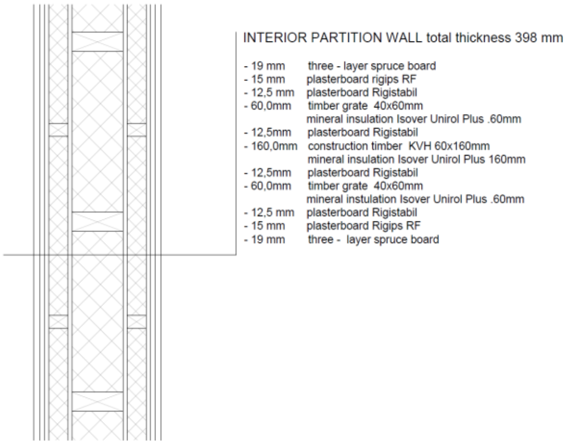
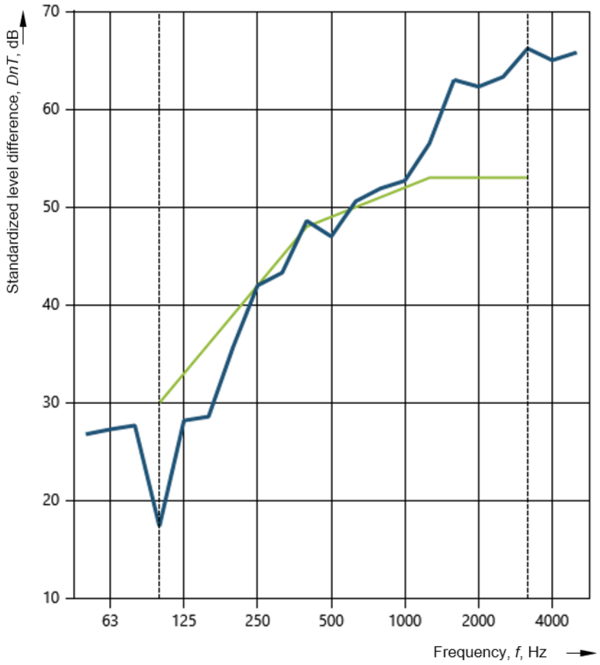
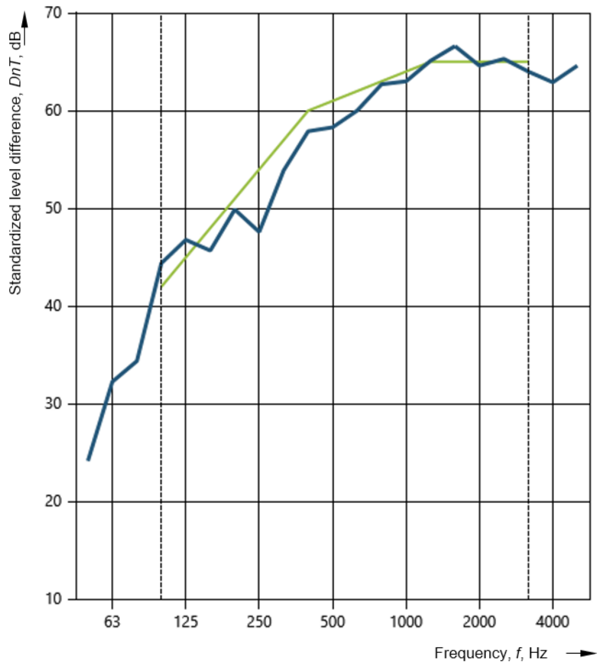


Figure 2. Composition of the partition walls of the residential houses.



1. building / $D_{nT,w}$ (C; Ctr) = 49 (-5; -13) dB



2. building / $D_{nT,w}$ (C; Ctr) = 61 (-1; -5) dB

Figure 3. Graphs of the standardized level difference dependence on 1/3 octave band frequencies.

Table 1. Results of the weighted standardized level difference of the partition walls and evaluation according to the STN 73 0532: 2013.

Residential houses	**1. building**	**2. building**
Requirement of standard (walls)	$D_{nT,w}$ = 47 dB	$D_{nT,w}$ = 47 dB
Weighted standardized level difference	**$D_{nT,w}$ (C; C_{tr}) = 49 (-5; -13) dB**	**$D_{nT,w}$ (C; C_{tr}) = 61 (-1; -5) dB**
Spectrum adaptation terms / $D_{nT,w}$ + C; Ctr	C = -5 dB / 44 dB $C_{50-5000}$ = -4 dB / 45 dB C_{tr}; $C_{tr50-5000}$ = -13 dB / 36 dB	C = -1 dB / 60 dB C_{tr} = -5 dB / 56 dB $C_{50-5000}$ = -3 dB / 58 dB $C_{tr50-5000}$ = -14 dB / 47 dB
Comparison with the standard (+ C; Ctr)	**Does not meet**	**Meet**

CONCLUSIONS

The weighted standardized level difference $D_{nT,w}$ of the partition wall in the first building meets the standard STN 73 0532: 2013 requirements. However, after taking into account all recommended spectrum adaptation terms (+C; C_{tr}), the requirement stated in the valid STN 73 0532:2013 standard is not met. The subjective evaluation of the sound pressure level in the evaluated space indicates that the soundproofing properties need to be assessed individually, it would be appropriate to take into account all additional factors. The measurements in the first building indicated a negative impact of lower frequencies on the overall perception of acoustic comfort in the given space.

In the second building, the requirement stated in the standard STN 73 0532:2013 was met even after accounting for all spectrum adaptation terms. The following probably contributed to meeting the requirements of the standard, opposite the first building:

- insertion of 19 mm thick three-layer spruce board on both sides of the partition wall, three-layer wall cladding and greater wall thickness,
- suitable connection and isolation of neighboring rooms, placement of furniture, doors, curtains, carpets.

The legislation in Slovakia does not require measurements of the sound insulation partition walls during the building construction, mainly wooden constructions. However, these measurements have shown the importance and justification of such measurements. Due to the increasingly frequent use of lightweight partition constructions (including wooden buildings), it is shown that the evaluation of sound insulation should also include measurement in the area of low frequencies, i.e. below 100 Hz.

Low-frequency noise is difficult to control, therefore the Weighted standardized level difference + Spectrum adaptation terms, i.e. $D_{nT,w}$ (C; C_{tr}) can be an important parameter for the judgment of airborne sound insulation in buildings and of building elements in the present time.

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STN 73 0532: 2013. *Acoustics. Rating of sound insulation in buildings and of building elements. Requirements*

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DRR & ILD CUE WEIGHTING IN AUDITORY DISTANCE PERCEPTION

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Abstract

Perceiving the sound source distance is important in many everyday activities. The estimates of auditory distance are typically dominated by the overall received stimulus intensity. However, distance processing can also be guided by intensity-independent cues. Specifically, the interaural level differences (ILDs) provide distance information for lateral stimuli and, in reverberant space, the direct-to-reverberant energy ratio (DRR) provides distance information for sources from all directions. Here we examine which of these cues dominates in intensity-independent distance perception. We conducted a behavioral experiment in a virtual reverberant environment using broadband noise stimuli. Binaural room impulse responses (BRIRs) were manipulated to either eliminate one of the cues, or to make them incongruent. The average results show that the subjects are more sensitive to the variation in ILD than DRR, when only one of the cues is available. However, a quarter of the subjects were more sensitive to DRR. These individual differences were also observed when the cues were presented incongruently, confirming that while the ILD is dominant among normal-hearing listeners, some listeners prefer the DRR cue.

Keywords: Auditory Distance Perception, Virtualization, Computational Modelling, Psychoacoustics

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INTRODUCTION

Localizing the objects of interest or threat is critical in daily life activities. Auditory modality is special in that it provides information even for objects that are occluded or behind the user (Kolarik et al., 2016; Zahorik et al., 2005). For example, consider a person reaching for a ringing phone in dark (Zahorik et al., 2005). Although auditory distance perception is critical in such scenarios, its functional mechanisms are not well understood (Kolarik et al., 2016; Zahorik et al., 2005). The estimates of auditory distance are typically dominated by the overall received stimulus intensity (Warren, 1999). However, in many situations, the emitted sound level is varying or unknown. In such cases, auditory distance perception relies on intensity-independent cues (Kopčo et al., 2012).

Recent results showed that robust intensity-independent distance perception is possible for nearby sources (up to 100 cm from the listener) in simulated reverberant environments. For such sources, two major intensity-independent distance cues exist, the inter-aural level difference (ILD) (Brungart, 1999; Shinn-Cunningham et al., 2005) and direct-to-reverberant energy ratio (DRR) which compares the sound energy received at the ears directly from the source to that reflected off the walls in reverberation (Mershon & King, 1975). ILDs provide distance information for stimuli off the midline, while DRRs provide distance information for sources from all directions. Although, we have started to understand which of the two cues the listeners use (N. Kopco et al., 2012; Kopčo & Shinn-Cunningham, 2011; Kopco et al., 2020), the question still remains which of these cues dominates in distance perception.

The current study focuses on understanding cue weighting in auditory distance perception. For this we examined auditory distance perception for lateral nearby sound sources located at various distances simulated along the interaural axis in a virtual reverberant environment (Figure 1B). To assess the individual cue contribution and relative weighting, we manipulated the BRIRs (KOPČO ET AL., 2012; SHINN-CUNNINGHAM ET AL., 2005) to affect the availability and congruency of the DRR and ILD cues (Figure 1A). Five types of stimuli were generated (Fig 1A). The unaltered BRIRs were used for the Congruent stimuli in which DRR and the ILD vary congruently with distance. In the ILD-only (or DRR-only) stimuli, the DRR (or ILD) was scaled so that it was fixed at the value of the 38-cm stimulus at all distances, while the other cue varied naturally. In the Incongruent(DRR) condition, the ILDs were unmodified while the DRRs were reversed at both ears by scaling the reverberant portion of the BRIRs so that the DRR of the stimulus at 15 cm corresponded to the DRR of the 100 cm unaltered BRIR, etc. Analogously, the Incongruent(ILD) condition was created by scaling the relative levels at the two ears. It was expected that the percepts would follow the cue that is weighted more when the cues were incongruent.

METHODS

SET UP & STIMULI

In a behavioral experiment, 15 human subjects (3 outliers) performed a distance discrimination task (Figure 1C). The subjects were seated in a double-walled soundproof booth in front of an LCD display and a keyboard connected to a control computer which ran a Matlab (Mathworks) script controlling the experiment. The pre-generated stimuli were played through Fireface 800 sound processor (RME), and Etymotic Research ER-1 insert earphones.

A single set of non-individualized BRIRs was used, measured in a midsize classroom on a listener that did not participate in this study (ZAHORIK, 2002). Unless specified otherwise, all details of the measurement procedures, including the microphone, speaker, and the BRIR measurement technique used are identical to our previous studies (KOPCO ET AL., 2020; KOPČO ET AL., 2012). Either the whole BRIR or only its reverberant tail were scaled to modify the ILD or DRR as shown in Figure 1A.

On each trial, two 300-ms broadband noise stimuli were presented consecutively from two different randomly chosen distances at a roved level. The listener indicated which sound was closer. Each listener performed 81 trials per condition. Feedback was provided on each trial in all conditions except the incongruent ones.

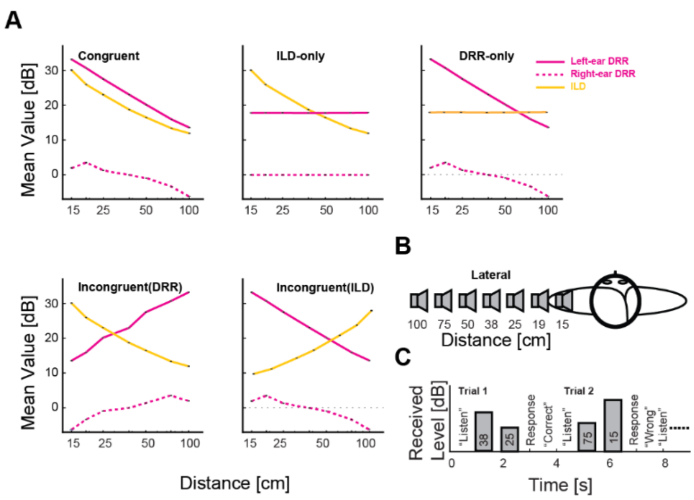

Figure 1. Experimental design. (A) Cue manipulation in different conditions. In the Congruent condition the cues ILD and DRR both were present and varied congruently with distance. In Incongruent condition one of the cues was reversed as a function of distance. In the ILD-only condition the DRR cue values were fixed at the values corresponding to distance of 38 cm. In DRR-only condition ILD was fixed. (B) Simulated source locations. (C) Design of trials: The instruction “Listen” appeared on the screen, followed by presentation of two stimuli from different distances at random levels. Listeners responded by indicating whether the second stimulus was closer or more distant than the first stimulus. On-screen feedback was provided in all conditions except for the incongruent ones.

DATA ANALYSIS

The proportion of correct responses was computed for each stimulus condition, distance pair, and subject. A simple decision theory model based on psychophysical decision theory (DURLACH & BRAIDA, 1969) was used to compute nominal distance sensitivity d'_N across all distance pairs (KOPČO ET AL., 2012) for all conditions except the incongruent ones. d'_N represents the sensitivity for a nominal distance separation (for difference of log(distance) equal 1). A similar measure d_{ILD} was used for the incongruent conditions (d_{ILD} has the same meaning as d'_N except that positive values mean that responses follow the ILD more than the DRR while negative values mean responses following DRR). Statistical comparisons were done using repeated measures ANOVAs.

FINDINGS AND ARGUMENT

Figure 2 shows the intensity-independent distance discrimination sensitivity for the three stimulus conditions of behavioral experiment. The sensitivity index d'_N was significantly higher for congruent condition than in the ILD-only and DRR-only conditions (3.36 vs. 2.59 and 1.27). These results are consistent with the hypothesis that both DRR and ILD are used as intensity-independent distance cues, contributing significantly to the distance percept, when both are available. Additionally, the value of d'_N for ILD-only condition was significantly higher than the DRR-only condition. This indicates that listeners were more sensitive to distance-dependent variations in ILD than to those in the DRR. A repeated measures ANOVA with the factors of sound types (3 levels) supports these observations, by finding a significant main effect of sound types ($F_{2,22}$ = 12.43, p = 0.0002). Post-hoc pairwise comparisons with Bonferroni correction found significant differences for all three condition pairs (p < 0.005). However, the results also show that 1/4th of subjects (marked in black) was more sensitive to the DRR.

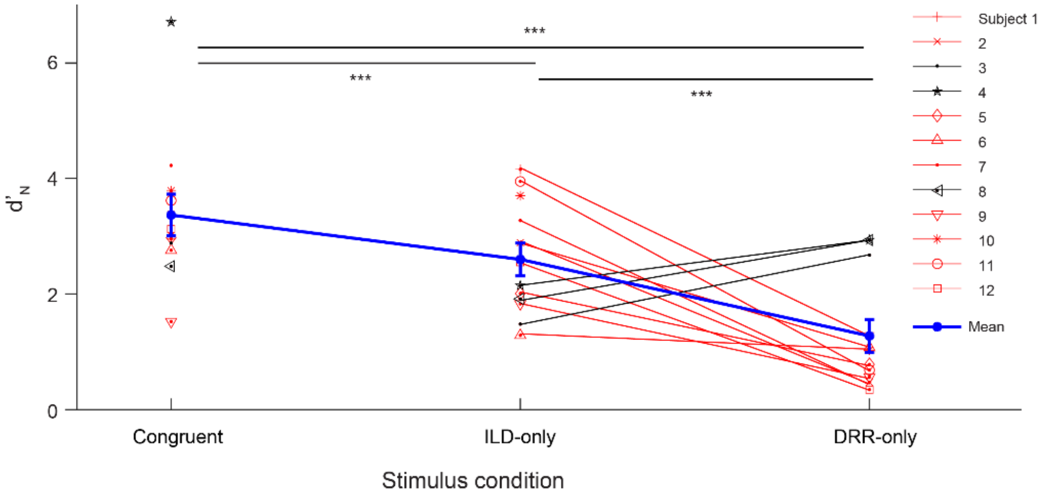

Figure 2. Discrimination sensitivity for the three stimulus conditions. The across-subject sensitivity index d'_N (+/-SEM) as well as individual values are shown. Horizontal lines and asterisks link conditions with performance significantly different in pairwise t-tests (*** for p < 0.005).

Figure 3A shows the performance for the two incongruent conditions, this time as a scatter plot using the d_{ILD} measure. Results in Figure 3A show that the two ways of creating the incongruent-cue stimuli are highly correlated, with a slight tendency for larger values in the Incongruent(DRR) stimuli. The black symbols in this figure indicate the 3 subjects whose d'_N was larger in DRR-only than ILD-only condition, showing that these three subjects were the only ones following the DRR cue in the incongruent conditions.

To directly test whether these differences in sensitivity to the individual cues predict how the cues are combined when available simultaneously, Figure 3B shows a scatterplot of the across-incongruent-condition average d_{ILD} (from Figure 3A) vs. the difference between d'_N in the ILD-only and DRR-only conditions (from Figure 2). This figure clearly shows a separation between the two groups of subjects in both measures.

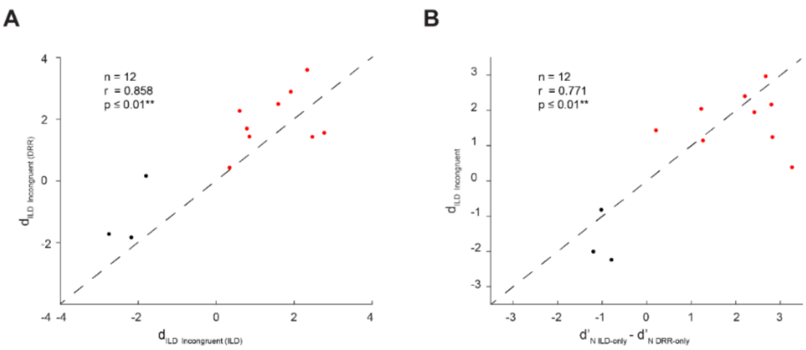

Figure 3. Correlation analysis. (A) Comparison of incongruent condition variants. (B) Comparison of incongruent and individual cue weighting.

CONCLUSIONS

The congruent condition had better performance than the ILD-only or DRR-only conditions, supporting the hypothesis that both cues contribute to the intensity-independent distance percepts. On average, the subjects were more sensitive to the distance-dependent variation in ILD than in DRR, suggesting that ILD is the dominant cue. However, there also were subjects more sensitive to the DRR cue. These between-subject differences were preserved even when the cues were pitched against each other in the incongruent condition, indicating that there is a large variation in the cue weighting even in in the normal-hearing subject population. These results are not consistent with those of (Kopčo & Shinn-Cunningham, 2011) who, based on modeling, suggested that monaural DRR is the primary cue used by the listeners when judging distance. It is possible that this difference is driven by the fact that only lateral stimuli were used in the current study, thus ILD was always available, while in (Kopčo & Shinn-Cunningham, 2011) also frontal stimuli with no ILDs were included. Thus, it is possible that listeners change the cue weighting dependent on the current context and cue availability.

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PRACTICAL APPLICATIONS OF ACOUSTIC TOMOGRAPH ARBOTOM

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Abstract

To accurately assess wood quality, it is important to consider negative characteristics such as diseases, damage, or growth abnormalities, as they may impact the wood's intended use. This work aims to describe the results and practical experience of using the acoustic stress tomograph ARBOTOM in various forestry operations and research conditions. The measurements were carried out from 2021 to 2024 in three different environments and conditions, and in forest stands, they showed that the tomograph has a problem with the accuracy of detecting qualitative features, especially in woody species that have softer wood. On average, the character range was overestimated by almost 15%. Conversely, it provided much more accurate results, underestimating the range of qualitative features by 1% compared to the actual state observed when cutting logs and analyzing sections from them. Additionally, we discovered that the tomograph is ineffective for tree trunks thinner than 20 centimeters due to its inability to accurately evaluate the propagation speeds of acoustic waves. Indeed, the inaccuracies in assessing the qualitative state of standing trees using an acoustic tomograph can be improved through various methods. In addition to clear methodological approaches to measurement, optimization of mathematical algorithms and trained neural networks can also be the key to increasing accuracy.

Keywords: quality of wood, acoustic stress wave, impulse tomograph, image analysis

Acknowledgements

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INTRODUCTION

Correctly determining the value of wood is crucial for forestry, as the sale of wood represents a significant part of its income. When evaluating wood, it is necessary to take into account technical parameters, which include quantitative and qualitative characteristics. When properly assessing the quality, it is also important to take into account negative characteristics such as the presence of diseases, damage, or growth abnormalities that may affect the purpose of its use. These factors determine the final economic value of wood and it is important to measure and evaluate them correctly (Gejdoš et al. 2021). Several methods exist for the qualitative evaluation of wood, categorized based on the degree of damage into destructive, semi-destructive, and non-destructive methods, each operating on different principles (Ondrejka et al. 2020). Assessing the quality of standing trees is currently problematic. It is often burdened with a large degree of subjectivity of the evaluator, or it requires time-consuming methods that are tied to the extraction of the given wood (destructive methods).

A quick and relatively accurate alternative is semi-destructive and non-destructive methods based on acoustic tomography, or measuring the resistance of penetration inside the trunk. The work aims to describe the results and practical experience of using the acoustic stress tomograph ARBOTOM in different conditions of forestry operation and research.

METHODS

For field measurements, an ARBOTOM acoustic tomograph from Rinntech was used, in a technical version with 24 sensors (possible modifications of 6, 12, and 18 sensors) with Arbotom v2 software. The measurements were conducted between 2021 and 2024. The tomograph was tested in the following conditions: Forest stands (150 trunks consisting of 97 oaks, 49 lindens, 3 pines, and 1 fir); Experimental planting of poplars (2 trunks); Log sections with different types of quality features (10 trunks including 4 spruce, 3 beech, 2 oak, and 1 ash). The measurement methodology was consistent across all experiments, following the operating manual of the tomograph. Measurements from the forest stand were verified by manual measurement and image analysis on 17 trunks. The freely available ImageJ software was used for image analysis and graphic evaluation, and the STATISTICA 12.0 software was used for statistical evaluations.

FINDINGS AND ARGUMENT

Measurements in forest stands have revealed that the tomograph encounters accuracy issues in detecting qualitative features, particularly in trees with softer wood, such as linden. In these instances, it delineated damage zones, despite subsequent verification post-harvesting indicating flawless wood. The tomograph depicts the propagation speeds of acoustic waves using a color spectrum comprising green, yellow, orange, and violet. The green color signifies the swiftest wave transition (indicating healthy wood), while purple denotes the slowest (representing damaged or less dense wood). Hence, only zones falling within the violet spectrum were assessed as areas exhibiting qualitative damage. The frequency histogram depicting the percentage of the purple zone from the trunk's cross-sectional areas is shown in Figure 1.

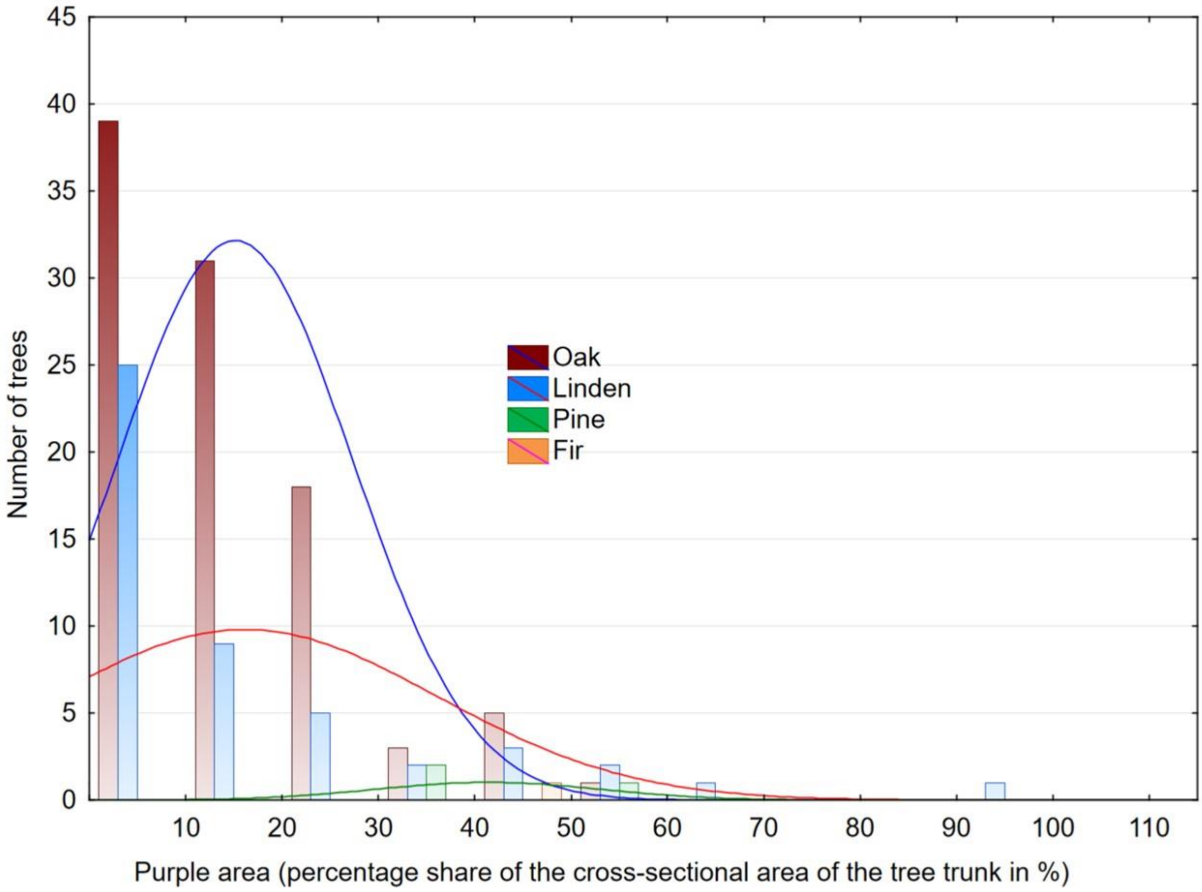
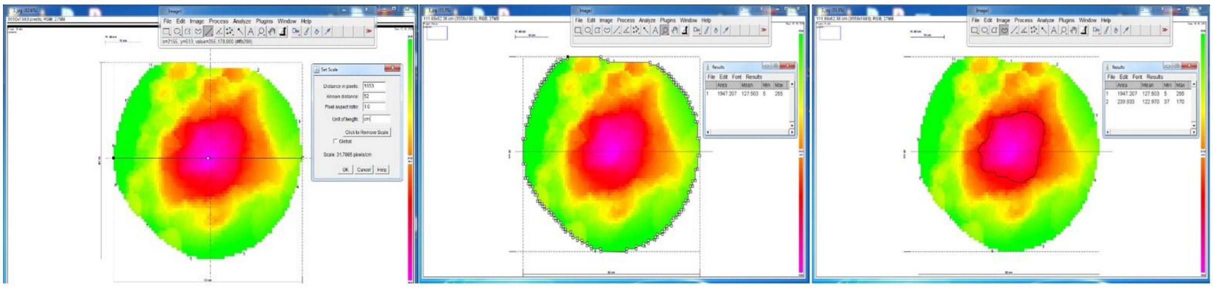


Figure 1. Histogram of frequencies according to the percentage share of purple zone from the cross-sectional area of individual wood species identified by the Arbotom.

The results indicate that the majority of trees exhibited minimal levels of identified wood damage in their cross-sections. These included the two most abundant tree species in the analysis, oak and linden. For both tree types, the highest number of trees with damaged areas fell within the 0%-10% interval. During the verification analysis of 17 harvested tree pieces previously scanned with the tomograph, it was observed that, on average, the tomograph overestimated the extent of damage caused by qualitative features compared to assessments derived from digital images of cross-sections of harvested trunks, by 15%.

In the study by GEJDOŠ et al. (2023), we scrutinized the accuracy of the tomograph using 10 sections of individual tree samples. In this scenario, disparities between the image analysis of digital photographs of sections and the images produced by the tomograph did not surpass 5%. Overall, the tomograph underestimated the range of qualitative features by less than 1% in this context. From this, we can infer that the acoustic tomograph yielded relatively precise results in evaluating qualitative features in this type of analysis. Paradoxically, the tomograph thus furnishes more accurate outcomes for a purpose for which it was not primarily designed. However, the obtained results may be partly influenced by the operator's experience with the tomograph (including sensor placement and software localization) as well as the accuracy of evaluation during image analysis using ImageJ software (Figure 2).



a) b) c)

Figure 2. Limitation of the area of the qualitative feature from Arbotom in the ImageJ software environment.

For practical validation, tomograph measurements were also conducted on thin poplar trees at the Borová Hora Arboretum of the Technical University in Zvolen. Two trunks, with diameters of 13 cm and 15 cm, were measured, with four tomograph sensors placed on each trunk. It has been demonstrated that at this thickness, the tomograph cannot accurately assess the algorithms of acoustic wave propagation speeds. During each measurement, it evaluates statistical deviations of signal propagation speeds. If these deviations fall within 10%, the measurement is considered valid. In both cases, the measurements exhibited statistical deviations exceeding 20% (maximum 26% and 22%), rendering the tomograph unreliable for small tree thicknesses. Consequently, it cannot be utilized for the qualitative analysis of individuals with trunk diameters less than 20 cm.

The reliability of the acoustic tomograph method may also be influenced, to a certain extent, by the software in which the algorithms for wave speed propagation in various wood types are programmed. However, apart from wood type, factors such as wood moisture content, seasonal and atmospheric conditions, wood origin, as well as wood varieties and subvarieties, can impact wave propagation speed. Current research also emphasizes the development of neural networks and mathematical algorithms aimed at enhancing tomograph results. The study by DU et al. (2024) affirmed that a well-selected mathematical algorithm can notably enhance tomograph results.

CONCLUSIONS

The assessment of the qualitative state of standing trees in forest stands using a tomograph revealed its limitations. The accuracy of identifying qualitative features for their classification into quality classes seems to be insufficient. Nevertheless, the tomograph was primarily developed for identifying trunk damage and assessing the risk of tree falls due to external mechanical influences.

Indeed, the inaccuracies in assessing the qualitative state of standing trees using an acoustic tomograph can be improved in several ways. Alongside clear methodological approaches to measurement, optimizing mathematical algorithms and training neural networks could also be key to increasing accuracy. In the future, assessing the qualitative state of trees in forest stands will likely become an even more important topic, potentially integrating this method into automation methods within precision forestry. Combining an acoustic tomograph with laser ground scanning and digital evidence, alongside the development of appropriate mathematical algorithms or trained neural networks, could lead to the creation of an automated system for assessing tree quality in forest stands. Such a system could enhance tree registration, improve harvesting planning, optimize marketing strategies, and facilitate more efficient trade in wood products. Integrating these technologies could create favorable conditions for leveraging modern information technologies to benefit forestry and promote the sustainable use of forest resources.

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TOWARDS A REFERENCE SPECTRUM FOR FAÇADE SOUND INSULATION: ON AVERAGE SPECTRA REPRESENTING TEMPORALLY VARYING SOUNDS

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Abstract

Excessive noise has an adverse outcome on the quality of life of humans. Sound insulation serves to reduce the exposure to environmental sounds intruding into living spaces. The performance of buildings and elements is described by single-number quantifiers, which, for façade sound insulation, weighs the frequency-dependent attenuation according to noise exposure at the façade in an averaged spectrum of road traffic noise. This paper presents a preliminary investigation in the evaluation of the perceptual relevance of average spectra to represent temporally varying sounds relevant to façade sound insulation. It evaluates if the overall loudness of a temporally varying sound corresponds to that of noise with the same average spectrum. This is done in a listening test where the participants adjust the level of noise to equal-loudness of the time-varying sound as the reference. Moreover, methodological aspects regarding the stimuli preparation and response collection method are also explored. The results indicate that the average spectrum of a temporally variable stimulus does not capture the loudness perception of the stimulus, although with stimuli-dependent deviations of less than 2 dB. Impacts of spectrum resolution and shape were negligible; however, the responses were greatly influenced by the direction of the adjustment.

Keywords: Façade sound insulation, Reference spectrum, Single number quantity, Subjective loudness, Listening test

Acknowledgements

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INTRODUCTION

In our daily life, the presence of excessive noise has an adverse outcome on the quality of life of humans (WHO, 2019). We spend the majority of our time indoors, where sound insulation serves to reduce the exposure to environmental sounds intruding into living spaces. To protect their populations from excessive noise exposure, many countries have imposed regulations regarding the sound-insulating performance of buildings. The measurements of sound insulation performance are described in the ISO 10140 series for laboratory measurements (ISO, 2021), and the ISO 16283 series for field measurements (ISO, 2014). The sound reduction index R in the 1/1 or 1/3rd octave band spectrum presents the frequency-dependent performance. Moreover, for easier comparison of building elements, this sound reduction index spectrum can be represented in single number quantities (SNQ) such as R_w, R_w+C and R_w+C_{tr} described in ISO 717-1 (ISO, 2020). While the R only describes the physical attenuation, the SNQs aim to achieve a rating that weighs the 1/3rd octave band values to the noise exposure and perceptual relevance.

Constructing an SNQ, therefore, has an inherently challenging aspect: an SNQ should describe the performance of stationary sound insulation regarding the perception of temporally varying sounds encountered in daily life. While several SNQs exist, R_w+C_{tr} is intended to evaluate facade sound insulation (ISO, 2020). It is calculated as the level difference of R with A-weighted road traffic noise spectrum and normalized to 0 dB. The spectrum for C_{tr} corresponds to the traffic noise spectrum from EN 1793-3:1997 and was derived as the average of road traffic noise spectra in Europe during the 1990s (Garai, 2000). The strategy in this descriptor is to represent the noise exposure at the façade in an averaged spectrum and consider the perceptual relevance through applying the A-weighting.

This study evaluates the perceptual relevance of average spectra to represent temporally varying sounds relevant to façade sound insulation. This paper presents a preliminary investigation of this study. It evaluates if the overall loudness of a temporally varying sound corresponds to that of noise with the same average spectrum. This is done in a listening test where the participants adjust the level of noise to equal-loudness of the time-varying sound as the reference. The noise is created using filters of different resolutions and shapes. The average noise spectrum is matched to that of the temporally varying stimulus in 1/1 octave bands, 1/3rd octave bands, or the FFT resolution, and the participants vary its overall level. Moreover, for the 1/1 and 1/3rd octave bands, the influence of the shape of the filter is explored through a flat spectrum within each band or interpolated between the centre frequencies. To investigate the relevance of the direction of adjustment, the participants had to adjust each noise two times: one starting from a loud stimulus towards a more silent one, and vice versa. The stimuli and response collection method are described in more detail in the section below. In the later paragraphs, the findings and conclusions are discussed.

METHODS

The responses were collected through a programmed interface. The noise signal started at the extremes of +/-10 dB and could be adjusted in steps of +/- 2dB. In total, 10 participants took part in this pre-experiment. The participants were a mix of students (no.: 3) and colleagues from the institute (no.: 7). The duration of the listening test ranged from 10 to 20 minutes. The stimuli were reproduced in a listening room with low reverberation and background noise by a two-loudspeaker setup with a reasonably flat frequency response above 50 Hz. The frequency content of the stimuli below 50 Hz was negligible, as the stimuli were filtered with a high-pass filter at this frequency. Before each listening test, the reproduction system was calibrated by adjusting the gain on the soundcard so that the level of pink noise matched its calculated value. The level was measured using a HEAD acoustics Squadriga II device and G.R.A.S. microphone. The pink noise was adjusted to 71 ± 1 dBA, which is representative of the levels of reference temporally varying stimuli.

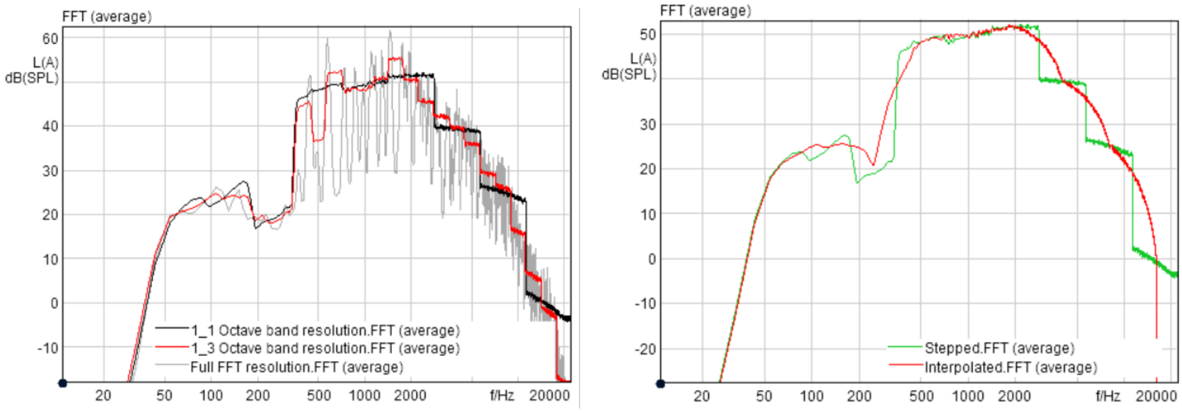

Figure 1. Comparison of filter resolution (left), and filter shape (right) for the ambulance stimulus.

Three different temporally varying stimuli were used as a reference: a pass-by of an ambulance and police vehicle where the tonal sirens were dominant, a hovering helicopter with dominant rough-sounding rotor noise, and lastly, two people having a heated argument in the street. The stimuli had different temporal structures and spectra. The comparison noises were created with the average spectra of the temporally varying signals in full octave bands, 1/3rd octave bands, or the FFT resolution, the three resolutions are compared in the figure in the left panel of Figure 1. Moreover, for the full and 1/3rd octave bands, the influence of the shape of the filter is explored through a flat spectrum within each band, resulting in a stepped shape, or interpolated between the centre frequencies, presented for the 1/1 octave band resolution in the right panel of Figure 1. In total, each participant performed 30 matchings.

RESULTS

The frequencies of the responses by the participants are presented in Figure 2, they are grouped per temporally varying reference stimulus. The responses are presented in terms of the level difference between the temporally varying stimulus and noise stimulus selected as equal in loudness. Each group includes the responses to noises based on different resolutions and shapes.

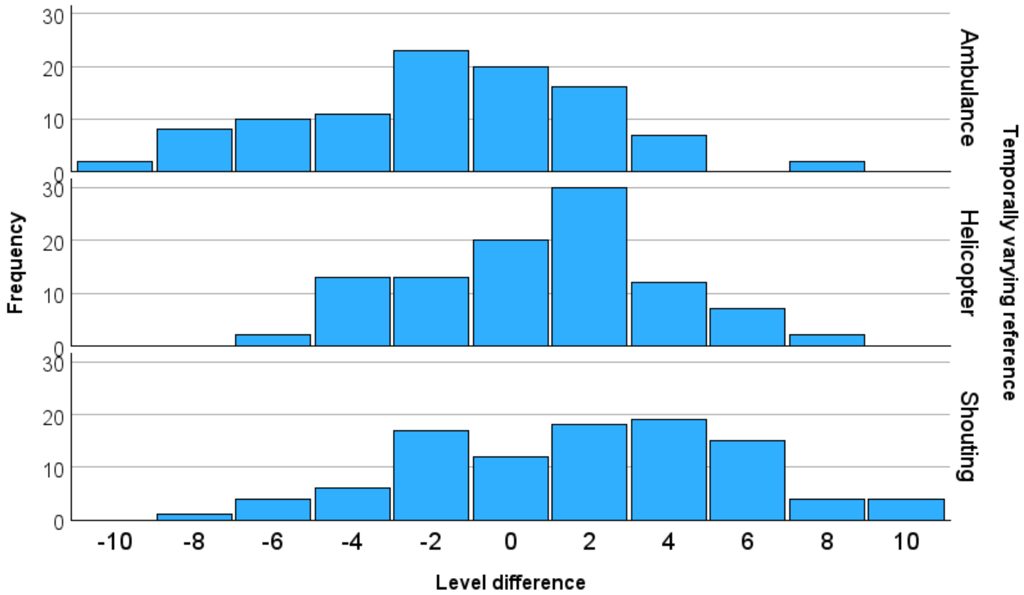

Figure 2. Frequencies of the responses grouped per temporally varying reference stimulus.

According to the research questions, the temporally varying reference stimulus, noise spectrum resolution, noise spectrum shape, and direction of adjustment were considered as potentially influencing factors. As the participants rated all comparisons, their responses are dependent and require a within-subject/repeated measures design. The remaining factors should be included as fixed factors. However, as the full FFT resolution did not have two types of filters, it is not a crossed design/factorial ANOVA. Therefore, the data was analysed in two separate repeated measures ANOVA models. For both models, the assumptions of normality and sphericity were met.

First, a model was built to investigate the influence of three factors: temporally varying reference stimulus, noise type, and direction. The comparisons with noises with different resolutions and shapes were included as separate levels of one combined ‘noise type’ factor, therefore their influence cannot be separated. The results indicate the significance of all three factors. The effects sizes indicate that the impact of the combined noise resolution and shape was only minor compared to the reference signal and direction effects. Interactions between the factors were not significant. Post-hoc tests revealed that the responses were significantly different among all the reference stimuli. Moreover, for the ambulance and shouting sounds, the mean of responses was significantly different from 0, indicating that the overall loudness perception of a temporally varying sound does not correspond to that of noise with the same average spectrum. However, these deviations and their direction depended on the reference stimulus: for the ambulance, helicopter and shouting, the average responses were -1.6; +0.8 and +1.8 dB respectively. The influence of the direction of adjustment was the largest among all effects, with an average 4.4 dB difference in the selected level.

To investigate the influence of the noise resolution and shape separately, another model was constructed. This was again a repeated-measures ANOVA, but now ‘four-way’. This time, the data of the full-spectrum comparisons was left out, therefore the remaining data was according to a crossed design. However, the influence of the full spectrum filter is not considered in this model. In this second model, sound source and direction were significant, as in the previous model. Concerning the filter bandwidth and type, only the bandwidth had a significant influence on the responses, while the filter shape did not. The impact of the resolution between 1/1 and 1/3rd octave bands was on average 0.4 dB, with a louder noise signal selected for the 1/3rd octave band noises.

CONCLUSIONS

The findings of this exploratory study with a small sample size (10) and a restricted number of stimuli (3) suggest that the average spectrum of a temporally variable stimulus does not capture the loudness perception of the stimulus. Nonetheless, the variations were stimulus-dependent and less than 2 dB. The effects of applying various average spectrum shapes and resolutions to the noise were investigated. There were only very slight variations in the responses to the average spectrum's resolution in the 1/1 and 1/3rd octave bands. Differences between these and the full FFT resolution were not yet analysed. No indication of the influence of the shape of the spectrum was found for the conditions evaluated in this experiment. Meanwhile, the responses were greatly influenced by the direction of the adjustment.

In the continuation of this experiment, more temporally varying stimuli and participants will be included to investigate the deviations in loudness perception in more detail. Moreover, to explore spectral contributions, temporally varying sounds will be spectrally modified to have the same average spectrum. This allows to study the influence of the temporal structure separately. Lastly, to ensure the relevance of the findings with regard to facade sound insulation, the experiment will be repeated with attenuated sounds.

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ACOUSTIC CHARACTERIZATION OF COFFEE GROUNDS AND COFFEE GROUNDS BASED MYCELIUM COMPOSITES

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Abstract

This research explores the acoustic properties of sustainable mycelium-bound coffee ground composites. Sound absorption measurements were conducted using an impedance tube within the 125–4000 Hz frequency range, while static airflow resistivity was measured according to ISO 9053. The tortuosity of the samples was estimated using the quarter wavelength rule. Results indicate that the high density of both loose coffee grounds and mycelium composites led to relatively low sound absorption. Peak absorption ranged from 0.60 to 0.75 at 1000 Hz. Airflow resistivity values for the coffee grounds and mycelium composites were 9.0 kNs/m^4 and 5.9 kNs/m^4, respectively, with the higher resistivity of the loose coffee grounds attributed to their greater density. The estimated tortuosity of the mycelium samples was 2.5. Despite the increased tortuosity, the high density and airflow resistivity resulted in lower than aspired acoustic absorption.

Keywords: Mycelium-based composites, sound absorption, coffee grounds, sustainable materials

Acknowledgements

This project has received funding from the European Union’s Horizon Europe research & innovation programme under the HORIZON-MSCA-2021-DN-01 grant agreement No. 101072598 – “ActaReBuild”.

INTRODUCTION

In recent years, the exploration of sustainable and renewable materials for acoustic applications has gotten significant attention (ASDRUBALI ET AL., 2012; COTTONE ET AL., 2023; GOMEZ ET AL., 2020; NAVACERRADA ET AL., 2021). Coffee grounds, a common byproduct of the coffee industry, present an opportunity due to their availability and small grain size (YUN ET AL., 2020). Previous research has dealt with coffee ground based composites. However, a comparison between the absorptive properties of loose coffee grounds and composites is lacking (YUN ET AL., 2020). Also, different bonding methods might have different effects on the properties of composites.

By incorporating mycelium, a fungal network, which is known for its binding capabilities, into coffee grounds, a novel composite material can be developed. Although mycelium-based composites have been tested, their acoustic properties beyond sound absorption or transmission loss have not been thoroughly characterized (GOMEZ ET AL., 2023). This research aims to evaluate the acoustic performance of mycelium-bound coffee grounds, focusing on their absorption characteristics.

METHODS

Coffee grounds were sourced from the coffee provider Pergamino, whose coffee beans are cultivated in Antioquia, Colombia at an altitude of 1750 meters above sea level (PERGAMINO, 2023). The grounds were finely ground to a particle size of 360-660 microns for the brewing process in a

Moka Pot (Honest Coffee Guide, 2023). After brewing, the spent coffee grounds were dried in a microwave at 500 W for 9 minutes to prevent the propagation of microorganisms during storage.

In order to reduce the risk of contamination by unwanted fungal strains, the substrate was sterilized in an autoclave at 120˚C and 100 kPa for one hour. After sterilization, the substrate was poured into a mold and mixed with mycelium grain spawn, which constituted 10% of the substrate's weight to ensure a homogeneous distribution for mycelial growth. The mixture was incubated at 27˚C for 15 days. Post incubation, the mold was removed, and the fungi were deactivated with heat treatment in a convection oven at 65˚C for 4 hours.

Three cylindrical samples with a diameter of 45 mm and 35 mm of thickness were extracted using a cutting tool for the impedance tube and flow resistivity test rigs. Sound absorption measurements were conducted following the transfer function method within the 125–4000 Hz range for both loose coffee grounds and mycelium based composites. Additionally, the static airflow resistivity was measured following the ISO 9053 procedure.

FINDINGS AND ARGUMENT

The resulting samples are show in Figure 1, the density of the samples was 419±44 kg/m^3 while the density of the tested loose coffee grounds were 489±50 kg/m^3.

Figure 1. Mycelium composite and extracted samples for sound absorption and flow resistivity tests 45 mm diameter samples.

Figure 2 shows the sound absorption coefficient in octave bands for both the mycelium composite samples and the loose coffee grounds. The mycelium composites exhibited a peak absorption between 0.60 and 0.75 around 1000±200 Hz, which then rapidly decreased. In contrast, the native loose coffee grounds demonstrated a porous absorber behavior, with absorption increasing with frequency and a value of about 0.7 at 4000 Hz. The relatively low absorption of both the loose coffee grounds and the mycelium composites can be attributed to their high density. On one hand, the loose coffee grounds results are similar to those presented by Yun et al. (2020) for thermally bonded finely ground coffee composites which also have a similar density, On the other hand, the mycelium bound coffee grounds show a higher absorption around 500 and 1000 Hz, for the particle size, however, based on (Yun et al., 2020) results, larger grain size leads to better absorption, within the boundaries of their experiments.

The measured flow resistivity for the coffee grounds was 9.0±0.3 kNs/m^4, in contrast the mycelium composites had an average flow resistivity of 5.9±0.3 kNs/m^4, in both cases the high flow resistivity values could be explained by the high density of the samples.

Given the known fact that absorption of a layer in front of a rigid backing shows amaximum when the layer thickness *d* is about one quarter of the acoustic wavelength, a simple estimation of the mycelium samples tortuosity can be made, from the first absorption peak. Taking the thickness of the samples of 35 mm, the results can be verified according to the quarter wavelength resonance principle ($f_{peak}=c/(4*d)$) and the relation between speed of sound and wavelength (λ = f/c).

The estimated speed of sound in the porous media is 140 m/s, then the estimated tortuosity is 2.45±0.49.

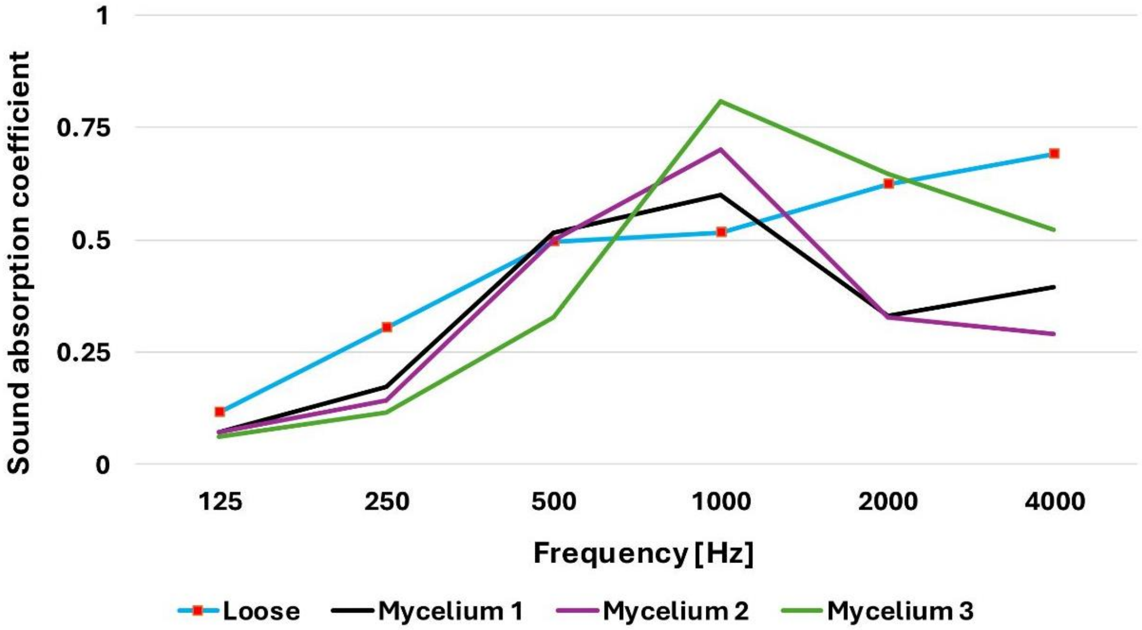

Figure 2. Sound absorption coefficient of coffee grounds and coffee ground based mycelium composites.

CONCLUSIONS

Coffee ground based mycelium absorbers were made and their main acoustic properties for acoustic absorption were tested, the mycelium growth seemed to have increased the samples tortuosity. However, given the small grain size, the density and airflow resistivity are larger than those of materials used in acoustic absorption applications.

Based on previous research, a larger coffee ground grind size would be beneficial for sound absorption. In the current study, the finely grounded aspect of the substrate deteriorated the acoustic absorption performance of the coffee ground mycelium composites.

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DIAĽKOVÉ OVLÁDANIE AKUSTICKÝCH MERANÍ POMOCOU MOBILNEJ APLIKÁCIE

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Abstract

Ručné zvukomery B&K 2245 a HBK 2255 umožňujú diaľkovo ovládať prístroj zo smartfónu. Mobilná aplikácia Building Acoustics Partner spolu s integrovanou bezdrôtovou sieťou vo zvukomere a výkonovom zosilňovači poskytuje úplné diaľkové ovládanie stavebno-akustických meraní.

Keywords: Zvukomer, akustika budov, mobilná aplikácia

ÚVOD

Zvukomery a analyzátory Brüel & Kjær sú prístroje na meranie zvuku triedy 1 s výnimočnou jednoduchosťou ovládania a flexibilitou. Najnovšiu generáciu prístrojov na meranie zvuku Brüel & Kjær možno priamo ovládať pomocou smartfónu. Prístroje je možné nastaviť a prispôsobiť pre širokú škálu meraní, pokročilých analýz a tvorbu správ pomocou špecializovaných aplikácií a softvéru na následné spracovanie.

ZVUKOMERY A ANALYZÁTORY ZVUKU

Zvukomery B&K 2245 a HBK 2255 spolu s osobitne vytvorenými mobilnými aplikáciami vytvárajú riešenia požadovaných úloh šité na mieru, s úplne novou úrovňou efektivity a riadenia procesu merania. Presné meranie hluku, analýza a tvorba správ sa výrazne zjednodušili.

Obrázok 1. Zvukomer B&K 2245.

Aplikácia Exhaust Noise Partner slúži na meranie hlučnosti výfukov áut, základná aplikácia Noise Partner na meranie celkových hladín hluku, aplikácia Work Noise Partner na meranie hluku v pracovnom prostredí, aplikácia Enviro Noise Partner na meranie hluku v životnom prostredí, aplikácia Product Noise Partner na meranie hlučnosti výrobkov a akustický výkon a aplikácia Building Acoustics Partner na akustiku budov.

BUILDING ACOUSTICS PARTNER

Zvukomer HBK 2255 je výkonný a pokročilý zvukomer určený na zložitejšie a komplexnejšie meracie úlohy. Prístroj možno použiť buď ako samostatné meracie zariadenie, alebo s aplikáciami pre mobilné telefóny a PC, a ponúka aj otvorené rozhranie pre integráciu do externých užívateľských systémov. S licenciou Building Acoustics Partner zmeria všetko, čo je potrebné na meranie nepriezvučnosti a zvukovej izolácie, od merania hladiny zvuku v 1/1- alebo 1/3-oktávových pásmach až po meranie času dozvuku použitím prerušovaných alebo impulzných signálov zvuku.

Hladiny zvuku zdroja (L1) a hladiny zvuku v prijímacej miestnosti (L2) je možné súčasne merať pripojením dvoch zvukomerov HBK 2255 k aplikácii. Týmto sa šetrí čas a zvýši sa efektivita merania.

MOBILNÁ APLIKÁCIA

Bezdrôtové prepojenie mobilnej aplikácie Building Acoustics Partner s integrovanou bezdrôtovou sieťou vo zvukomere HBK 2255 a vo výkonovom zosilňovači HBK 2755 poskytuje úplné diaľkové ovládanie akustických meraní a plnú podporu meracieho procesu.

Obrázok 2. Mobilná aplikácia Building Acoustics Partner poskytuje bezdrôtové diaľkové ovládanie.

ZÁVER

Mobilná aplikácia Building Acoustics Partner prináša novú úroveň efektivity a kontroly do meraní zvukovej izolácie. Plánovanie merania a automatizácia meracieho procesu v mobilnej aplikácii pomáhajú zaistiť, aby ste nevynechali meraciu pozíciu. Opätovné použitie vykonaného merania minimalizuje celkový počet potrebných meraní. Mobilná aplikácia vypočítava výsledky automaticky. Výsledky sú k dispozícii okamžite. Indikátory kvality včas identifikujú problémy. Diskutabilné merania je možné podrobne kontrolovať a odchýlky je možné skúmať priamo na mieste a v prípade potreby ihneď zopakovať meranie.

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SOUND LINEAR VARIETY OF NORMED PRINCIPAL MENSURE

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Abstract

There is introduced a 12-TET system based on the whole Fourier tone decomposition sequence and Normal Principal stop. Further, it is introduced a couple of l-groups with respect to (⊕; <<) (in music: a transposition of tones and linear ordering, respectively) and with respect to (⊗; <) (in music: an operation derived from the cycle of tempered fifths and the tempered fifths ordering, respectively). Additionally, we equip such algebra with a mixed operation multiplication of vectors and real scalars (in music: loudness of tones, for pipe organs this operation is possible in the case of dynamic keyboard) and we ask to have the same timbre for all tones. Such an enriched 12-TET is called the Generalized 12-TET. We show that such this introduced synergetic vector object Generalized 12-TET can be isomorphically studied from many mathematical sides: as a homomorphism of cyclic algebras of generalized Gaussian complex numbers over R; arithmetic of the duodecimal (= dozenal) position number system; the linear and cyclic ordered vector algebras of generalized complex numbers over R; as scalar product structures; Hilbert space structures; subalgebras that have invertible elements, etc. The existence of invertible elements can serve as tangible output on which be founded a innovative restoration practise of historical organ instruments: each tone has various physical properties because of material pipe damages, like the corrosion, putrefaction, worms activity, etc. This causes an audible transversal additional sound which we can be measured via detectable ruled existence of zero divisor of sound of damaged pipes.

Keywords: Fourier tone, organ pipe, 12-TET

Acknowledgements

The paper was supported with the Grants VEGA 2/0106/19 (Wooden pipe configuration of historic organ positives in Slovakia) and (2) VEGA 2/0134/23 (Influence of materials on acoustic properties of historical single-manual pipe organs in Slovakia). (3) The author is cordially grateful to late Professor Nikolaj Vasilevskij, who pointed him out about the existence of twins of great king pipe organs in the Mexican City Cathedral during his mathematical study visit in CINVESTAV, Mexico.

INTRODUCTION

A method of restoring demaged organ pipes based on zero divisors of the generalized complex numbers. More information in the author's book – Figure 1.

Contents

55 references (Operations, orders, subalgebras; Octave equivalence; Affine spaces; Organ building and miscelaneous), 2 figures, 13 tables, 24 theorems, 12 examples

Figure 1. Contents of the author's book.

MOTIVATION FOR STEAM EDUCATION FROM PRIMARY TO TERTIARY

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Abstract

One of the ways we can motivate young people is by implementing Children's Universities as a form of motivating young people for future studies in science and technology. Young people expect a wide use of information and communication technologies in education. They are eager to work actively and implement their own ideas. Children up to the age of 10 undoubtedly have a real but hidden interest in natural and technical sciences, they want to become scientists and explorers. However, after a few years of education at the primary level, the situation changes completely. Simple acoustic experiments included in the teaching from the lowest levels of the education system stimulate children from early childhood to explore and lead from initial play to subsequent experimentation and discovery of new knowledge. Initial playful experimentation that involves multiple child senses (hearing, sight, and touch) stimulates experimentation at the time of primary education and later at the time of secondary and tertiary education in technical universities motivates analysis and evaluation at higher levels of cognitive goals according to Bloom's taxonomy.

Keywords: STEAM education, motivation to study, acoustic experiments

Acknowledgments

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INTRODUCTION

The project of the Children's University of Zilina (CHUZ), which is organized annually during the summer holidays at the University of Zilina (UNIZA) is intended for children attending primary school. This project is aimed at solving the current problem - the insufficient level of manual skills and intellectual abilities of students coming to study at universities of technical orientation. To address this issue, we want to motivate primary school pupils to study natural and technical sciences by experimenting in a university environment, and later offer technical lectures to secondary school students and allow them to experiment in laboratories. Through these activities, we want to help students coming to university overcome the misconceptions with which they come to study STEAM (Science - Technology - Engineering – Art and Mathematics) subjects at university.

METHODS

Acoustic experiments are a suitable tool that can be used from the early years of primary school to develop science literacy, which is seen as one of the key competencies in the PISA study. Even at a young school age, it is possible to attract children to science and technology by explaining to them, at their level of knowledge, the working principles of the apparatus they encounter. This gives children the opportunity to become scientists, if only for a little while so that they can experiment, discover, and investigate the devices and phenomena on which machines operate today. At the same time, by experimenting, they improve their manual skills and develop their intellectual abilities.

The simple acoustic experiments implemented at CHUZ (Figure 1) can be suitably incorporated into the teaching process at primary school as demonstration experiments that familiarize students with basic natural principles at the knowledge level according to Bloom's taxonomy of cognitive objectives (Hockicko, 2010).

Figure 1. Interactive acoustic experiments - Chladni Plates on exercise: Sound and ultrasound.

In the upper grades of elementary school and later in engineering universities, these experiments can be used to prepare problem tasks, either with a well-defined problem or an incompletely defined problem. In this case, the problems will be solved at the higher levels of Bloom's taxonomy of cognitive objectives - analysis, synthesis, or evaluation.

For those who would like to see and try experimenting at home, we have prepared a set of experiments in collaboration with international partners and universities, which can be accessed on our YouTube channel: https://www.youtube.com/@films4edu607/videos. A video can be found on that channel: Chladni Plates | ACOUSTICS: https://youtu.be/dpVulKVPf8U (Figure 2).

For primary and secondary school teachers we have prepared scripts on USB (Hockicko et al, 2023), on which, in addition to the aforementioned videos prepared at UNIZA, they will also find scenarios, descriptions, and explanations of the principles and laws of physics for individual experiments.

FINDINGS AND ARGUMENT

As shown by questionnaires completed by children after attending CHUZ summer activities over 17 years (Figures 3 and 4) (in 2020 and 2021 only the online CHUZ model was implemented due to COVID-19), children attending primary schools would like to see more playful teaching, more hands-on demonstrations and experiments presented, and more work on experiments in laboratories with pupils' own activity (Hockicko et al, 2020).

Children like classes in which they can realize their own ideas and work actively and creatively.

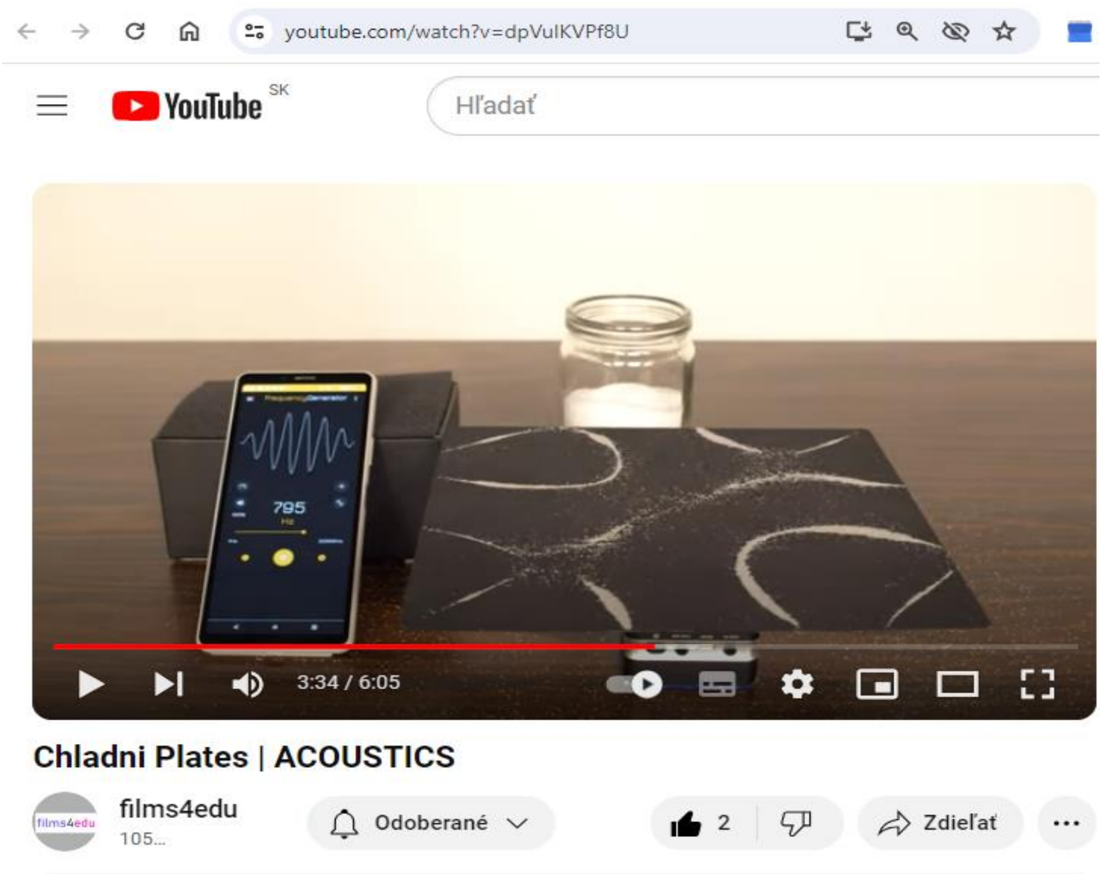

Figure 2. Chladni Plates - a video accessible via YouTube created within the Films4edu project.

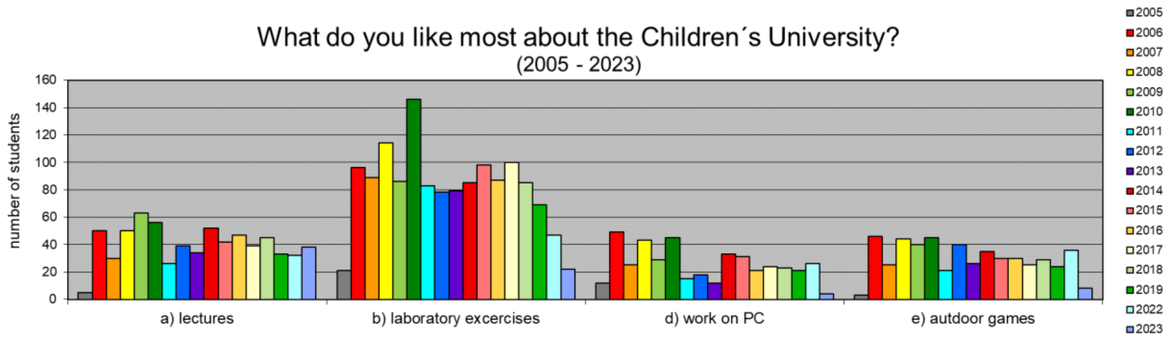

Figure 3. Some of the results from questionnaires in CHUZ.

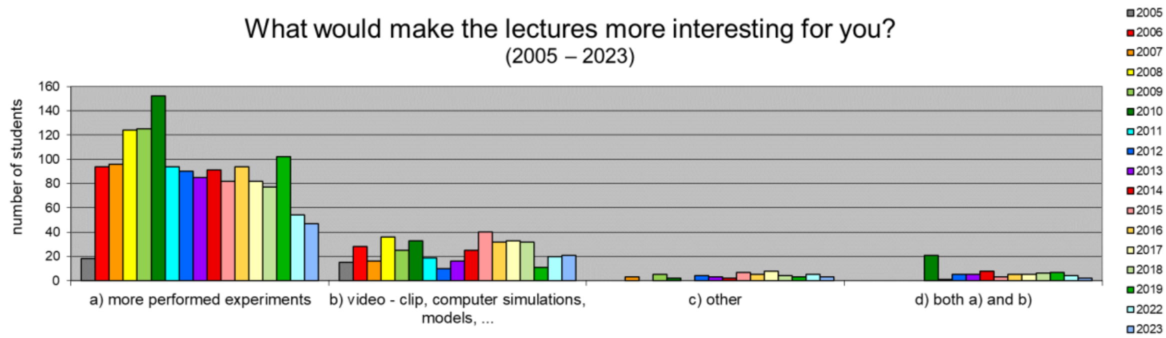

Figure 4. Some of the results from questionnaires in CHUZ.

CONCLUSIONS

One of the ways we can motivate young people is by implementing Children's Universities as a form of motivating young people for future studies in science and technology. Young people expect to make extensive use of information and communication technologies in education. They are willing to work actively and implement their own ideas. Children under 10 undoubtedly have a real but hidden interest in natural and technical sciences, they want to become scientists and explorers. However, after a few years of education at the primary level, the situation changes completely.

Simple acoustic experiments included in the teaching from the lowest levels of the education system stimulate children from early childhood to explore and lead from initial play to subsequent experimentation and discovery of new knowledge. Initial playful experimentation that involves multiple child senses (hearing, sight, and touch) stimulates experimentation at the time of primary education, and later at the time of secondary and tertiary education in technical universities motivates analysis and evaluation at higher levels of cognitive goals according to Bloom's taxonomy.

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COMPARISON OF ACOUSTIC PARAMETERS OF DIFFERENT SHAPES OF WOODEN LOUDSPEAKER ENCLOSURES

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Abstract

This paper deals with the comparison of the "design" shape loudspeaker enclosure with the usually used block baffle of the same internal volume. Both enclosures were made of maple wood. Acoustic filling was also installed in both baffles, if it could improve the acoustic properties. Both speaker systems were subsequently tested in an anechoic room using the "sine sweep" method to compare their resonance and impedance characteristics.

Keywords: Loudspeaker enclosure, impedance characteristics, resonance characteristics, acer

Acknowledgements

We would like to thank the Internal Grant Agency (IGA) of the Faculty of Forestry and Wood of the Czech University of Life Sciences, Prague, Czech Republic, for the support of the project "Optimalization of parameters of wood-based loudspeaker enclosures".

INTRODUCTION

When discussing speaker cabinets or baffles, it is essential to consider the significant presence of wood and wood-based materials in the industry. Agglomerated materials are frequently utilized due to their homogeneous properties; however, the unique qualities of solid wood should not be overlooked (Čulík, 2013). Solid wood stands out not only for its distinctive appearance but also for its purely natural character, which holds particular importance in modern times.

The sound performance of loudspeakers can be heavily influenced by the design of the enclosures, including factors such as the chosen shape and the material used, along with its inherent properties. While loudspeakers of conventional shapes crafted from commonly used materials are prevalent, they may not always yield the optimal effects on sound output. This study aims to address this crucial aspect by examining how different design elements impact the audio performance of loudspeakers.

METHODS

In this study, we employed the retuned harmonic signal method, commonly referred to as "retuned sine" or "Sine Sweep," utilizing the Room EQ Wizard (REW) software for room acoustics and audio analysis (Anderson, 2022). This technique was implemented to accurately measure the loudspeaker's impulse response. The methodology involves exciting the system with a harmonic signal whose frequency increases over time in an exponential manner, specific to our case. The system's response to this signal is recorded, enabling the extraction of the impulse response through subsequent processing. This can be achieved either by filtering the recorded signal with an inverse filter or by performing division in the spectral domain, though the latter method does have certain limitations (Farina, 2007).

One of the significant advantages of using the retuned harmonic signal method is its ability to separate harmonic distortions from the primary response, thereby providing a clearer and more accurate measurement of the loudspeaker's performance. For this study, the measurements were conducted at a high sampling frequency of 192 kHz with a 16-bit depth, ensuring a detailed capture of the audio signal. The duration of the sine sweep was set to 512,000 samples, equivalent to 2.7 seconds (Toft, 2024). This duration was deliberately chosen to be longer than the room's reverberation time to avoid any adverse effects on the measurement accuracy. To ensure reliability, each measurement was repeated four times.

The timing reference for the measurements was maintained using the feedback connection of the sound card, ensuring precise synchronization. The loudspeaker system was strategically positioned at a height of approximately 1.5 meters. The microphone, essential for capturing the audio response, was placed at a distance of 0.5 meters from the loudspeaker, as illustrated in Figure 1. This setup was designed to optimize the accuracy and reliability of the measurements, thereby facilitating a comprehensive analysis of the loudspeaker's impulse response.

Figure 1. Measurement of loudspeaker system (Photo Jan Kozel).

FINDINGS AND ARGUMENT

As the differences between the wood species were not so significant during the production of speaker enclosures, the following figure 2 shows a comparison of both shapes of the maple enclosure. In this case, without internal filling (KOZEL, 2021).

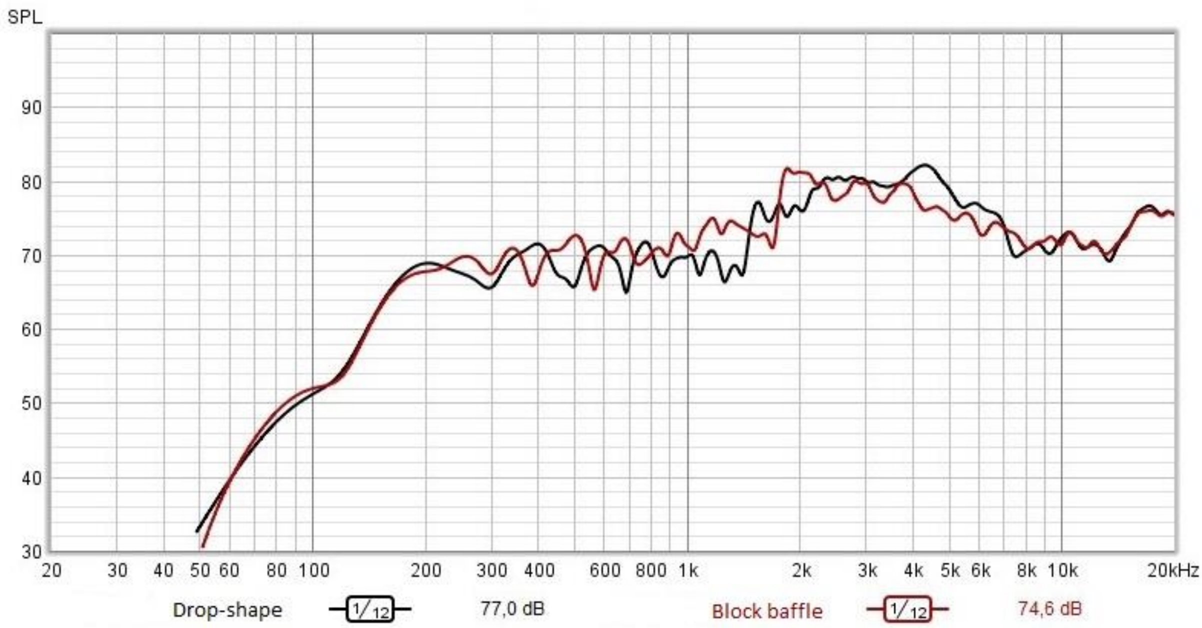

Figure 2. Comparison of frequency characteristics of loudspeaker enclosures.

In Figure 2, the differences between the curves are distinctly visible, particularly from frequencies above approximately 400 Hz. Significant deviations occur between 1 and 2 kHz, where the teardrop-shaped enclosure exhibits a greater drop in sound pressure level, about 6 dB lower than that of the cuboidal enclosure. Additionally, a deviation occurs around 200 Hz higher in the cuboidal enclosure compared to the teardrop shape. Notably, a pronounced peak is observed in the teardrop shape between 4 and 5 kHz, where the curve rises by approximately 4 dB compared to the cuboidal enclosure. Thus, it can be concluded that a block-shaped enclosure without damping exhibits a slightly smoother and more balanced frequency response compared to a teardrop-shaped enclosure.

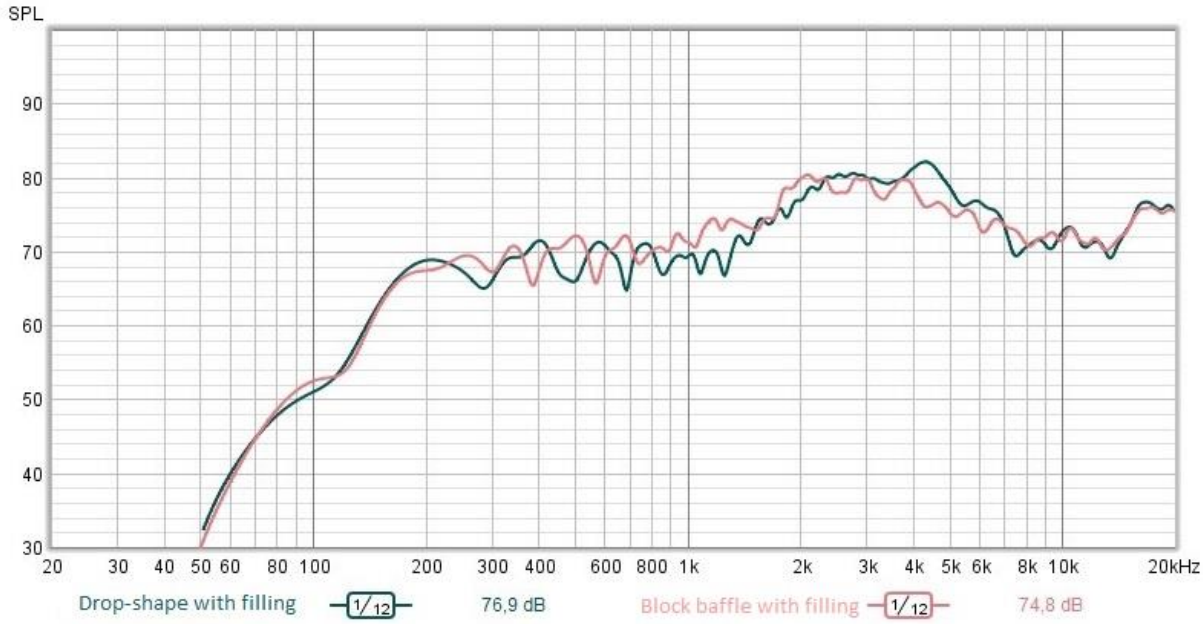

Figure 3. Comparison of frequency characteristics of loudspeaker enclosures with filling.

By damping the baffles, both curves straightened out and the more prominent dips softened, as illustrated in Figure 3. Although there remains a noticeable deviation between the baffles in the previously described frequency ranges, these deviations are less pronounced after damping. The peak between 4 and 5 kHz remains unchanged, which is likely due to the diffraction effect caused by the front edge of the teardrop-shaped enclosure (Gu et al., 2021; D'Appolito, 2016). Despite the damping, the block-shaped enclosure continues to exhibit a smoother frequency response. It is important to note that the differences between the two enclosures are not highly significant, and neither response curve exhibits substantial dips, indicating an overall improvement in the frequency characteristics for both shapes (Newell et al., 2007).

CONCLUSIONS

During the assessment of loudspeaker frequency characteristics, discernible disparities were noted between cuboid-shaped and teardrop-shaped enclosures. Notably, the cuboid-shaped enclosure exhibited a more uniform and balanced frequency response in comparison to its teardrop-shaped counterpart. These findings underscore the significant influence of both external and internal enclosure geometries on sound propagation (Olson, 1969). However, it is essential to contextualize that while discernable, the magnitude of this influence may vary depending on specific design parameters and environmental factors.

Furthermore, the beneficial impact of integrating damping materials into the baffle structure was unequivocally demonstrated. This augmentation effectively attenuated baffle resonance, leading to a smoother and more refined output response, which also reported in their publications Newell and Holland (2018), Walker (1953), Bauer (1953).

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BINAURAL HEARING AND SPEECH INTELLIGIBILITY

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Abstract

Binaural hearing is essential for speech intelligibility, mainly when dealing with separate signal and noise sources in different locations. This study explores how binaural factors affect speech intelligibility in various signal and noise spatial setups in both anechoic and reverberant environments. It focuses on three specific configurations and involves listening tests in the Slovak language using two types of noise. The study found that Slovak speech material (SLPS) is easier to understand in an anechoic environment than in a reverberant environment, especially with background noise. It also confirmed that it is more challenging to understand speech when multiple people are talking (MT noise) than speech-weighted noise (SW noise). Additionally, the study revealed that separating the sound and noise sources by a 90-degree angle improves speech intelligibility in anechoic environments but has minimal effect in reverberant environments.

Keywords: Speech intelligibility, binaural hearing, anechoic room, reverberant room

Acknowledgments

We gratefully acknowledge the financial support provided by the SAIA grant through the National Scholarship Programme of the Slovak Republic, as well as the Slovak national grants VEGA 1/0205/22 and KEGA 033STU-4/2024, which made the publication of this paper possible. Additionally, we extend our heartfelt thanks to all the test participants who volunteered their time for the listening tests.

INTRODUCTION

Understanding speech is difficult in environments with multiple sound sources. Previous studies have shown that spatial separation significantly impacts speech intelligibility. Binaural listening improves speech intelligibility compared to monaural conditions, especially in specific spatial separations with higher or lower signal-to-noise ratios (HAWLEY ET AL.,1999). Accurate binaural cues (such as interaural time and level differences) improved word recognition, especially in uncertain target locations (Singh et al., 2008). The spatial separation between the target and noise sources improved the speech reception threshold due to spatial release from masking and the binaural squelch effect (RYCHTÁRIKOVÁ ET AL., 2011).

In summary, spatial separation between the signal of interest and background noise is crucial for optimal speech comprehension in complex environments. Access to comprehensive binaural cues helps in precise source localization, making it easier to focus on the target amid unwanted distractions.

This paper explores speech intelligibility in challenging auditory conditions (anechoic room and reverberant room) using Slovak sentences (HÚDOKOVÁ ET AL., 2024) and two types of masking noise:

stationary speech-weighted noise (SW) and time-varying multi-talker noise (MT). Three different signal and noise configurations were investigated.

METHODS

The binaural room impulse response (BRIR) for a virtual reverberant room was created using the Odeon software, which combines the image source method and early-scattered rays for initial sound reflections, along with a modified ray-tracing algorithm. When binaural sound is needed, the room impulse response (RIR) is combined with a head-related transfer function (HRTF) to produce a BRIR. This captures the characteristics of each arriving ray, which is then convolved with corresponding HRTFs for the left and right ears, considering the angular orientation of the rays relative to the listener's head.
The listening test was administered using an adaptive procedure. The intensity level varied in steps of 2 dB adaptively in a one-down, one-up procedure to target the 50% intercept (Plomp & Mimpen, 1979). The speech reception threshold (SRT) was determined from the last six levels reached during the procedure.
This research studied speech intelligibility in noisy environments using two different acoustic scenarios: free field and diffuse field. Both scenarios were simulated as 3D acoustic models in Odeon software. The virtual reverberant chamber (diffuse field) was modeled to have the same properties as an existing chamber at the Laboratory of Acoustics, KU Leuven, with a volume of 197 m^3 and a total interior surface area of 202 m^2. The virtual anechoic chamber (free field) was simulated as a room in Odeon with a 100% absorption coefficient set for all interior surfaces. Within these two acoustic scenarios, three specific configurations of signal (S) and noise (N) were chosen, as outlined in the paper of Rychtarikova et al. (2011). In all configurations, the signal came from the front, and the noise source was placed in three positions: front (0°), on the right side (90°), and from the back (180°), always at a distance of 1 meter, as illustrated in Figure 1.

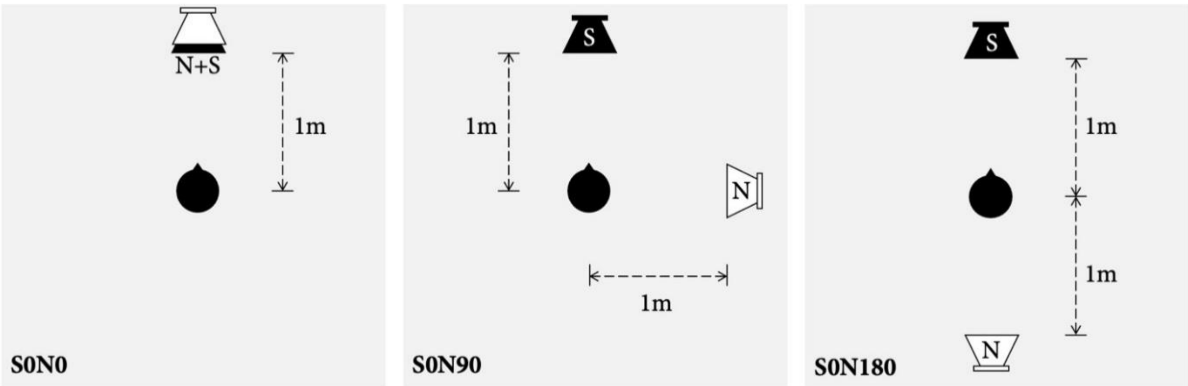

Figure 1. Listening configurations of signal (S) and noise (N)
(*Húdoková et al., (2024) Study of speech intelligibility in anechoic and reverberant environments using Slovak language, Internoise 2024, Nantes, France*).

Fourteen participants with normal hearing (audiometric thresholds below 20 dB HL from 125 Hz to 8000 Hz) participated, including seven females and seven males aged 18-26, took part in the study. All of them completed 12 listening tests.
The listening tests used the Slovak Semantically Predictable Sentences (SLPS), recorded by a female speaker, as the source material (Húdoková et al., 2024). Two different types of masking noise were used: speech-weighted noise (SW) and multi-talker noise (MT).
The listening tests took place in a semi-anechoic chamber at the Faculty of Civil Engineering, Slovak University of Technology in Bratislava. The chamber's background noise level was measured as $L_{A,eq}$ = 17 dB (Zelem et al., 2022). A computer with the APEX application (Francart et al., 2008) played back the sentence material at 60 dB, interfering with noise during the testing.
During the listening test, the operator played the sentences and masking noises to participants via open-back headphones connected to the sound card and computer using the APEX application. The participant then repeated the sentence, and the operator assessed and recorded the result in the APEX test application.

RESULTS

The repeated ANOVA measures were used for data analysis using the SPSS software. Overall, the results indicate that the speech reception thresholds (SRTs) in the anechoic room are significantly lower for both masking noise sounds (speech-weighted noise and multi-talker noise) and all configurations (S0N0; S0N90; S0N180) compared to a reverberant room [F(1, 13) = 158.25; p=0.000].
When comparing the results for the two different masking noise sounds, it is evident that higher SRT values are reached with multi-talker masking noise [F(1, 13) = 22.692; p=0.000)]. Regarding the three configurations, in an anechoic environment, it is notable that when the sound source is in the front, and the noise is coming from the side (S0N90), the SRT results are significantly lower [F(2, 12) = 30.017; p=0.000] compared to the other two configurations (S0N0 and S0N180). In a reverberant environment, the results between the configurations are not significantly different [F(2, 12) = 2.017, p = 0.176].

Table 1. SRTs and their standard deviations in the anechoic room within the SW and MT noise in the three different listening configurations.
(*Húdoková et al., (2024) Study of speech intelligibility in anechoic and reverberant environments using Slovak language, Internoise 2024, Nantes, France*).

	A-SW S0N0	A-MT S0N0	A-SW S0N90	A-MT S0N90	A-SW S0N180	A-MT S0N180
SRT (dB)	-5.33	-3.24	-11.74	-11.12	-6.55	-4.93
SD (dB)	±1.0	±1.5	±1.0	±1.3	±1.0	±0.7

Table 2. SRTs and their standard deviations in the reverberant room within the SW and MT noise in the three different listening configurations.
(*Húdoková et al., (2024) Study of speech intelligibility in anechoic and reverberant environments using Slovak language, Internoise 2024, Nantes, France*).

	R-SW S0N0	R-MT S0N0	R-SW S0N90	R-MT S0N90	R-SW S0N180	R-MT S0N180
SRT (dB)	-1.98	0.93	-1.73	-0.50	-2.19	0.43
SD (dB)	±1.0	±1.3	±0.6	±1.3	±0.8	±1.0

CONCLUSIONS

This study showed that Slovak speech material is more intelligible in anechoic environments than reverberant ones, especially with background noise (SW and MT). Separating sound and noise sources within by a 90-degree angle enhances speech intelligibility in anechoic settings but has minimal effect in reverberant environments.
Our research found that understanding speech is more challenging when multiple people talk (MT noise) than speech-weighted background noise (SW noise). These results only apply to our experiment, where the source and receiver were 1 meter apart. Further evaluation is needed to check the influence of the source and receiver distance.

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ANALYSIS OF VIBRATION AND NOISE OF HIGH-SPEED HEADSTOCKS DURING SPINNING

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Abstract

The article deals with the effective design of vibro-diagnostics of sources caused by self-excited vibrations of a high-speed spinning headstock bearing generated by residual unbalance, the quality of production and assembly of high-speed spinning headstock components. It also analyses the dynamic load from external vibration sources, primarily from the guide and pressure pulleys of the drive belt, as well as the effect of the Eigen frequencies of the Eigen modes of the test equipment. The article suggests the possibilities of analysing the dynamic load of high-speed headstock bearings using diagnostic sensors and it also indicates the calculation of the sound power level from the vibration velocity of the high-speed spinning headstock and/or another analysed component. The aim of this article is therefore to contribute to the reduction of energetic, dynamic (vibration and noise) and economic demands in the production of textile yarn by improving the performance properties of high-speed bearings of spinning headstocks, which form/represent an essential part of spinning technology.

Keywords: high-speed spinning headstock, diagnostic sensor, vibration and noise reduction, methodology

Acknowledgements

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INTRODUCTION

Dynamic loading has a significant effect on the lifetime of the high-speed spinning headstock bearings as well as on increasing the noise in the working environment, which negatively affects the health and life of employees. The operability and lifetime of high-speed spinning headstocks is increased if their dynamic load is reduced, either from their primary source of vibration and/or from external sources such as the belt drive, guide, idler pulleys and natural frequency of the test equipment. For high-speed spinning headstocks, the primary sources of vibration are the degree of balance of the bowl, since the centrifugal force generated from the imbalance with the given mass and geometric parameters is proportional to the square of the angular velocity of the rotor of the high-speed spinning unit (Šooš, 2020). Diagnostic sensors also analyse the influence of the natural frequencies of the test equipment components and using the values measured by the sensor, it is possible to calculate the sound power level of the high-speed spinning unit) and also enable the calculation of the sound power level of the spinning unit (Žiaran at al., 2023 and STN CEN ISO/TS 7849-1).

By reducing the dynamic load of the high-speed spinning unit bearings, with respect to the surrounding environment and people, the emissions of noise and mechanical vibrations will be reduced, i.e. the working environment will be improved and the maintenance-free lifetime will increase, which was also the goal of the research. The previous research employing dynamic analysis confirms that minimizing dynamic forces may be achieved by a vibro-acoustic diagnosis based on creation of diagnostic models and designing diagnostic systems for determining the quality of production of high-speed spinning unit headstocks, or methods and techniques of monitoring, determining their operational status and measures to reduce vibration and noise (Chlebo at al. 2019).

Compared to other diagnostic methods, vibro-diagnostics makes it possible to determine not only structural defects or faults, but also their causes, namely ovality, excessive clearance, fault to bearing elements, insufficient and unprofessional technological assembly, insufficient balance, wear, insufficient lubrication. In this case, the analysis of the vibration of high-speed spinning headstocks is focused on the primary reduction of dynamic load, that is, on detecting the causes of increased dynamic load on the bearing of high-speed spinning headstocks with the use of diagnostic sensors in order to increase their lifetime and reliability without the necessary maintenance and re-lubrication during their operational lifetime. On the basis of performed long-term frequency analysis and the processed trend characteristics with the use of diagnostic sensors, effective measures for increasing the lifetime of high-speed spinning units were proposed to the manufacturer and the operator. On the other hand, the user can take advantage of trend characteristics for the appropriate selection of lubricants which extend the maintenance interval and the bearing lifetime of high-speed spinning headstocks.

SUBJECT AND METHODOLOGY OF VIBRATION MEASUREMENT

Frequency analysis: The content of the article also includes the processing of measurement methodology and criteria for evaluating the vibration of manufactured and operated bearings. A temperature sensor was used to measure the temperature and a special accelerometer B&K 4518 was used to measure the vibration acceleration. Both sensors were attached to the outer ring of the headstock bearing as is shown in Figure 2(a). The accelerometer was screwed into the locking screw of the bearing and the thermocouple was glued to the metal part of the outer ring of the bearing. The measurement was performed at a set rotational frequency of 85 000 r/min, 100 000 r/min and 130 000 r/min. However, due to belt slippage, the actual rotational frequency was lower than the set frequency. The methodology presented in the article can also be used to measure other rotating components as vibration sources, especially components with low mass.

From the measured time history, a frequency spectrum was processed to identify the exact rotational frequency, which was 75 600 r/min at the set rotational frequency of 85 000 r/min. Based on the rotational frequency, the characteristic frequencies belonging to the individual components of the bearing were calculated and subsequently, they were identified as is shown in Figure 1.

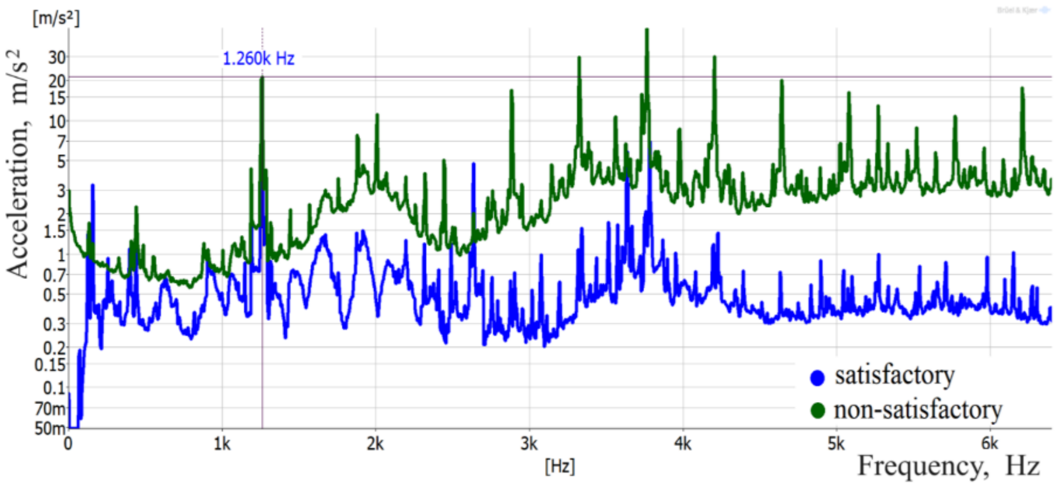
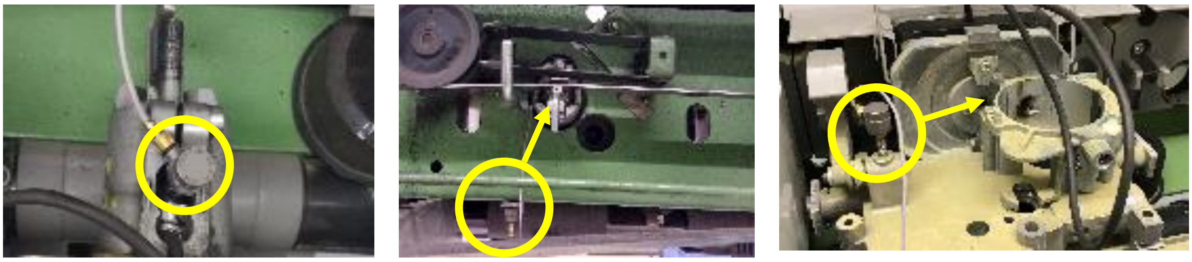


Figure 1. The bearing frequency spectrum of satisfactory and non-satisfactory spinning unit.

FINDINGS AND ARGUMENT

It is very important to correctly determine the measurement points, which must be as close as possible to the observed source of vibration. The objective of the one-time measurements was the verification of the influence of the chosen measurement position on the actual dynamic load of the spinning unit and the verification of the proposed measurement methodology for vibro-diagnostics of the bearing spinning headstocks, as well as the analysis of the operating state of the bearings near the planned end of their lifetime. Sensing elements, also called headstock diagnostic sensor (CHLEBO AT AL., 2022) of vibrations and temperature should be attached as close as possible to the bearing, which was not done until this point. However, the wavelength of the excited frequency should also be taken into account in relation to the maximum amplitude of the generated vibration. Otherwise, a smaller or larger distortion of the useful signal occurs, see Tab. 1. Three different measuring points of the vibration acceleration were chosen, directly on the bearing, support frame and frame of the aggregate drive, shown in Figure 2. Such a distribution of measuring points enabled the assessment of the quality of vibration isolation, i.e. the transmission loss from the source of vibration (headstock) to the surrounding structures, i.e. the mounting of the headstock in the support frame of the drive unit, but also vice versa, i.e. the effect of ambient vibration on the bearing of the spinning headstock (DARULA, 2011).



(a) (b) (c)

Figure 2. Different measurement locations of the accelerometers of the analysed bearing, (a) using a grub screw resting directly on the outer ring of the headstock bearing, (b) fixing with a magnet on the supporting frame of the drive unit under the analysed bearing and (c) on the spinning unit (frame) using a grub screw.

The dynamic load (vibration) of the spinning headstock bearings was measured in two operating modes. The first mode was at a set rotational frequency of 50 000 r/min, while the real rotational frequency due to slippage was 49 080 r/min, which corresponds to a frequency of 818 Hz. The second operating mode was at the set rotational frequency of 100 000 r/min, while the real rotational frequency was 98 160 r/min, which corresponds to a frequency of 1 636 Hz. The effective values of the vibration acceleration for the selected frequency range of the spinning unit for the three selected measurement locations and the two operating modes of the rotational frequency are shown in Table 1 and the corresponding frequency distribution of the vibration of the spinning unit are shown in Figure 3.

Table 1. Effective vibration acceleration values measured directly on the headstock bearing, on the supporting frame and its frame.

Acceleration	50 000 r/min Frequency range, Hz			100 000 r/min Frequency range, Hz		
m/s^2	(12-12 800)	(1 375-2 193)	818	(12-12 800)	(2 696-4 332)	1 636
Bearing	71.159	8.531	3.305	141.251	84.416	23.156
Support frame	3.889	0.518	0.312	5.951	3.243	0.233
Frame	1.975	0.486	0.685	4.468	1.91	1.259

From the effective values of the vibration acceleration, a significant transmission damping on the silent blocks of the spinning headstock was evident. From the performed vibro-diagnosis of the operating state of the selected bearing of the spinning unit, it was clear that the optimal measuring point was directly on the bearing of this spinning unit. This was also confirmed by the frequency spectra of the diagnosed headstock bearing, shown in Figure 3, for higher operating mode and three selected measurement points.

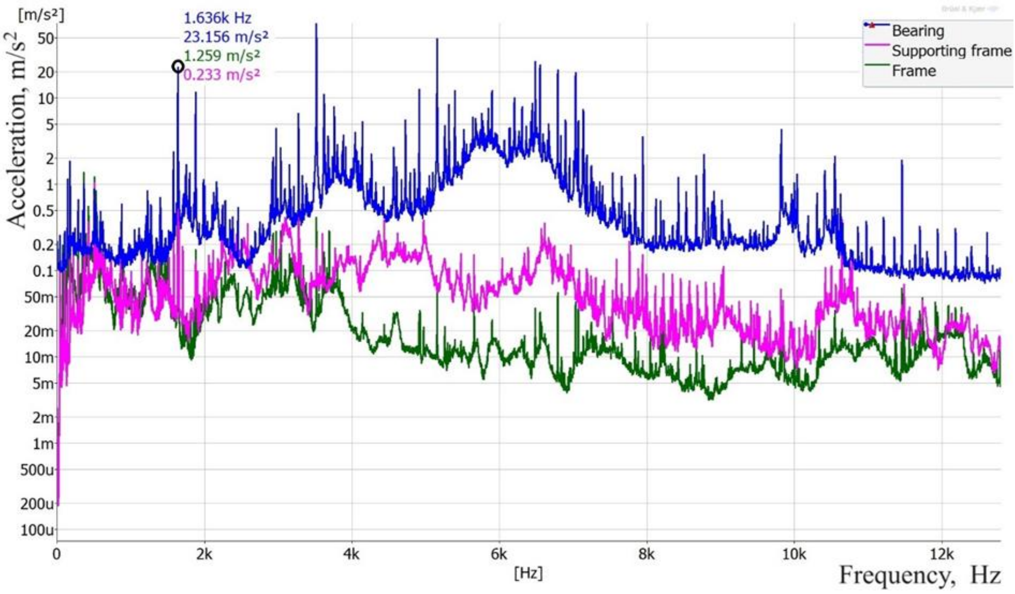


Figure 3. Frequency spectrum of the diagnosed bearing at the set rotation frequency of 100 000 r/min.

CONCLUSIONS

This article suggests the importance of the correct way to diagnose high-speed spinning headstocks. The results presented in this article were based on experimental tests of 6 randomly selected high-speed spinning headstocks. With the use of diagnostic sensors, the analysis of data from experimental tests showed a discrepancy between the temperature and dynamic parameters. When diagnosing the operational condition of machines and machine components with the help of a diagnostic sensor, all potential problems related to the operational condition of machines and machine components can be identified in time and with its long-term use it also brings significant financial benefits savings that typically reach up to 60 % of maintenance costs for machine components (RANDAL, 2011 AND ŽIARAN AT AL., 2021).

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RASPBERRY PI SOUND PROJECTS: STEM EDUCATION

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Abstract

Generative AI, particularly language models, are transforming industries by automating content creation and enhancing human-computer interactions. The STEM education approach in our engineering program is crucial to develop skills and insights that complement and go beyond what language models can achieve. Students must be educated with a highly flexible STEM approach, as AI already can easily handle highly repeatable tasks at a fraction of the cost compared to employee salaries. Without this kind of education, they risk losing their jobs to automation. The aim of this work is to highlight the STEM approach in obtaining and simple processing of sound data using Raspberry Pi.

Keywords: STEM, Raspberry Pi, MEMS microphone

Acknowledgements

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INTRODUCTION

STEM education in engineering emphasizes critical thinking, problem-solving, creativity, and collaboration through hands-on, project-based learning. It develops skills in science, math, coding, and engineering design, preparing students for in-demand STEM careers, and enhancing economic competitiveness. The STEM education approach in engineering is even more critical in the artificial intelligence (AI) era. Generative AI, including language models, does not truly "think" in the human sense; it processes data and generates responses based on patterns and algorithms. It lacks consciousness, understanding, and intentionality, relying solely on learned data to produce outputs.

There are many articles discussing the use of Raspberry Pi (Raspberry Pi, 2024) in student education. Raspberry Pi is an excellent tool for practical learning in programming, electronics, robotics, and other STEM fields. Arduino (Arduino, 2024) also plays a significant role in STEM education by providing hands-on experience with electronics and programming. It enables students to build and experiment with their own projects, fostering creativity and practical problem-solving skills. The VEML7700 light sensor has proven to be an effective tool for measuring illuminance levels of light sources. The inverse square law is verified in (Janek, 2024), the sensor was used in Arduino platform. Refraction, diffraction, and energy losses studies using Arduino and Raspberry Pi were conducted in (Janek, 2024). The setup for measuring the diffraction of light on an optical element, specifically a diffraction grating, in a remote manner based on Raspberry Pi and Arduino is presented in (Janek, 2024(2)).

In this work, we describe the setup for audio recording and what can be done in STEM approach by students on the Raspberry Pi platform. Finally, we provide a short summary.

SETUP

For microcontrollers lacking analog input or seeking to bypass potential noise issues inherent in analog microphone systems, there is I2S Microphone Breakout, e.g. (Adafruit, 2024). Designed for use with microcomputers with I2S peripherals, this breakout facilitates the transmission of digital audio data. Instead of traditional analog outputs, it features Clock, Data, and Word-Select digital pins, eliminating the need for analog conversion.

Compatibility is crucial, as not all microcontroller boards support I2S; however, it pairs seamlessly with hardware that does, including Cortex M-series chips like the Arduino Zero, Feather M0, and single-board computers like the Raspberry Pi. I2S library is also available for Arduinos powered by the SAMD processor (I2S library, 2024). Example codes are accessible from the dropdown menu after installing libraries. Overall sound pressure level and Fourier transformation can be performed to analyse signal; however, this approach is quite restrictive.

In our scenario, Raspberry Pi Zero are employed to harness the full potential of data acquisition and processing. Node-RED (NODE-RED, 2024) can be executed on Raspberry Pi, providing a versatile platform for visual programming and IoT applications. One advantage is its user-friendly interface, enabling quick prototyping and development through drag-and-drop functionality. Additionally, Node-RED's extensive library of pre-built nodes simplifies integration with various devices and services, enhancing flexibility. Moreover, its compatibility with Raspberry Pi's GPIO pins facilitates seamless interaction with hardware components. One can observe that Node-RED operates within a browser, utilizing widely recognizable components. This ensures that students are not confronted with an unfamiliar graphical user interface (GUI), facilitating ease of understanding.

In Figure 1. The photography of I2S microphones a) which are enclosed in the front panel b) are stacked on top of a Raspberry Pi Zero board (under the microphone plate) c) is shown.

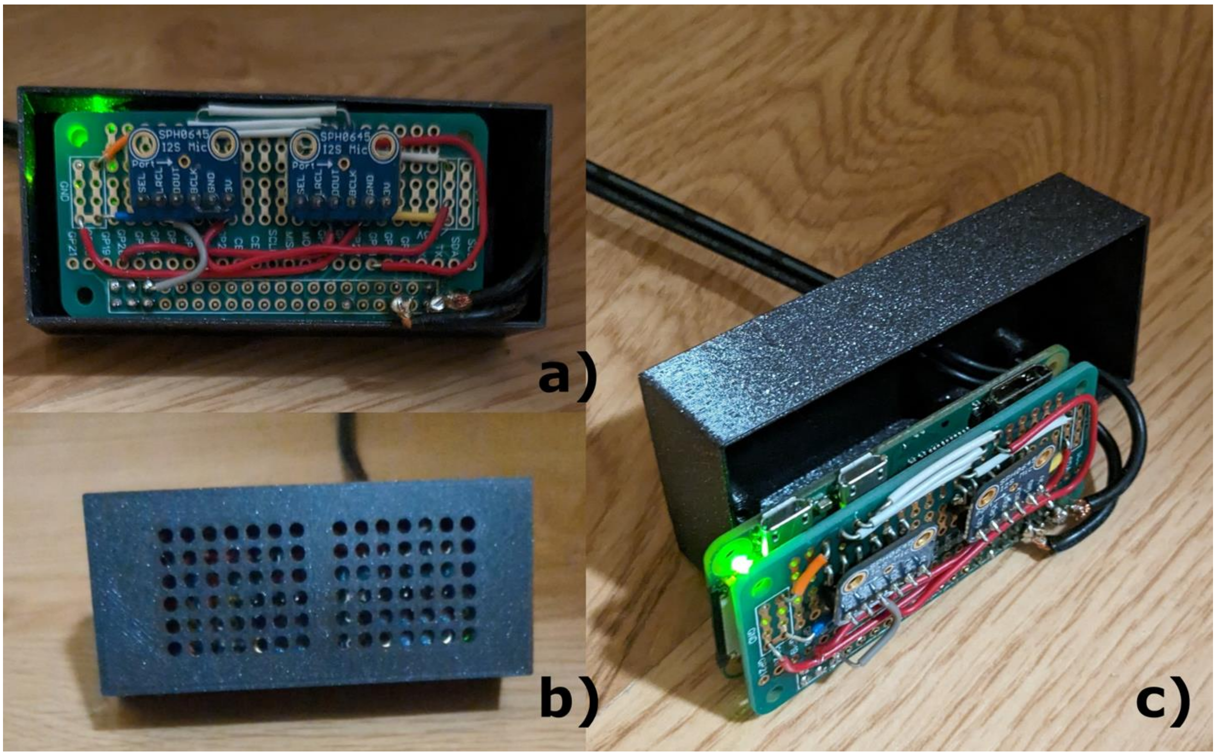

Figure 1. Photography of I2S microphones a) which are enclosed in the front panel b) are stacked on top of a Raspberry Pi Zero board (under the microphone plate) c).

DISCUSSION

Collection of audio data begins by pressing the start button in the graphical user interface in Node-RED. The graphical interface is not shown here. The data collection ends by pressing the stop button or after reaching the time limit, which is set to one minute for compressed files. For uncompressed audio files, the timeout is set to 10 seconds. The audio data is displayed in one graph showing the last second, and another graph shows processed data after applying the Fourier transform. The audio files can be downloaded to a computer for further processing, but the primary goal is to manipulate and process the data on a Raspberry Pi.

Below is one of the possible scenarios of how students could work with the described setup. A few steps could be carried out, but it is better to perform as many as possible steps to show the advantages of the STEM-based approach.

In the subject of Materials and Technologies, students work on developing a printed circuit board (PCB), simulating it, mounting components, soldering them to the PCB, and calculating the probability of failure.

In this subject (Materials and Technologies), the following steps could be taken by analogy. Students could solder MEMS microphones onto the PCB or install other electronic components to eliminate external electromagnetic fields and connect this PCB to a Raspberry Pi. The next step would involve recording audio data. There are several possibilities: one is writing a short program in Python, and another is writing a bash script using built-in bash functions for recording sound. Simple sound processing can be done on the Raspberry Pi again in Python or another language as needed. The goal is not to use the Fourier transform from libraries but to write their own code, which, although is not as efficient as the Fast Fourier Transform. This helps students better understand the mathematical apparatus associated with the Fourier transform. The implementation in any language should not take more than 20 to 30 lines of code, so it is not so difficult to realize. On the other hand, students go through the entire process of recording and processing audio signals.

Filtering or other modifications of audio data can be performed using the inverse Fourier transform. Initially, it is not so complicated to program a low-pass or high-pass filter or smooth the audio spectrum in the frequency domain. The goal should be to better understand how these filters affect the resulting signal, even in this simplest approach. This should all be done with an emphasis on processing signals, which do not necessarily have to be audio signals.

Another application could be investigating standing waves on a string. In Physics 1 laboratory exercises, there is an measurement on investigating standing waves on a string, where a problem arises with higher harmonic frequencies since the displacement on the string is relatively small, making it difficult for students to read or find the frequency at which the string vibrates.

The proposed setup could be used in this case to record the sound of the vibrating string with subsequent data analysis. The physical processing of the measurement and understanding of the physics would proceed as described in the scripts.

Further development possibilities of the task include installing an operating system on an SD card for the Raspberry Pi, working in the Linux OS environment, debugging code, and solving various interdisciplinary problems which arises through completing task.

The problem could be trivial, hidden in the code, or in a cold solder joint, and finding the cause may not be easy. First, it is necessary to identify in which part the problem is located and then specifically solve it. In physics labs at courses, problems that are not related to physics are often solved, such as connecting electronics, misunderstanding the mathematical apparatus, misunderstanding electrical or electronic connections, incorrect overall approach by the student, and negligence. With a complex task like this, which involves mathematics, programming, electronics, and possibly physics, students should learn how to approach and solve complex problems, focusing on the specific issue because any unresolved error in the initial stages can be very difficult to solve later, is harder to identify, and can affect further stages and overall progress in development and understanding.

CONCLUSIONS

The process of collecting and processing of audio data is performed on Raspberry Pi in Node-RED graphical user interface and in Python language, preferably. Students in Materials and Technologies subject or similar can make their PCB by soldering MEMS microphones and connecting to a Raspberry Pi for data collection. Students delve into audio signal processing, gaining insights into Fourier transforms and filtering. This task can be extended to physics in which the standing waves can be analysed. This interdisciplinary approach not only enhances technical skills but also fosters problem-solving abilities crucial for tackling complex issues that may arise during project development. Solving complex tasks is becoming an increasingly urgent issue due to the continuous advancement in automation.

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PERCEPTUAL ASSESSMENT OF ROOM MODE DAMPING BY MEANS OF ABX LISTENING PROCEDURE

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Abstract

In small rooms dedicated to music playing and production, such as rehearsal rooms and recording studios, frequency-wise isolated room modes fall in the frequency range of many musical instruments. This low modal density leads to non-diffuse reverberation and to the amplification of certain musical tones played while diminishing room response to others. In the music-oriented spaces, there is always some reverberation preferred over completely anechoic environment. Because of this constraint, it is not feasible to damp the mode to its detection threshold and other solutions and compromises need to be employed. In order to evaluate the perceptual relevance of different room acoustic measures, listening tests need to be designed and performed by a sufficient number of participants. This contribution describes one of the most common listening test protocol – ABX, its principle and the means of analysis of the retrieved results.

Keywords: Room acoustics, room modes, ABX listening test, mode damping, modal decay

Acknowledgements

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INTRODUCTION

Following the authors' previously published work (Jun et al., 2024), this article tries to enlighten the importance of subjective perceptual evaluation of room acoustic treatments. This is illustrated on an example of ABX listening test focusing on room modes in rehearsal rooms.

In the room acoustic design of rehearsal rooms, several key aspects are usually taken into account: volume, aspect ratio, reverberation time, room strength and background noise (Rindel, 2014; Olsen and Rindel, 2017; Olsen and Engesnes, 2023). While the common approach tries to find the optimum compromise between room strength and reverberation, room modes are often taken into account only as a part of the aspect ratio of the room.

While the perception of resonances has been studied already, most of the works focused on single resonances from electro-acoustician point of view (Toole and Olive, 1988; Olive et al., 1997). Other authors aimed on the potentially related audibility of spectral peaks and dips in a broadband signal and on the coincidence dips of lightweight wall structures (Kritly et al., 2018). The first perception oriented studies on room modes were focused more towards their absolute detection threshold, at first from the quality of resonance perspective (Avis, Fazenda and Davies, 2007), in the second case from the perspective of modal decay (Fazenda, Stephenson and Goldberg, 2015).

Based on these studies, in order to prevent hearing the modes, they would need to be damped to lower decays than the ones recommended by the standards for reverberation time in rehearsal rooms and similar spaces. The following listening test example is a part of a wider parametric study on the audible differences in room mode damping.

METHODS

To auralize the room mode damping, stereo room impulse responses are calculated and convolved with the musical stimulus in the same way as in the previous study of the authors (Jun et al., 2024).

The main difference compared to that study is the variable on which this study focuses: the bandwidth in which the room mode damping changes. In this case, the reverberation is changed in several bandwidths (2 octaves, 1 octave, 1/3rd octave and 1/6th octave centred around 131 Hz and single axial mode at the 131 Hz frequency). The modal decay was kept constant for each mode at two levels: 0.72 s for modes having their center frequency inside the specified frequency interval, 0.4 s for the ones laying outside of the interval. The test was performed on 3 types of stimulus (the same ones as in the previous study): kick drum sound, 1 tone (C2) and 2 tones (C2, D2) played with a bow on a double bass (i.e. in the *arco* style). The tone C2 has in the used tuning fundamental frequency of 131 Hz, and it is therefore aligned with the central frequency of the change in room modes.

The ABX listening test originates from 1950 (Munson and Gardner, 1950), and its core is a combination of three stimuli: A, B and Reference (X), where the Reference stimulus is the same as A or B. The participant is asked to choose, which from A or B is the same as Reference. From this point of view, it falls in the family of the two alternative forced-choice tests (DE LA PRIDA ET AL., 2021). Each of the combinations of unique A and B are commonly presented several times to the same participant, always in random order and at random position within the test. In the present test, each combination consists of two different sounds auralized using the same stimulus (e.g. drum) and two stereo impulse responses reflecting two different bandwidths of change of room mode damping.

Analyzing the ABX listening test results is done statistically by searching for the significances on a certain level of confidence, typically 95%. Different software can be used for this analysis, this work uses functions from the *pingouin* (VALLAT, 2018) Python package. The Table 1 shows the typical questions asked when analysing similar tests, the statistical method used for the evaluation and the function from the *pingouin* library.

Table 1. Typical questions asked while analysing the ABX listening test.

Question	Test	*Pingouin* function
Did the participant performed *significantly better* than 0.5 (limit of the test for quessing)?	T-test	*pingouin.ttest*
Is the performance on different combinations *significantly different*?	ANOVA repeated measures	*pingouin.rm_anova*
Which are the combinations on which the performance significantly differs?	Pairwise T-test (with Bonferroni correction)	*pingouin.pairwise_tests*
Is there a significant difference in performance within *certain grouping of results*? (E.g. stimuli)	ANOVA repeated measures	*pingouin.rm_anova*
Is there a significant difference in performance within *certain groups of participants*? (E.g. testing place, musicianship)	Mixed ANOVA	*pingouin.mixed_anova*
Is a difference perceived in a combination *noticeable*? (performance > 0.5)	T-test	*pingouin.ttest*

The significance on the 95% level of confidence is found whenever the probability value of the test falls bellow 0.05 and thus the null hypothesis can be rejected.

FINDINGS AND ARGUMENT

The above described test was performed by 18 participants, from whom 13 also did the retest for learning effect evaluation. First, the limit of guessing was checked using each participant's results and based on this analysis, results of only 9 participants are kept for further analysis of the combinations. To analyse this unexpected result, the participants were further split into 3 groups based on their active musicianship: *active musician* is each participant playing an instrument on a regular basis, *participative musician* is in some way encouraged to participate in music (e.g. in the church environment), *non-musician* is not actively producing music. The results of the t-test sorted by the confidence interval reveal that the active musicians performed the best while the non-musicians the worst. ANOVA repeated measures (ANOVA-RM) confirms that the difference in performance between these groups is significant.

The further analysis was done on the responses from the remaining 8 participants, who both scored significantly higher than 0.5 and performed both the test and retest. The test-retest analysis using ANOVA-RM shows no significant difference between the score of the two attempts of each participant and the two attempts can therefore be analysed together. ANOVA-RM shows significant difference between the drum sound and the bowed instrument sounds, but also no significant difference was found between the 1 tone and 2 tone stimuli. ANOVA-RM also showed that the performance differ between the combinations. Pairwise T-test is used to further determine which combination significantly differ from each other in terms of performance. Figure 1 shows the results in terms of average score and standard deviation for each combination.

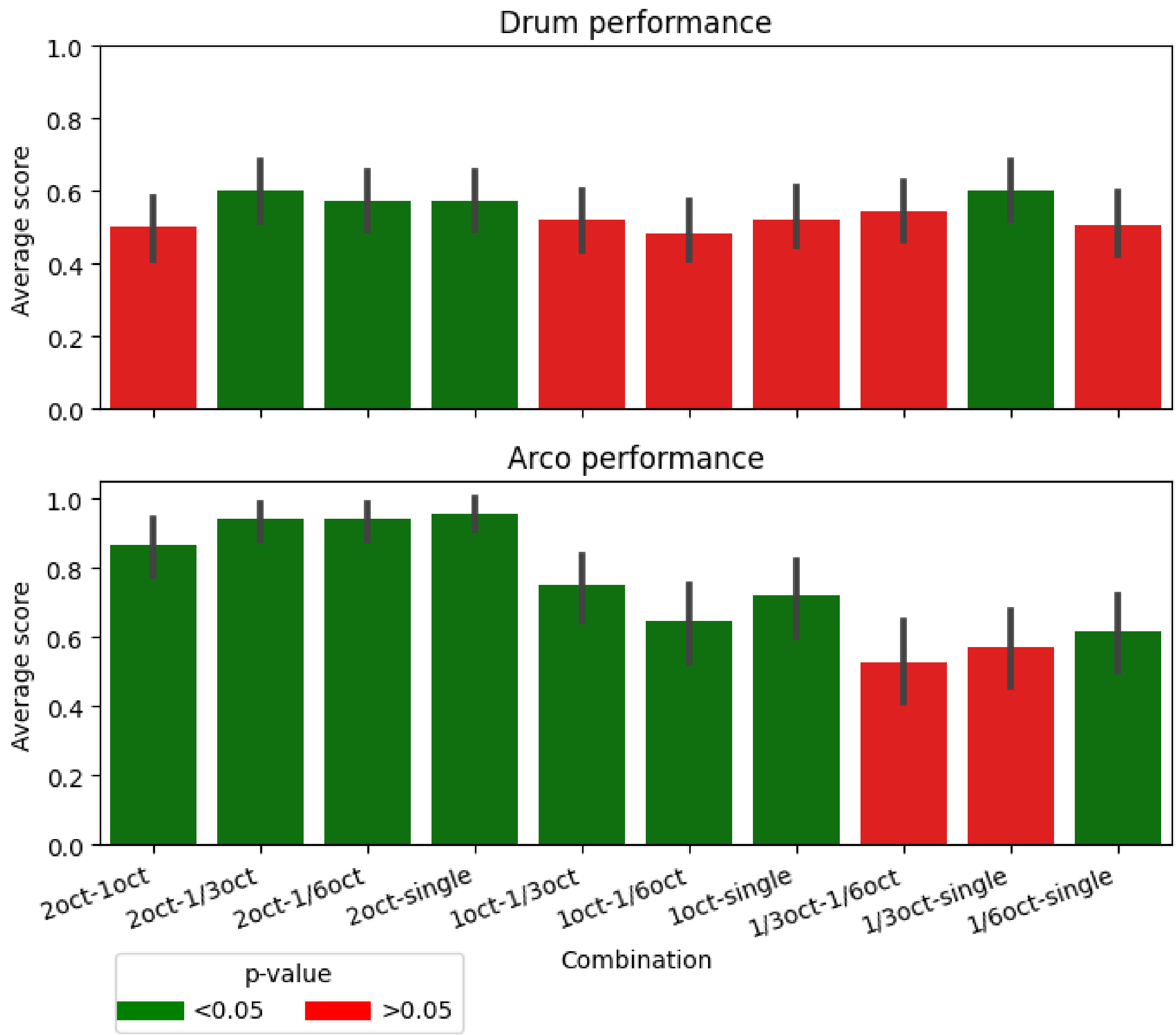

Figure 1. Listening test results in terms of average score and standard deviation for each ABX combination. The top plot shows the results for the kick drum stimulus and the bottom one for the two arco stimuli. The green colour denotes that the score is significantly higher than 0.5 and the red one the opposite cases.

CONCLUSIONS

ABX listening test is a powerful tool enabling the evaluation of perceptual relevance of certain room acoustic measures. While it may not be the most efficient when seeking for thresholds, it can provide a good overview on the measure of interest. In the particular case of this study, several conclusions can be drawn on a 95% confidence level: (a) The different bandwidths of change in room mode damping are perceived differently. (b) The different stimuli are differently sensitive to the modal changes. (c) The active musicianship of the participant plays a role in his/her sensitivity to mode-damping changes.

This test will serve for the upcoming listening test design, for which only a selection of bandwidths of change in mode damping needs to be used to keep the test reasonably time-consuming.

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DEVELOPMENT OF A 'SPEECH IN NOISE TEST' FOR THE SLOVAK LANGUAGE – A FOLLOW UP STUDY

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Abstract
In this work, we follow up on the research of HÚDOKOVÁ ET AL. (2023), that deals with the development of a balanced sentence sets of semantically predictable sentences in Slovak language. This follow-up study is essential in terms of enrichment of the speech material with new sentence sets which will allow for larger research studies on speech intelligibility, in a wide range of clinical and non-clinical applications with fewer participants. Preliminary study results show that it will be possible to create approximately 20-22 sets of 10 sentences each, each with an average SRT in noise equal to -4.02 dB SNR and with an average power intensity curve slope of 28.17%/dB. Once completed and fully evaluated, validation of selected sentences can continue with listening tests using the adaptive method.

Keywords: Speech intelligibility, speech understanding in noise, listening test

INTRODUCTION

Speech intelligibility is a crucial aspect of everyday life, facilitating effective communication between people. In most of everyday life situation, a conversation between people is masked by ambient noise, background sounds, or sound reverberation. Research on speech intelligibility in noisy or reverberant acoustic environments in everyday life is therefore highly relevant. Within Europe and around the world, several types of speech materials already exist (E.G., VAN WIERINGEN & WOUTERS, 2009, HOUBEN ET AL, 2014, E.G., OZIMEK ET AL., 2009, E.G., NIELSEN & DAU, 2009).

The Slovak language belongs to the group of Slavic languages, specifically to the West Slavic branch. Regarding phonology, the Slovak language has a clear and stable system of vowels and consonants. It has five basic vowels (a, e, i, o, u), each of which can be short or long. Consonants can be soft, hard, or both. Pronunciation is phonetic, which means that letters are usually pronounced as they are written. The Slovak language is flective, which means that words bend according to falls, number, gender and time. It has seven falls, three genera and two numbers. Slovak word order is relatively free due to the rich bending of words. The order of words in a sentence can be flexible, allowing emphasis to be placed on different parts of the sentence.

The first part of semantically predictable sentence speech material for the Slovak language has been created and validated by HÚDOKOVÁ ET AL. (2024). It consists of 18 sets of 10 equally difficult sentences. The main idea of creating the sentence material is to assess speech intelligibility in real-life scenarios and evaluate architectural environments. Our paper focuses on the extension of already created speech material. The extension will allow for efficient comparisons of more cases/variants, with stronger statistics and working with fewer test participants.

METHODS

Selection of sentence material

The design the additional sentences we followed the procedure and rules used and published by HÚDOKOVÁ ET AL (2023 and 2024). The newly recorded sentence material contains 330 sentences. Sentences were chosen following the requirements of Plomp & Mimpen (PLOMP & MIMPEN, 1979). The material includes (a) conversational, everyday speech that sounds natural despite contrasts in dialect, education, and basic knowledge of test takers. The sentences are (b) short enough to be easily repeated with two to eight words. Sentence length cannot require a large memory. There are (c) no questions or exclamation points, (d) no hard words, (e) no proverbs, (f) no proper nouns, and (g) the sentence had at least one verb and one noun. Sentences are grammatically and syntactically accurate and semantically predictable, sentence structure is not fixed.

Speech stimuli

Recordings of 330 sentences were performed in the semi-anechoic chamber at STU Bratislava, Faculty of Civil Engineering by an operator by means of Audacity software. The sentences were recorded by a 27-year-old female native speaker. The average fundamental frequency of her voice (f0) is 275 Hz, and her average speaking rate is 5.3 syllables per second. During the recording of sentence material, the speaker maintained the natural rhythm of speech and avoided emphasizing any specific words. During the recordings, the speaker stood perpendicular to the microphone at a distance of 1 m. All sentences were recorded in the same position in the room and the same mutual (speaker-microphone) distance, so that the sound pressure level of the recorded voice would stay constant. The recordings were carried out using a condenser microphone (Marshall MXLV671) connected to a computer via sound card (Focusrite Scarlett 6i6). The recorded signals were sampled at 44100 Hz (16-bit A/D converter). Each sentence was saved as a separate ".wav" file on the computer disk. The silent intervals before and after each sentence were later removed, and a 30ms cosine window was applied at the beginning and end of each sentence to prevent clicking.

Speech-weighted noise

The stationary masking noise required for further speech in noise listening tests (SRT measurement in noise) was calculated from the long-term speech average spectrum (LTASS) of all recorded sentences. Using a masker that matches the spectral profile ensures that the SNR will be almost uniform on average at all frequencies. The average frequency spectrum of the originally (HÚDOKOVÁ ET AL., 2023), and newly recorded sentences (used also as masking noise) is compared in the Figure 1. The shapes of these frequency spectra are very similar. Note that the newly recorded sentences were recorded at louder levels. This can be caused by slightly different settings on the sound card, or sensitivity of microphone. Base in this observation it can be concluded, that after calibration of sound pressure level, the new sentences / and sentence sets can be later used together with the original ones.

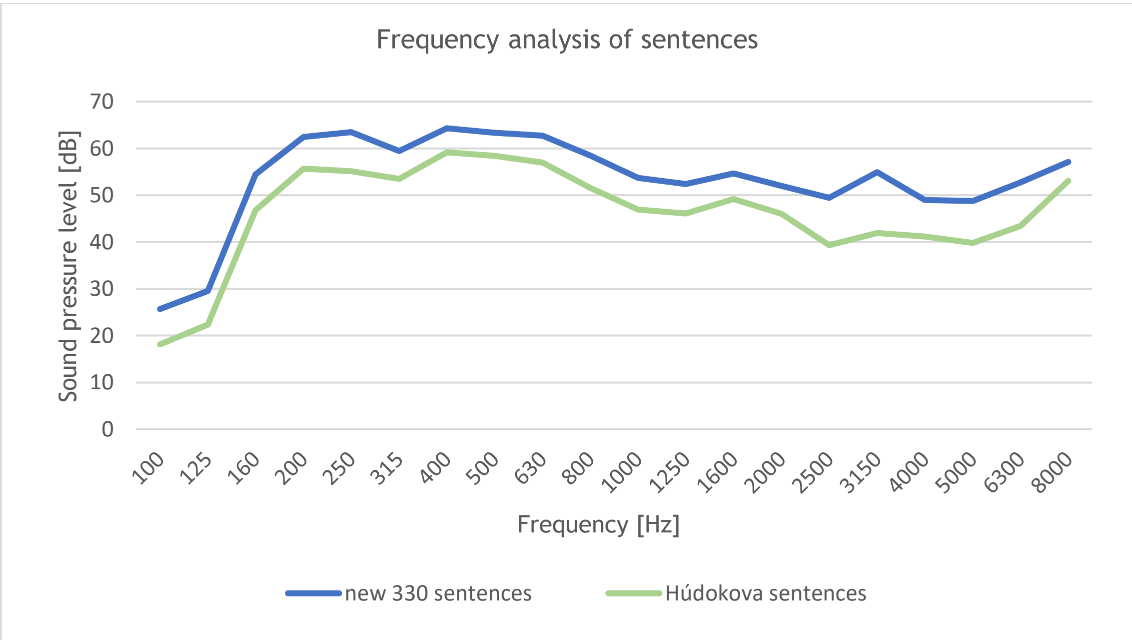

Figure 1: Frequency analysis of sentences.

Listening tests subjects

Forty native Slovak listeners (15 women and 25 men) have perform the listening test. All participants were tested for normal hearing (audiometric thresholds <20 dB HL for octave frequencies from 125 Hz to 8000 Hz) by pure audiometric examination. None of the participants had a history of hearing loss. They had no previous experience with sentence material. Their age ranged from 18 to 54 years. The median age of the participants was 26 years.

Set up of listening test

Listening tests were performed in a sound proofed semi-anechoic environment with background noise not exceeding $L_{A,eq}$ = 17 dB. The stimuli were presented through open headphones (Sennheiser HD650) with a flat frequency response. Sound card (Focusrite Scarlett 6i6) and APEX software were used in the experiments. The setup used in the testing consisted of a Java script routine for reading and playback of this material, including noise in various SNR values. The signals were presented to the participants diotically, i.e., the same sound information was presented in both ears. The schematic picture of the setup can be seen in Figure 2. Each test participant sat in the room together with the test operator.

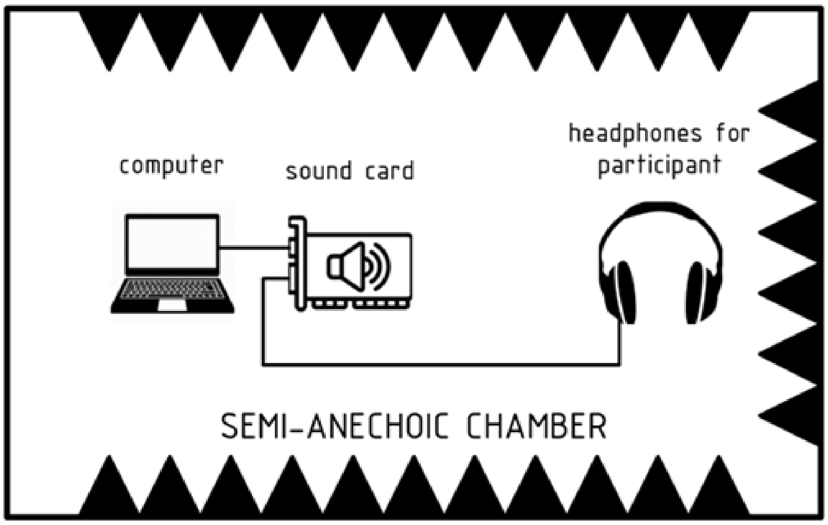

Figure 2: Setup scheme for the listening tests.

Procedure - Fixed method (listening log)

All 330 sentences were presented at five signal-to-noise (SNR) values: -8 dB; -6 dB; -4 dB; -2 dB; 0 dB to determine the appropriate speech reception threshold. The sentence level was fixed at 65 dB SPL and masking noise was set to achieve a specific SNR. All 330 sentences were divided into three groups of 110 sentences so that each participant was tested for three different SNR values. This procedure was chosen to avoid possible fatigue of testing participants. The sentences were presented in random order. In the beginning of the listening session, the test operator informed and explained the course of the test to each participant individually. The task of each participant was to repeat sentences heart in particular SNR. The test operator could listen to each sentence without presence of noise an at the same time displayed on the PC screen to judge the correctness of the answer. Only a sentence repeated with 100 % correctness were considered as correct answer. Each sentence was played only once.

Participants could take a break during the test anytime needed, for sake of avoidance of tiredness. Duration of one test took approximately one hour and fifteen minutes.

Data presented in this paper are based on 8-10 different participants/ per SNR. The SRT value was determined and adjusted to 50% of the curve per sentence based on the average percentage score on the SNR.

Preliminary calculation of SRT and slope

For each sentence, the SRT was estimated according to the calculation of performance intensity curves at the point 50%, taking into account the scores of 40 test subjects. The curves were estimated using adjusting function (1) within a nonlinear regression of the power intensity curve for each sentence at fixed SNR levels (E.G., VAN WIERINGEN & WOUTERS, 2009), (IBM SPSS, 2021). Preliminary analysis showed which sentences were likely to be removed as inappropriate. The following criteria have been established for assessing the appropriateness of the sentences: (a) SRT standard deviation and slope; (b) SRT value and slope. The preliminary customized SRT value is -4.02 dB with SD=0.30 dB and an average slope of 28.17%/dB and SD=7.81%.

RESULTS

Table 1 compares results from HÚDOKOVÁ ET AL (2024) and preliminary results from current testing. The results from the first research on well-balanced sentences in the Slovak language are similar to those from the currently tested sentences.

Table 1. Comparison of SRT and slope results.

	Results Húdoková	Results now
Average SRT	-3.94 dB	-4.02 dB
Average SRT SD	0.65 dB	0.30 dB
Average slope	13.21 %/dB	28.17 %/dB
Average slope SD	3.72 %/dB	7.81 %/dB

CONCLUSIONS

This research aimed to extend the already created semantically predictable sentence material for the Slovak language. Preliminary results show that the new 220 sentences might serve as a very good bases for creation of new 22 sentence sets that will enlarge the semantically predictable sentence material for the Slovak language.

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SACRAL ARCHITECTURE AND ITS ACOUSTICS FROM EARLY CHRISTIANITY TO THE SECOND VATICAN COUNCIL

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Abstract

Sacred objects represent items with immeasurable cultural-historical value. Increasingly, the question of preserving their acoustic properties as intangible cultural heritage is being emphasized. Speech intelligibility was necessary in Catholic Church liturgies even before in certain historical periods. In the 16th century, because of the Council of Trent and the importance attributed to preaching as a tool against the Reformation movement, several changes were made during the celebration of the liturgy. These changes were further strengthened during the Second Vatican Council, when significant changes were made to the manner and places from which speeches were delivered during the liturgy.

Keywords: Sacral architecture, liturgical reform, speech intelligibility, speaker desk, pulpit

Acknowledgements

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INTRODUCTION

The church represents a space for giving thanks and prayers towards God and for listening to His words. The acoustics of sacred spaces provide a suitable environment for such activities. The characteristic of such spaces is very complex, as interior design varies from case to case. Additionally, there is often a wide range of sounds present, such as spoken word, music, or congregational singing. Therefore, determining optimal acoustic conditions for a sacred space is very challenging (SOETA ET AL. 2012).

Architectural analysis of the typology of churches is incomplete unless it includes an evaluation of the acoustic properties of these buildings. Good audibility of spoken word, especially during prayer, was a priority in the early Christian basilicas. Despite this, it is very challenging to find mentions of the acoustic properties of these spaces in architectural, liturgical, and musical contexts, even though there is a large amount of literature and documents on the relationship between architecture and music, or between architecture and liturgy (NAVARRO ET AL. 2009).

The acoustic conditions of historical objects have been the subject of research on a global scale for several decades, providing often unique and historically significant findings. The measurement and archiving of acoustic space data are of great importance.

FINDINGS AND ARGUMENT

In early Christianity, the Romanesque Basilica was considered the main typological model. Its harmonious proportions, high wooden ceilings, and absence of bare walls provided good internal acoustic properties, which had to meet the requirements for the acoustics of the indoor environment at that time: attracting many people, spreading the faith, and teaching Christian religion (NAVARRO ET AL. 2009).

The transition from early Christian architecture to Romanesque architecture was relatively slow. Particularly due to civil conflicts and fires, many wooden roofs and ceilings burned, resulting in significant damage. This phenomenon motivated Romanesque architects to design less flammable and more durable constructions, leading to the introduction of vaulted ceilings. Such a decision resulted in a significant change in acoustic conditions. Originally acoustically harmonious early Christian basilicas, where sound was evenly dispersed with the help of wooden ceilings and the presence of few bare wall surfaces, were replaced by churches with irregular proportions. The width, length, or height of the church, along with hard, vaulted ceilings with directional characteristics and clearly reflecting walls, meant a significant step backward in terms of acoustic properties (NAVARRO ET AL. 2009).

At the end of the Middle Ages, in the 13th century, mendicant began to emerge. They arose in response to new social demands associated with greater spirituality in the church with a clear mission, distinguishing themselves from the concept of traditional monastic life. Among these orders, the Franciscans and Dominicans stood out.

The typology of churches of mendicant orders can be partially defined as typical for these orders, although construction principles often depended on the place or country in which they were built. The common feature of these churches was their subordination to two main purposes: liturgy and preaching.

The Dominicans reduced the size of the churches while also striving to keep the height of the main nave from being too high. For the Franciscans, it was considered that the ceilings in churches should not be vaulted, except for the presbytery. The ceilings of the naves were wooden, although in many cases they were later replaced with vaults. Additionally, they designed churches with only one nave, departing from the earlier monastic church typology, which was more typical of a three-nave basilica. The selection of this typology was related to the ideas of the Franciscans and other mendicant orders to open churches to the faithful so that they could participate in the liturgical act, preach to them, and organize various other types of public gatherings. This allowed them to approach the lay public and catechize them. The openness of the interior in general allowed for better visibility, and the reduction of the presence of other supporting structures also reduced the number of acoustic shadows (NAVARRO ET AL. 2009).

Among other ascetic interests, one of them was probably also an effort to improve the comprehensibility and understandability of the word compared to other medieval churches. Based on this, preaching to the faithful in the vernacular language was shown to be useful, contradicting the Church's recommendations to preach in traditional Latin, which was incomprehensible to the majority of the faithful. However, from an acoustic perspective, there is no official evidence that these efforts were made to improve the comprehensibility of spoken word. From the beginning of the 14th century, mendicant orders began to move away from the idea of simplicity, as churches became larger, and preaching became increasingly demanding.

During this period, the pulpit gained an important role in the celebration of the liturgy. It was a necessary element for the possibilities of apostolization and catechesis of the faithful. There are many analogies to visible elevated places intended for proclaiming the word of God. In the Western Church, with certain exceptions, this place was primarily located in the presbytery.

In the early Middle Ages, the position of the ambo gradually changed and moved away from the presbytery. It approached closer to the main nave of the church, eventually evolving into the form of the pulpit – a place not expressly designated for reading the word of God but reserved for sermons. At the altar, the priest worshipped God on behalf of the faithful, but he was distant from them. During preaching, the priest came closer to the people. Such proximity to the people contributed to better comprehensibility of the spoken word, which was particularly important in the case of larger churches. Additionally, most of these pulpits had roofs, which were intended as sound reflectors, or canopies designed to direct a larger portion of sound energy towards the faithful (NAVARRO ET AL. 2009).

Pulpit reflectors prevent delayed echoes in areas with very high ceilings, thus improving audibility at a moderate distance from the pulpit. The effectiveness of such a feature decrease or is entirely disadvantageous in spaces where the ceiling height is less than 10 m and at a greater distance from the speaker. Changes in speech intelligibility ratings are negligible in such cases, but values may increase in the presence of a congregation. Canopies are most effective in churches with higher ceilings, and they have no effect over long distances. In churches with ceilings lower than 10 m, the canopy's effect at short and moderate distances is unfavourable. The presence of a canopy eliminates early reflections from the church ceiling, which are favourable for the listener (CARVALHO ET AL. 2001).

In the second half of the 16th century, there was a significant shift in the perception of the acoustics of sacred spaces, influenced mainly by the decisions of the Council of Trent and the importance attributed to preaching as a tool in the hands of the Counter-Reformation. The Council advocated against the pure aesthetic principle of the Renaissance centralized floor plan. It chose the single-nave church as its typological principle, which corresponded to the needs of worship.

At least four important documents from this period are evidence that the solution to the ceilings was closely linked to the acoustic conditions of the interiors. The oldest of these documents is Franciscan, while the other three are Jesuit. These four mentioned documents illustrate, on one hand, the importance attributed by certain religious orders, especially those with a more active role in the Council of Trent, in this period of reform, to the acoustic conditions in churches for preaching in the vernacular - speech intelligibility - emphasizing the importance of preaching as a tool of the Counter-Reformation. On the other hand, they show how during this period, good acoustic conditions for preaching in churches were associated with how they were covered: with a wooden ceiling or vaults (NAVARRO ET AL. 2009).

From an acoustic perspective, in the case of Baroque churches, conditions for music and speech improved compared to Renaissance ones. The main cause of this phenomenon was the rich ornamentation. The shaping, columns and pillars, entablatures, and cornices variously adorned contributed to a greater spread of mid and high frequencies. The presence of side chapels also contributed to the propagation of low frequencies. Moreover, many of these churches were heirs to the architecture of Borromini and Guarini, who designed alternating concave and convex forms in churches, creating spatial dynamism, which also contributes to greater sound propagation (NAVARRO ET AL. 2009).

Wooden ceilings represent an important element for quality acoustics in sacred spaces. Such means to achieve the desired acoustic parameters were often recommended by significant architects during the early Baroque period but were rarely implemented in practice. They favoured wooden ceilings over domes and vaulted spaces because their use worsened the acoustics of enclosed spaces. However, recent studies have shown that vaulted spaces reduce reverberation time values at low frequencies compared to flat ceilings. This advantage can also be attributed to the larger absorption area of the dome (DOMENIGHINI ET AL. 2023).

During this period, there were also experiments with temporarily adding draperies to improve acoustic conditions for music and choral entrances. Although this meant improvement in acoustic conditions for spoken word as well, it was not a priority during this period since preaching was again done in Latin, which most believers did not understand anyway (NAVARRO ET AL. 2009).

Speech intelligibility was not as important during this period to become the main subject of interest. Its importance fully manifested itself during the Second Vatican Council.

From an acoustic perspective, there have been significant changes in the liturgy of the Catholic Church relatively recently, after 1965. One of the most notable changes following the Second Vatican Council was the priest facing the congregation during the celebration and the introduction of national languages instead of the traditional Latin used in the Tridentine Mass. The adoption of national languages meant an increased demand for good speech intelligibility during the celebration. Present people were no longer mere spectators during the liturgy but could fully participate in it (SCHLOEDER 1998).

Speech intelligibility became a priority in churches built after the Second Vatican Council. The Roman Missal stipulated that the word should be proclaimed from a place that is sufficiently visible and dignified. Greater scientific knowledge of architectural acoustics, as well as the implementation of electroacoustic installations to address voice projection issues, contributed to improved acoustic performance overall in Catholic churches after the Second Vatican Council compared to their predecessors (NAVARRO ET AL. 2009).

Currently, many churches have installed sound reinforcement systems to enhance speech intelligibility, as it is the primary acoustic function of modern churches. Comparisons between acoustics with sound reinforcement systems and without have been conducted in several studies (SOETA ET AL. 2012).

CONCLUSIONS

The evolution of sacred buildings and their acoustic properties represents the combination of theological, architectural, and cultural approaches. Each historical era has reflected a unique understanding of the relationship between acoustics, space, and spirituality. As technology advances, the challenge persists in balancing tradition with innovation, ensuring that the acoustics of sacred building continue to serve their fundamental purpose in facilitating spiritual communion.

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ACOUSTIC WOOD IMPRESSION STAND - DOUBLE BASS

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Abstract

The work focuses on the design and construction of a specific interior furniture accessory enriched with sound producing elements. It is a synthesis of design, furniture functionality and acoustic elements in one product. The subject of the research was the investigation and optimization of the parameters of this special product. The Acoustic Wood Impression Stand – Double Bass is one of special product of wood with multiple purposes and combines many functions in one interior object and also it is fully mobile, so the position in the interior can be easily changed according to most used function from many that this object has.

Keywords: Wood, musical instruments, furniture, acoustics, special wood products

INTRODUCTION

Among the customers, furniture seems to have position as a utility for daily use, that we cannot live without. However, purposes of single types of furniture are varying a lot within the field of daily used items by the customers. There are types with design, that strictly response to purely pragmatic aim of human physical needs. Also, there are types with purpose of an interior elements with aesthetical qualities and less practical capacity. Of course, one of primary purposes of interior design is to compose the mix of furniture elements that allows people to fully comfort their physical and psychical needs and expectations. Some of the elements are mobile objects that do not have fix position and they can be moved along the interior, so the residents have a possibility of changing the position of the object and modify the interior design accordingly to their personal needs. There are often attempts of designing products with combined purpose especially for smaller types of interiors. First step in process of designing furniture is the conceptual idea and has to be as good as it is possible, because from the start it determines the whole result. In this process it is very important for designer to make drawings of his ideas and take a time for thinking out every technical detail of it.

The first idea in innovative special product from wood was, that the furniture elements have to be bound somehow to the object with has appearance of a musical instrument or capability of making sounds or music. It opens the possibilities of making the whole furniture object a musical instrument with its unique functionality (ČULÍK ET AL., 2012).

CONSTRUCTION DESIGN IDEAS

The proposed product with concept went through some concepts of open shelves with appearance of classical instrument corpus. Then there was an idea of making shelves inside of functional double bass.

Technical options were limited by the construction of that instrument related to its acoustical functioning as an instrument, so the idea of shelves was transformed into a special rack on a rotational base fixed to a back plate of the instrument in the area of original structure elements of classical instrument construction. There were many options of doors to close this cabinet rack with bottles. Possibilities of doors hanged on a common furniture metal were considered as too heavy and sound affecting elements for instrument construction, so the best reasonable concept option was to use a construction element from wood materials.

Final conclusion was to make experimental rotation opening doors rotating around wooden dowel joint. The main problem of this idea was the stopping element that prevents the doors to rotate over and over. This problem was finally solved by adding the stop dowel under the doors and placing the main rotation dowel eccentrically so both sides of the doors are laying on the dowels when the doors are closed. Additional idea is to prevent the doors rattling by placing in a little magnet so there will not be unwanted vibrating areas. Some double bass players are making trapdoors like this in the back plate or in the “C” bout sides, so they can adjust the soundpost inside the instrument.

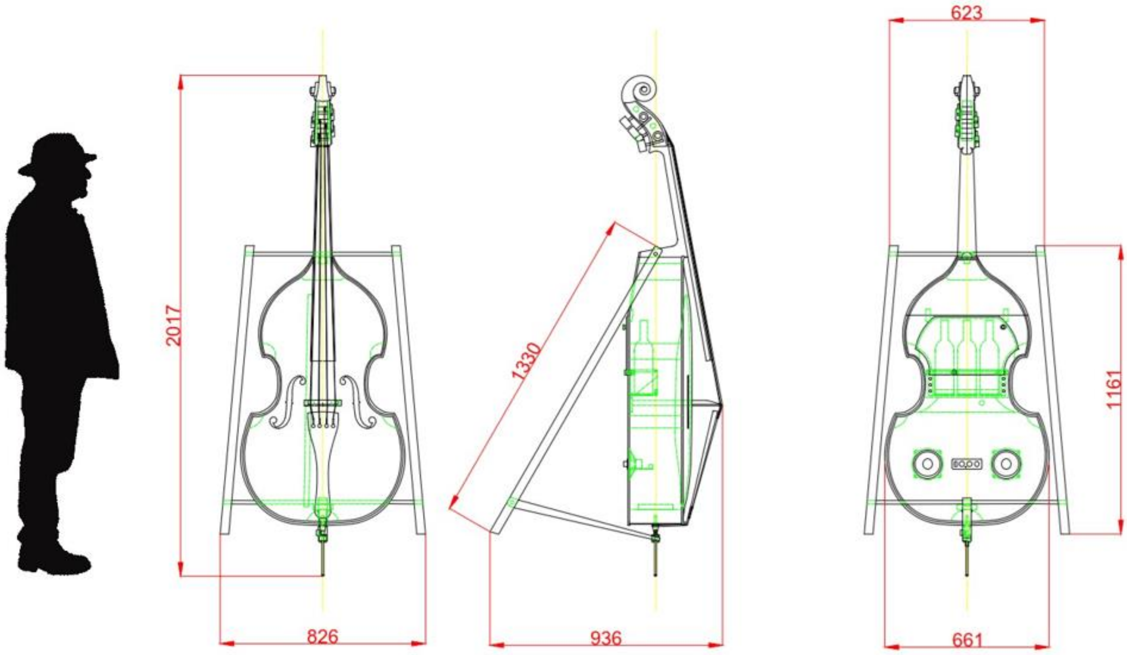

Figure 1. Basic dimensions of the special double bass and its comparation to average male figure.

MATERIAL REQUIREMENTS

The technical concept of this particular product is to create an exact copy of the double bass instrument with all its sizes and parameters but modify its back plate adding a furniture and music reproduction elements. The back plate conversion should be done with as little as possible affection of the sound of instrument therefore the added elements are in the areas of structural stiffening ribs. The two types of back plates are known: flat back and arched back. For this type of construction is reasonable to choose flat back for its good options to add elements on this type of back. Most reasonable option for back plate of this product is plywood that is used on most of modern student class double basses for its good mechanical reliability and size stability. Rest of the innovation product just strictly follows the technical documentation plans using materials and sizes that belong to classical double bass instrument (Figure 1).

Sides of the instrument are almost in every case from maple wood (*Acer pseudoplatanus* L.) and also the neck. The top plate is from resonant spruce (*Picea abies* L.), which is the wood with one of the most superior properties in terms of sound radiation. A very special feature of the material side of this project is using domestic wood specimen for a fingerboard of instrument instead of one from ebony or another of exotic wood species. Fingerboard has a requirement to be really stiff and hard so it will not bend at the end neck where fingerboard is no longer under supported. Also, its hardness is necessary for it to be scratchproof, because the metal strings are in direct contact with the surface. The solution for hard task to create fingerboard from domestic specimen has been solved finding the great properties and aesthetics of plum wood. In terms of hardness and density it is compared to the hardest European woods, and it has a beautiful red-purple colour, which is dark enough to not get visible dirty after short time period of playing. The timber from plum growing in high mountain altitudes has been bought for this purpose. Also, the rest of this timber could be used for small decorative parts of the instrument, so it will shine in white and red colours from solid woods.

The selection of suitable material for musical instruments (special wood products) could be inspired by the Slovak standard (STN 48 0059: 2014).

TESTING OF MATERIALS

Base of this product is musical instrument construction which requires many different types of materials filling its own purposes. Therefore, input materials are varying in sort, quality and properties. Every single component has its own requirements, so the material in its natural form has to be tested to prove its qualities before the manufacturing process starts. Most important material to analyse completely (subjective as well as objective methods of assessment) is the resonant wood for the top plate because is the main part of the resonant corpus of this product.

In the case of evaluating the quality of material for musical instruments making, most important are physical and acoustical properties of wood, which can be evaluated by non-destructive acoustic method of modal analysis for harmonic excitation using the Chladni patterns (ČULÍK, 2013).

ACOUSTICAL PROPERTIES AND SOUND EVALUATION

Acoustical properties are the under category of mechanical properties. It is determined by material behaviour under action of mechanical waves. These properties affect the acoustical behaviour of the special wooden product as a whole. It affects the tonal character of classical musical instrument part and also the sound of high-quality stereo music reproducing station built in the product.

The acoustical-wise concept of the proposed construction is the same as on the classical bowed string musical instrument. The main material, which by its properties contributes the most to the sound and acoustic performance of the object, is the top plate from resonant spruce wood (SM). One of the most important acoustical properties for string musical instruments material is acoustical constant (*A*) that can determines the loudness level, clarity of tone, or whole quality of sound timbre. Acoustical properties depend on the certain ratio of material density and its modulus of elasticity. Calculation results of relevant physico-acoustical characteristics of test specimens, while ρ_w is density of wood, E_L is dynamic modulus of elasticity along the wood grain, A is acoustical constant and c_L is speed of sound along the wood grain, Z is specific acoustic impedance, are showed in Table 1. The wood used for the making of the double bass can be considered as a good quality material.

Table 1. Physical and acoustical characteristics of wood test specimens:
SM – spruce, JV – maple, BP – birch plywood, SL - plum.

Wood	ρ_w / kg/m^3	E_L / GPa	A / m^4.kg^{-1}.s^{-1}	c_L / m.s^{-1}	Z / kg.m^{-2}.s^{-1}.10^{-5}
SM_1	375	7.45	11.87	4455	16.71
SM_2	412	11.14	12.64	5202	21.43
SM_3	408	11.29	12.91	5262	21.47
JV_1	557	13.52	8.62	4884	27.20
JV_2	571	13.44	8.49	4851	27.70
JV_3	560	12.21	8.34	4670	26.15
$BP4_1$	672	15.47	7.14	4798	32.24
$BP4_2$	671	16.40	7.37	4944	33.17
$BP4_3$	697	16.00	6.88	4791	33.39
$BP9_1$	710	13.18	6.07	4308	30.59
$BP9_2$	703	13.00	6.12	4299	30.23
$BP9_3$	714	13.01	5.98	4269	30.49
SL_1	751				
SL_2	712				
SL_3	732				

The reference instrument (classical double bass) in compare with innovative product had in all the sound tests significantly larger values of low frequency amplitudes in the sound frequency spectrum and more balanced tone visualized in less peaks in random frequencies. Also, the sound sustain is little bit shorter on impression stand subject or in other words slope of dampening is little steeper. The test by hammer impulse shown results similar to the test with open strings or bow playing. The impact of doors, the bottle rack, the presence of bottles, on the impression stand sound is not very significant, however the results of sound measurements indicated certain differences in the frequency spectrum.

Figure 2. The essential parts of an innovative product Acoustic wood impression stand - Double bass.

CONCLUSIONS

The acoustic wood impression stand (Figure 2) has proven its exceptional aesthetic appearance and unusual mix of functions that makes it a product worth interest. It has also proven the good functionality as a double bass musical instrument with the overall character of sound spectre very similar to classical full solid wood double bass instrument. In conclusion, this product has fulfilled all the expectations including functional storage for (wine, water) bottles, high quality music playback station and functional double bass instrument that is very comfortable for home playing.

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FOAMED WOOD AS AN ACOUSTIC INSULATION MATERIAL

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Abstract

This paper deals with the potential use of so-called "foamed wood" as an acoustic insulation material. This material is being developed as part of a dissertation as a porous thermal insulation material. As part of the effort to develop a heat-insulating and acoustic-insulating material that does not pollute the environment. Therefore, emphasis is placed on the input raw material. The main raw material is wood flour and wood fibre, which can be obtained by grinding residual waste from the wood processing industry. This contribution summarizes the possibilities of using the developed material based on foamed wood as acoustic insulation.

Keywords: Foamed wood, acoustic insulation, wood-based sound absorber, wooden waste

Acknowledgements

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INTRODUCTION

Materials that can significantly absorb sound are called sound absorbers. Sound absorption occurs when sound waves pass through a porous material, and the sound energy is reduced due to friction against the pore walls and heat exchange, therefore the porosity of the insulating material has a major effect on sound absorption (Taiwo et al., 2019). Other factors affecting sound absorption are fibre size, temperature, flow resistance, density, thickness, compression, and design or placement, which significantly affect the acoustic properties of fibre materials and their composites (Reif et al., 2016).

Sustainability has been a big topic in recent years, and the materials industry is no different (Ali et al., 2020). more and more emphasis is being placed on the ecological production of materials and their recycling or ecological disposal (Pescari et al., 2022, Arenas et al., 2020). That's why we decided to develop an insulating material that would meet these requirements in a truly innovative way. By mixing the mixture with foaming agents and thereby ensuring the porous structure of the material, which has favourable thermal and acoustic insulation properties.

“Foamed wood” offers numerous advantages, making it an innovative and eco-friendly insulation material. Its lightweight nature, achieved by incorporating air into its structure during the foaming process, provides excellent insulating properties. Developed as thermal insulation, this material also has great potential as an acoustic insulation material that can dampen sound transmission in buildings. Moreover, foamed wood demonstrates increased strength and durability while being sustainable, as it is typically sourced from renewable materials (Ferreira et al., 2023).

PRINCIPLES OF SOUND ABSORPTION

When sound waves hit porous materials, there are three types of sound energy transformations: reflection, absorption, and transmission. The fully sound energy can be considered as the sum of the energy that has been reflected, absorbed, and transmitted (Amares et al.,2017) Sound energy in sound absorbers follows the following principles: Air molecules contained in the pores of the absorber vibrate and hit the walls of the pores, which leads to the conversion of sound energy into thermal energy, after which it is dissipated. The other principle is that when the longitudinal sound waves penetrate into the porous absorbent, the air in the pores is periodically compressed and released, and the sound energy is gradually consumed in the material due to energy conversion (ROSSING ET AL., 2014). These principles follow the criteria when designing acoustic insulation. the material should have a sufficiently large number of pores, cavities, gaps, or channels, which should be of the right size and interconnected (CROCKER ET AL., 2007). Furthermore, there should be channels and an open structure between the surface of the absorbent material and the inner structure.

Sound absorption can be included among the basic characteristics of acoustic insulation. Sound absorption coefficient (SAC) can be calculated by measuring the total amount of sound energy absorbed by materials. The SAC range is between 0 and 1, 1representingthe highest absorption, while 0 shows no absorption. Absorption of low-frequency sounds, e.g.500 Hz, is very difficult compared to high-frequency sounds (HASSAN ET AL., 2012). The propagation of sound waves through a medium without absorption and frequency loss is known as transmission. The transmission coefficient (t) is the fraction of incident energy that is not reflected or absorbed. The transmission loss can be defined as 10log(t) dB. When the sound waves strike surfaces, some part is absorbed, while the rest is reflected (EVEREST ET AL., 2001).

There are mainly two methods of measurement reported for sound absorption: the reverberation chamber method and the impedance tube method (BUJOREANU ET AL., 2017). The reverberation chamber method is widely used for a bigger sample size to determine the sound absorption coefficient. The sample is mounted inside a sound insulated reverberation room/chamber. The walls, roof, floor, etc., are highly reflective (HASSAN ET AL., 2012).

DEVELOPED MATERIALS

Two prototypes of thermal insulation with a final thickness of 40 mm were created, which were named as FW1 and FW2. These prototypes use an inorganic blowing agent. Materials parameters of two prototypes of thermal insulation are given in Table 1.

Table 1. Material parameters.

Parameter	FW1	FW2
Material components	wood fibres	wood flour
Fibres/particles size [mm]	0.03 - 5	0.01 – 0.5
Pore size [µm]	400-1500	1 - 1000
Density ρ [kg.m-3]	97.8	265.7
λ [W.m-1.K-1]	0.041	0.97
R [m2·K.W-1]	0.97	0.90

For the FW1 sample, wood fibre was used for production. Thanks to the longer fibres, a highly porous structure was created, as we can see in Figure 1.

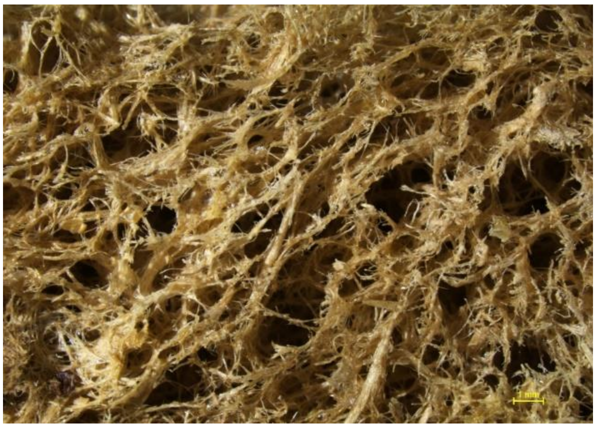

Figure 1. Structure of sample FW1, 12.7x6.3.

For the FW2 sample, wood flour was used in the production. During the production of wood flour, the fibres are significantly shortened and therefore the structure of the resulting material contains finer pores and the resulting material has a higher density as we can see in Figure 2.

Figure 2. Structure of sample FW2, 12.7x6.3.

Table 1 also lists the measured values of the thermal conductivity coefficient (λ), thermal resistance (R) and density (ρ). It is clear from the table that material made purely from wood fibre has a much lower density than material made from wood flour. This is due to the ability of the FW1 material to create a structure with larger pores, while the FW2 has a slight subsidence, and the pores are therefore smaller.

CONCLUSIONS

This work is intended to serve as an overview and presentation of a newly developed wood-based insulation material. This material, which is also being developed as thermal insulation, has the potential to be a good acoustic insulator thanks to its porous structure. Of course, this statement must be substantiated by proper research and study of this material. The next step is to further develop and modify this material so that it meets the demanding requirements of the construction industry. The material described in this article is a type of prototype of insulation materials using the principle of inflating materials based on wood fibres of various sizes. It is the ability to use a small percentage of wood fibre in the form of wood flour that allows even a small percentage of wood waste, or low-quality wood waste, to be used.

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CHALLENGES IN MEASURING NATURAL RAIN NOISE

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Abstract

Accurately predicting the sound generated by natural rainfall is important for adequate assessment of potential adverse effects of rain noise on speech intelligibility and comfort. This article summarizes the main challenges related to the measurement and systematic study of natural rain.

Keywords: Natural rain, rain noise, measurement, challenge

Acknowledgements

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INTRODUCTION

The acoustic environment significantly influences communication, sleep quality, cognitive functions, and various other aspects of life (Environmental noise in Europe — 2020 — European Environment Agency [no date]; Moudon 2009; Theakston, Weltgesundheitsorganisation 2011; World Health Organization. Regional Office for Europe 2018). Rain noise ranges from a soothing background sound to a source of substantial discomfort. Predicting the sound radiated by underroof surfaces due to natural rainfall is is of substantial importance, as increased noise levels can negatively impact speech intelligibility, comfort, and listening conditions for occupants (Yu, Hopkins 2020). Natural rainfall varies in drop impact rate and has a statistical distribution of raindrop diameters, making it difficult to replicate in laboratory settings. Therefore, artificial rain, which provided greater control over the rainfall properties- standardized by ISO 10140-5:2021-is commonly used in studies (Guigou-Carter, Villot 2003; Hopkins 2006; Schmid, Kingan, Panton, Willmott, Yang, Decraene, Reynders, Hall 2021; Toyoda, Takahashi 2013). The significant differences between natural and artificial rain may lead to variations in generated noise, while insight in the generation process of noise from natural rain is crucial for practical applications (Yu & Hopkins, 2020). However, measuring it in real-world scenarios presents significant challenges.

ENVIRONMENTAL AND EXPERIMENTAL CHALLENGES

1. WEATHER AND CLIMATE CHALLENGES

The inherent unpredictability of weather patterns, particularly in regions such as Belgium, presents a notable challenge. The dynamic nature of weather conditions complicates the identification of suitable measurement periods and sites. Furthermore, wind plays a pivotal role, as wind-driven rain, characterized by a substantial horizontal velocity component, significantly influences the noise generated by natural rainfall. For instance, below the frequency of 200 Hz, the rain sound intensity at an angle of 60° is approximately 7 dB lower than that at 30° during intense, heavy, and moderate rainfall events (Yu & Hopkins, 2020). The generalization of findings from test experiments conducted within specific climatic and geographical contexts poses another significant challenge. The applicability of results may not extend seamlessly to dissimilar regions.

2. BACKGROUND NOISE

Mitigating background noise is essential for accurate data collection. While selecting test locations away from traffic noise helps, it introduces additional challenges such as equipment protection and mobility. Moreover, natural environments are susceptible to unwanted ambient sounds like bird calls.

3. DRYNESS

The challenge of maintaining equipment dry during the recording of natural rain noise, encompassing microphones, cables, soundcards, sonometers, and computers, is notable. A strategic approach employed to mitigate this challenge involves leveraging lengthy cables to relocate equipment to sheltered areas, thereby minimizing exposure to moisture. However, the proximity of microphones to the samples necessitates positioning them before the onset of heavy rainfall or during periods of reduced intensity. An additional challenge pertains to recording background noise concurrently with rain. Covering microphones risks capturing the impact of water on the covering material, potentially distorting the recorded sound. Conversely, leaving microphones uncovered poses a risk of damage. The use of a sonometer also presents logistical difficulties during heavy rainfall. Conventional methods involving traversing the recording area to measure acoustic parameters tend to be impractical due to potential equipment damage. As a workaround, the utilization of extended cables facilitates remote data collection from the sonometer, ensuring the safety of the device and microphone.

4. REFLECTIONS

To achieve optimal clarity in recording natural rain noise, minimizing reflections from surrounding surfaces is imperative. Ideally, placing samples in a free field area devoid of reflective surfaces would be preferable. However, ground reflections remain unavoidable. To address this, positioning samples on a grass surface, characterized by a high scattering and absorption coefficient, has emerged as the most effective solution. In our research, concurrently recording rain noise on both cushion and membrane in the framework of comparing their rain noise generating characteristics necessitates strategic placement to prevent mutual interference. In the performed experiments, samples were positioned behind walls to mitigate cross-talk. However, this approach increases the likelihood of reflections from the walls. As a compromise, samples were positioned on two sides of the building's exterior corner, sufficiently distant from the wall to reduce the impact of reflections.

RAIN PROPERTIES EVALUATION CHALLENGES

1. RAIN INTENSITY

The intensity of natural rainfall is probably the most important rain property, which influences both its flow rate and raindrop size distribution (YAN ET AL., 2016). Natural rain exhibits a wide range of intensities, typically ranging from 0 mm/h to 100 mm/h (IEC 60721-2-2:2012) Consequently, precise determination of the rain intensity is essential for establishing correlations with the spectrum and intensity of natural rain noise. Conventional gauges typically offer only hourly average intensity measurements. Therefore, the utilization of advanced equipment capable of real-time rain intensity measurement becomes imperative for in-depth analysis.

2. RAIN DROP SIZE AND DISTRIBUTION

The utilization of high-speed cameras presents a prospective, albeit costly, method for capturing raindrop characteristics. However, the inherent variability in natural raindrop sizes poses a significant challenge, complicating accurate quantification of the drop size distribution. MARSHALL AND PALMER (1948) proposed a logarithmic equation to approximate the drop size distribution, providing a general framework. Nevertheless, it should be acknowledged that the drop size distribution may vary across different weather conditions and seasons, necessitating further investigation into the unique characteristics of each rainfall episode.

The pivotal distinction between natural rain and artificially generated rain, as delineated in ISO 10140-5:2021, lies in their respective raindrop size distributions. Unlike artificial rain, which conforms to a standardized distribution typically centered around 5mm, natural rain exhibits considerable variability in drop size, with maximum values around 1mm diameter. This inherent difference results in substantial differences in noise intensity between natural and artificial rain environments (YAN, LU, LI, 2016).

3. TERMINAL VELOCITY

The terminal velocity of raindrops adds another layer of complexity to rain property evaluation. While the terminal velocity is inherently linked to the drop size(Figure 1), it is commonly assumed to be uniform across drops of similar size. This parameter also plays an important role in distinguishing natural rain from artificially generated rain. Natural raindrops typically exhibit a terminal velocity of approximately 10m/s, whereas according to ISO 10140-5:2021 standards, artificial drops falling from a height of 3.5m reach the ground with a terminal velocity of 7m/s.

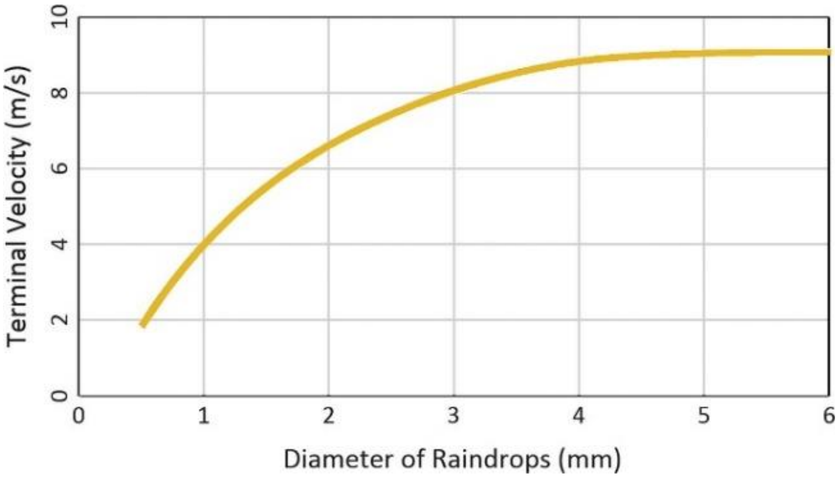

Figure 1. Dependence of the terminal velocity of rain drops on the drop diameter (YAN, LU, LI 2016).

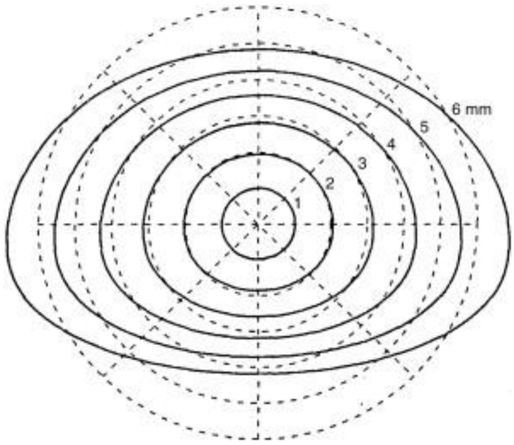

Figure 2. Computed shapes for *D* = 1, 2, 3, 4, 5 and 6 mm with origin at the center of mass. Shown for comparison are dashed circles of diameter D divided in 45° sectors (BEARD, CHUANG 1987).

4. DROP SHAPE

Assessment of rain properties is further complicated by the shape of raindrops. At their terminal velocity, smaller drops, typically measuring less than 2 mm, exhibit nearly spherical shapes, whereas drops with a diameter of 6 mm feature an almost flattened bottom (YU, 2019). This variation in drop morphology introduces additional complexity to the theoretical modeling of natural rain noise. Figure 2 shows computed shapes for raindrop diameters ranging from 1 to 6 mm, which have been validated through wind tunnel experiments and the Two-Dimensional Video Disdrometer (2DVD) method (Beard, Bringi, Thurai, 2010).

CONCLUSIONS

Assessment of rain noise in natural environments presents multifaceted challenges spanning experimental setup, rain property evaluation, and environmental factors. Addressing these challenges requires innovative approaches, employing advanced equipment and meticulous attention to detail. Moreover, accounting for the dynamic nature of weather conditions and the variability in rain properties across different regions is essential for generating robust and applicable findings.

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OPPORTUNITIES AND RESEARCH CHALLENGES OF BIO-BASED PCM IN MEDIUM-TEMPERATURE ENERGY STORAGE APPLICATIONS

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Abstract

This contribution examines the opportunities and research challenges associated with phase change materials (PCMs) in medium-temperature applications, to guide future advancements in sustainable energy storage technologies. Bio-based PCMs provide significant sustainability benefits and excellent latent heat storage capacity. However, there are a few drawbacks, like low thermal conductivity, chemical stability, and life cycle, which should be considered and figured out. Even though during comparison for heat storage of 547 MJ in 1 m^3 tank volume, a latent heat storage tank (erythritol) has a temperature change of Δt=100°C, and a sensible heat storage tank (sand) has a temperature change of Δt=412°C. The latent heat storage is superior in many aspects, especially the temperature change. The potential to improve energy efficiency in solar systems is present by integrating bio-based PCMs into sustainable energy systems.

Keywords: Energy storage, sensible heat, latent heat, PCM, bio-based

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INTRODUCTION

The decline of non-renewable energy sources and the imperative for environmental conservation are propelling a global transition towards solar power as a primary renewable energy source, replacing fossil fuels. Since solar energy is predominantly available during the day, efficient heat storage solutions are necessary for night-time usage. Thermal energy storage (TES) systems play a critical role in enhancing energy efficiency and facilitating the integration of renewable energy sources (Figure 1). TES systems can be divided into sensible heat storage (SHS) and latent heat storage (LHS). SHS systems depend on the heat capacity of materials, leading to notable temperature variations, whereas LHS systems employ phase change materials (PCMs) to store and release heat with minimal temperature fluctuation. LHS is particularly effective for medium-temperature applications (100°C to 300°C) (MEHLING, 2008). Bio-based PCMs (BioPCMs) present environmental advantages and are renewable, yet they face several challenges such as thermal stability, system compatibility, cost, and scalability.

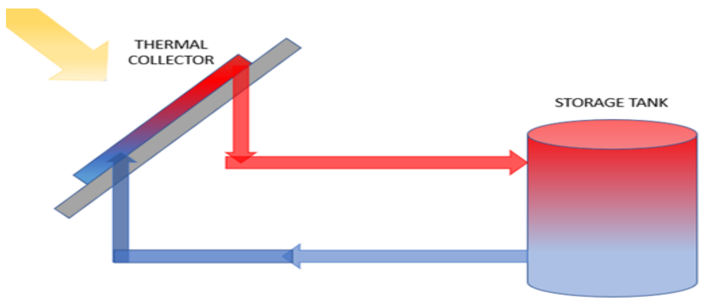

Figure 1. Block diagram of solar thermal collector and storage tank.

METHODS

An analysis of several selected papers revealed that older studies predominantly focused on SHS rather than LHS systems. However, recent research highlights the potential of PCMs as promising solutions for thermal energy storage in building applications (BENHORMA, 2024). For instance, a heat storage tank filled with a BioPCM type sugar alcohol (erythritol) operating at 120 °C can store the same thermal energy as a tank filled with sand, which would need to reach 432 °C. Calculations of energy demand were made to describe the difference between LHS and SHS systems, as well as several factors that could affect the cost directly and indirectly have to be considered during the development phase as required temperature, heat losses, tank temperature, and dead load (Figure 2). This demonstrates the efficiency of LHS systems over SHS systems in terms of temperature management. As interest in LHS continues to grow, further research and development could lead to even more effective and practical applications of PCMs in various energy storage contexts.

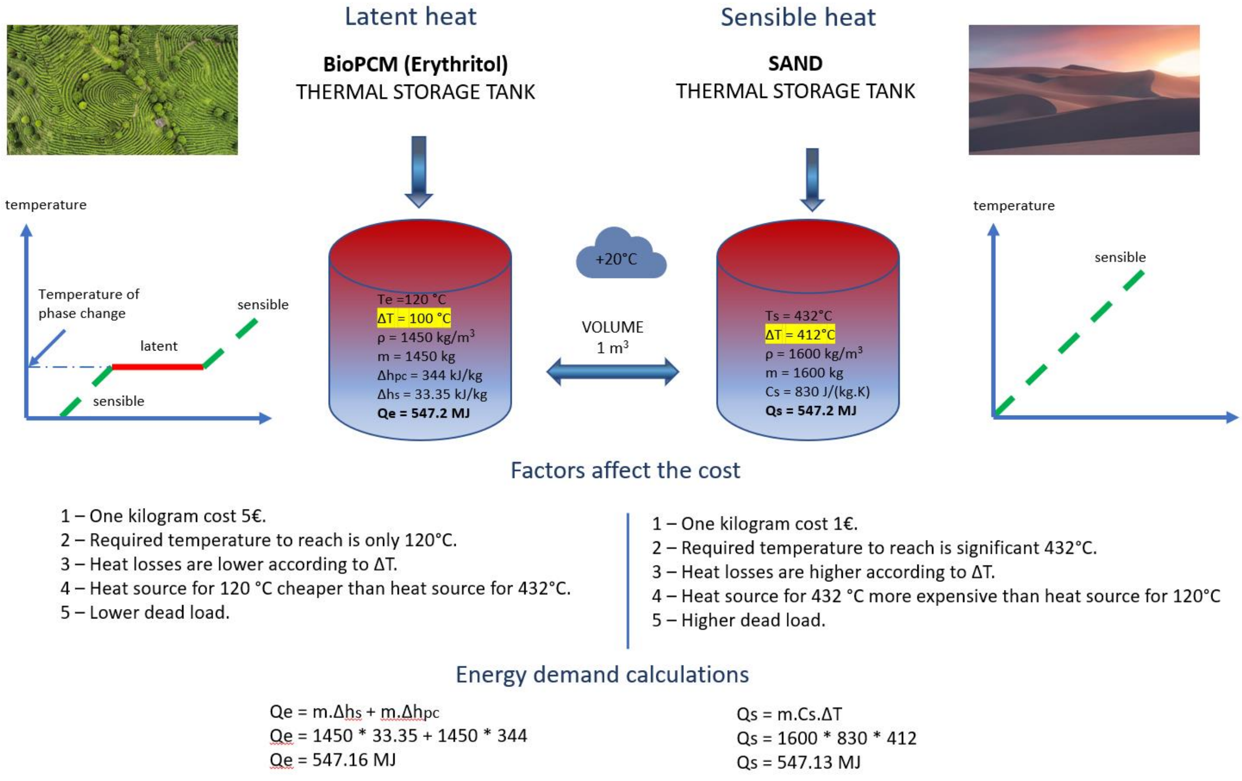

Figure 2. Analyses and comparison between PCM tank (LHS) and sand tank (SHS).

FINDINGS AND ARGUMENT

BioPCMs for latent heat storage are environmentally friendly, sourced from renewable resources, and offer various melting temperatures and enthalpies. Additionally, BioPCMs exhibit thermal conductivities in the range of 0.01-0.7 W/(m.K) (KOŚNY, 2015). They are also cost-effective and non-flammable. BioPCMs can be classified into three categories: sugar alcohols, fatty alcohols, and fatty acids (MEHLING, 2008). The presented paper explains the opportunities (Table 1) and challenges (Table 2) of these materials for medium-temperature energy storage applications. Collaborative efforts between researchers, industry stakeholders, and policymakers are essential to overcome these challenges and unlock the full potential of BioPCMs. By focusing on innovative solutions and technological advancements, BioPCMs can play a vital role in sustainable energy systems, contributing to energy efficiency, environmental sustainability, and the global transition to renewable energy sources.

Table 1. Opportunities of BioPCMs in medium-temperature energy storage applications.

	Sustainability and Environmental Impact	
Renewable Sources	• BioPCMs are made from renewable resources like sugars, oils from plants, and animal fats, are eco-friendly alternatives to petroleum-based PCMs like paraffin, reducing fossil fuel dependence and enhancing sustainability;	(Benhorma, 2024)
Biodegradability	• BioPCMs are biodegradable and non-toxic, reducing environmental impact and easing waste disposal issues compared to synthetic counterparts like paraffin wax.	(Junaid, 2022)
	Thermal Energy Storage Efficiency	
High Latent Heat	• BioPCMs exhibit high latent heat storage capacity (150-350) kJ/kg, which enhances the efficiency of thermal energy storage systems.	(Sharma, 2023)
Temperature Stabilization	• BioPCMs can effectively regulate the room temperature by absorbing and releasing heat at constant temperatures during phase transitions, which is crucial for applications like solar thermal systems.	(Sharma, 2023)
	Economic and Market Potential	
Cost-Effective	• Utilizing by-products from the agricultural or food industry and add value to waste materials, making BioPCMs a cost-effective solution.	(Hopkins, 2021)
Growing Market Demand	• Increasing demand for sustainable and energy-efficient materials, driven by global energy policies and consumer awareness, creating a significant market opportunity for BioPCMs.	(Hopkins, 2021)
	Technological Integration	
Renewable Energy Systems	• BioPCMs can be integrated with solar thermal systems, enhancing their efficiency by storing excess thermal energy for later use, thus, smoothing out energy supply and demand.	(Rashid, 2023)
Building Applications	• BioPCMs can be used in building materials to improve thermal comfort and reduce energy consumption by stabilizing indoor temperatures.	(Rashid, 2023)

Table 2. Challenges of BioPCMs in medium-temperature energy storage applications.

	Material Properties	
Thermal conductivity	• In general, BioPCMs generally have low thermal conductivity, limiting the heat transfer rate. Enhancing conductivity through composite materials or additives is a significant research focus.	(Baylis, 2023)
Phase transition temperatures	• Identifying BioPCMs with suitable phase transition temperatures for specific applications, typically ranging from 30°C to 200°C, remains challenging.	(Mao, 2022)
Thermal stability	• It is crucial to ensure that BioPCMs maintain their thermal properties over numerous cycles without degradation. This involves studying these materials' thermal and chemical stability over extended use.	(Mehrizi, 2023)
	Performance and Durability	
Cycling Stability	• BioPCMs must withstand repeated phase change cycles without significant loss of performance. Research shows that some fatty acids can degrade over time, affecting their reliability. Stabilization techniques are being developed to address this issue.	(Jamekhorshid, 2014)
Compatibility	• Ensuring chemical compatibility with other materials used in storage systems to prevent reactions that could degrade PCMs or the system components is essential.	(Nazari, 2020)
Encapsulation Techniques	• Encapsulation of BioPCMs is crucial for preventing leakage and enhancing heat transfer efficiency. Techniques such as macro-encapsulation, micro-encapsulation, and shape-stabilized PCMs face challenges related to cost and thermal performance. Optimization is essential for practical medium-temperature energy storage applications.	(Junaid, 2022)
Economic Viability	• PCM-based energy storage systems face high costs for materials, processing, and encapsulation. Reducing these costs through material advancements, optimized manufacturing, and efficient encapsulation is essential for market competitiveness.	(Hopkins, 2021)

CONCLUSIONS

BioPCMs present a promising solution for medium-temperature energy storage applications in buildings, offering significant sustainability benefits and high latent heat storage capacities. The integration of BioPCMs into solar thermal systems and building materials can enhance energy efficiency, stabilize indoor temperatures, and meet the growing market demand for sustainable and energy-efficient solutions. However, challenges remain in optimizing BioPCMs for practical applications. Issues such as low thermal conductivity, phase transition temperature suitability, thermal stability, cycling durability, chemical compatibility, and encapsulation techniques need to be addressed through ongoing research and material science advancements. Enhancing the thermal performance and economic viability of BioPCMs is crucial for their widespread adoption in TES systems.

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SOUND-ABSORBING PROPERTIES OF GRANULATED PLASTIC WASTE MATERIALS

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Abstract

This paper investigates the sound-absorbing properties of recycled loose plastic granules. The study focuses on three types of foam plastics: ethylene-vinyl acetate (EVA), polyethylene (PE), and polystyrene (PS). The sound absorption coefficient *α* of plastic granules is compared with the one of polyester (PES) fiberboard, a conventional sound-absorbing material. Also, the bulk density is analyzed to elucidate the effect of porosity on the sound-absorbing characteristics. The findings suggest that using recycled waste plastics as alternatives to conventional materials can effectively address both waste disposal and noise pollution challenges.

Keywords: Sound absorption, recycling, plastics

Acknowledgments

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INTRODUCTION

Recycled waste plastic granules present a viable alternative to traditional fibrous sound-absorbing materials. Their sound absorption capabilities are influenced by factors such as structure, grain size, and used binder.

VORONINA AND HOROSHENKOV (2003) classified granular media, including vermiculite, granulated rubber, perlite, and granulated nitrile foam, demonstrating that granules from old tires and cables can effectively be used to produce customized sound-absorbing materials. By selecting the appropriate granule size and material thickness, maximum sound absorption can be tailored to specific frequency ranges. Generally, larger grains were found to exhibit lower absorption, the highest *α* values were achieved with grain sizes between 0,5-1 mm.

BISKUPIČOVÁ ET AL. (2021) further investigated the impact of grain size on sound absorption. They examined five composite materials made of plastic grains (EVA, PP, PS, PVC) bonded with glue. The study revealed distinct differences in acoustic absorption spectra between mixtures containing only large grains (4-8 mm) and those with both large and small (0-4 mm) grains.

BUMANIS ET AL. (2023) measured sound-absorbing properties of recycled EPS-gypsum composites. As composite density increased, the peak of sound absorption showed higher values (in the range of *α* = 0,69-0,97; depending on the composite) and slightly shifted to lower frequencies. The most effective range for this material ranges between 600 to 700 Hz.

METHODS

Three types of plastic granules were investigated (Figure 1): ethylene-vinyl acetate (EVA), polyethylene (PE), and polystyrene (PS). These materials were obtained via the Faculty of Civil

Engineering of STU Bratislava, which obtained them from a local waste processor. For all plastics, a grain size of 2-4 mm was achieved by sieving. The bulk density values of the plastic granules are listed in Table 1.

Considering the loose structure of bulk (granulated) material and the horizontal position of the impedance tube, the granules were held in a paper tube with a length of 50 mm and a diameter of 45 mm, which was filled with plastic granules and covered with nylon fabric (Figure 2).

The measured properties were also compared with the ones of polyester (PES) fiberboard cylinder samples with the same dimensions.

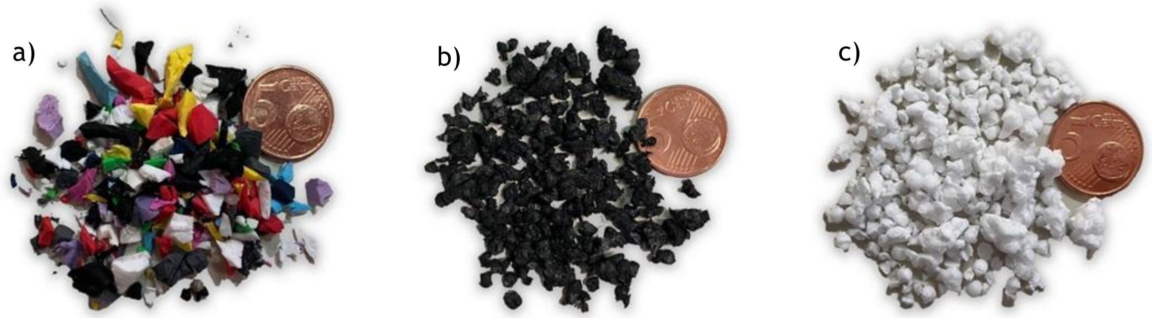

Figure 1. Investigated plastic granules: a) ethylene-vinyl acetate (EVA), b) polyethylene (PE), c) polystyrene (PS).

Table 1. Bulk density of plastic granules.

Material	Grain size (mm)	Bulk density (kg/m³)
EVA	2-4	133
PE	2-4	36
PS	2-4	29,5
PES fiberboard	-	40,2

Sound absorption measurements were performed at the Laboratory of Acoustics (KU Leuven) using an impedance tube with two microphones, according to EN ISO 10534-2. The transfer function method was used to determine the normal incident sound absorption coefficient and impedance in the 125-4000 Hz range. To obtain the measurement uncertainty, each sample was measured 3 times under different respective orientations around the axis of the tube.

FINDINGS AND ARGUMENT

In Figure 3, the sound absorption spectrum of the PES fiberboard is presented. This material has the typical behavior of porous-fibrous material, with low α values at low frequencies (α = 0,07 at 125 Hz) followed by a gradual increase, saturating at a high α value at high frequencies (α = 0,93 at 2500 Hz).

To understand how much nylon fabric will affect the α of the material, the PES fiberboard was also measured with nylon. The results show a minor increase of α in the range 315-2500 Hz, with a maximum at 2500 Hz (α = 0,94).

Figure 4 shows the acoustic performances of granular plastic waste materials. The shape of the sound absorption coefficient curves exhibits typical oscillating quarter wavelength resonance behavior, where the air gaps around the granules cause the oscillations of sound absorption (LEVI, SGARBI, PIANA, 2021). For all three samples, the first peak is at 1250 Hz, reaching the maximum of α = 0,9 for EVA and PS respectively.

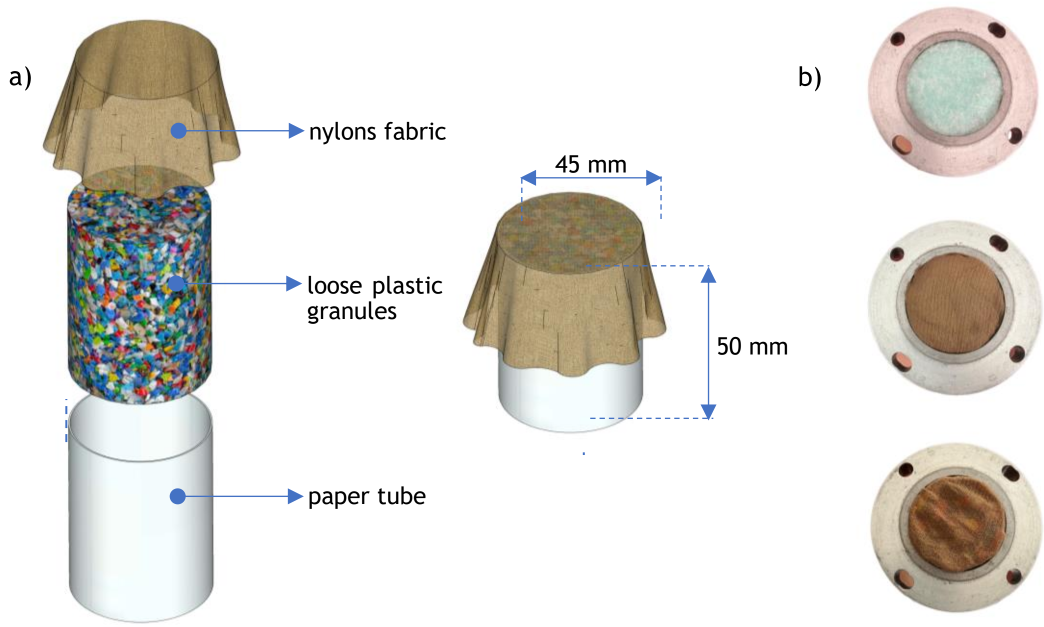

Figure 2. a) Sample composition, b) Front view of samples placed in the impedance tube.

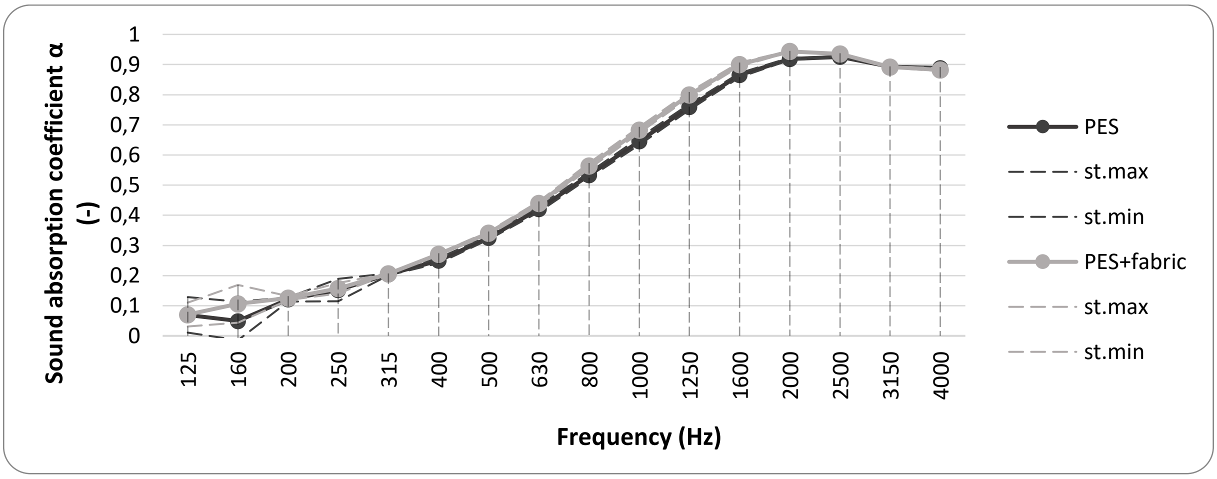

Figure 3. Sound absorption coefficient – PES fiberboard with and without the nylon fabric.

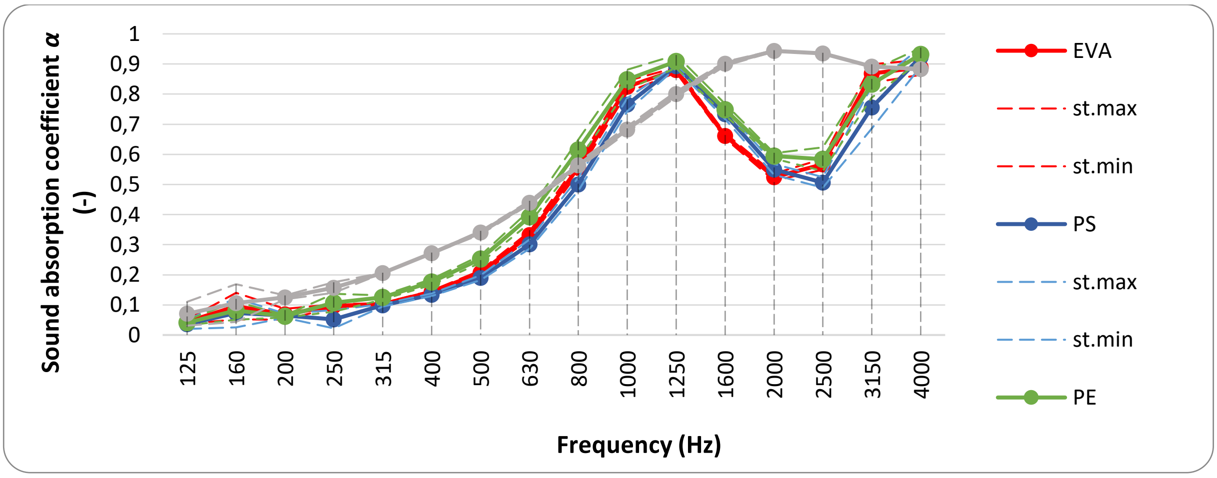

Figure 4. Sound absorption coefficient of porous granulated plastic materials.

Given that the thickness of the sample is d = 50 mm (0,05 meters), the results can be verified according to the quarter-wavelength resonance principle $\lambda = \frac{c}{f}$; $f_{\text{peak}} = \frac{c}{4d}$; where λ (m) is the wavelength of the sound wave with a frequency f_{peak} (Hz).

Combining this with the experimentally observed peak frequency of 1250 Hz, yields a speed of sound in the sample of

$$c = f_{\text{peak}} \cdot \lambda = 1250 \cdot (4.0{,}05) = 250 \text{ m/s}$$

corresponding with a tortuosity of 1,4.

CONCLUSIONS

The peak sound absorption of almost 90% at 1250 Hz indicates that the loose plastic granules are highly effective at absorbing sound in the mid-frequency range, which is interesting for several applications.

Compared to traditional sound-absorbing materials (like fiberglass or foam), plastic waste granules offer an environmentally friendly alternative to recycling waste materials.

For further research, additional direct measurements of tortuosity, flow resistivity, and porosity will be needed, to obtain the overall acoustic properties of the material.

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EXPERIMENTAL VALIDATION OF SEMIEMPIRICAL MODEL BASED ON ACOUSTIC RADIATION MATRIX METHOD

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Abstract

Sound power determination using the surface velocity of the source has been a research interest for a long. While the theoretical foundation of this method is well-established in the literature the experimental validation of this method has still not yet been explored satisfactorily. To provide experimental support for this method and to discuss its limitations this work emphasizes on the experimental approach. In this work, a flat plate, vibrating in the air medium is studied for the determination of radiated sound power from a vibrating structure. To do so a semi-empirical model based on a radiation resistance matrix and source surface velocity is exploited. The radiation resistance matrix was calculated theoretically using two attributes of the source and medium say the geometry of the radiating source in this case a flat square plate and the density of the radiating medium respectively. On the other hand, another quantity required for the sound power determination namely the surface velocity was measured experimentally using laser scanning. Using this radiation matrix and surface velocity the radiated sound power was calculated and the obtained results were compared with the standard methods. Unlike the archived studies on this method, this work aims to implement this method for designing the appropriate measurement techniques for the acoustic performance of the large building envelopes having flexible façade.

Keywords: Sound-radiation, surface-vibration, façade

Acknowledgments

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INTRODUCTION

Sound radiation is a phenomenon of propagation of elastic waves in the fluid medium. To be more precise, when a structure vibrates in a medium, the fluid next to the vibrating surface is actuated resulting in the radiation of the sound into the surroundings. While realising this phenomenon is easy to comprehend such as the sound radiating from the vibration in engines, speakers, machinery, and the human larynx, etc, quantifying such disturbance for determining radiated sound power is relatively complicated. In the current state of the art, this quantification can be done through a couple of methods, such as measurement of the pressure fluctuation in the medium and secondly through the vibrational velocity of the source. These methods have their own merits and limitations. Starting with the pressure-based quantification whereas this method is fast and easy, it shows inaccuracy in low-frequency regions and requires a special acoustic environment for the sound pressure measurement. On the other hand, while vibration velocity-based measurements are more accurate and suitable for in situ measurements they ask for high computational cost and still need to be explored for complicated surfaces. Nevertheless vibration-based sound power measurements in this study named as acoustic radiation matrix method (ARM) show improved results in the lower frequency region. In this work, we will briefly discuss these measurement techniques with different approaches mainly focusing on the ARM method. These sound power determination methods will be supported by experiments and the results will be compared to comment on the feasibility and accuracy of these different methods.

MODEL AND METHODOLOGY

- The surface velocity-based sound power determination method [1] also known as the acoustic radiation matrix method (ARM) is used in this study.
- ARM computes the sound power using surface velocity (v) and radiation resistance matrix (R).
- Surface velocity is measured using LDV and the resistance matrix is calculated using surface geometry and the surrounding medium.
- Moving ahead with ARM the source surface is discretized and each element is approximated as the baffled piston radiating in half space.
- Sound pressure is approximated [2] at each element using surface velocity.

$$\tilde{p}_{ei}(x_i, z_i) = \frac{j\omega\rho_0 A_e e^{-jkR_{ij}}}{2\pi R_{ij}} \tilde{v}_{ej}(x_j, z_j) = \tilde{Z}_{ij}\tilde{v}_{ej}(x_j, z_j) \qquad (1)$$

- Radiated sound power from each element is computed individually and summed up for the total sound power.

$$\bar{P}(\omega) = \sum_{r=1}^{N} \frac{A_e}{2} \mathrm{Re}[\tilde{v}_{er}^* \tilde{p}_{er}] \qquad (2)$$

- Consequently, sound power in terms of surface velocity by substituting $\boldsymbol{p}$ in terms of $\boldsymbol{v}$ is determined as [3].

$$\bar{P}(\omega) = \frac{A}{4N} \tilde{v}_e^H \left([\tilde{Z}] + [\tilde{Z}]^H\right) \tilde{v}_e = \tilde{v}_e^H [R] \tilde{v}_e \qquad (3)$$

- To validate the ARM obtained results were also compared with the results obtained from standard measurement methods.

RESULT AND DISCUSSION

- Structural modes are analyzed to predict the acoustic radiation modes.
- Major modes such as 48 and 102Hz show good agreement while a few minor modes are absent.
- Discrepancies in the determined sound power are seen as the radiation inefficiency of modes.
- Sound power determined using ARM is compared with the standard method, ISO 9614-2.
- Rayleigh's integral method (RIM) was also tested for verification of ARM.
- Figure 3(b) shows the comparison of results obtained from ARM and ISO; a good agreement was found for low frequencies while discrepancies were found in high-frequency regions.
- These discrepancies could be a violation of Rayleigh's model [3] of elemental size for sound pressure calculation on discrete surfaces.
- To validate our observations a grid refinement test was performed shown in Figure 3(d) and the results show promising outcomes with the observations made.
- RIM and ARM show good agreement in the wider frequency range.
- RIM with the introduction of the radiation efficiency factor can lead to better results in far fields as well.

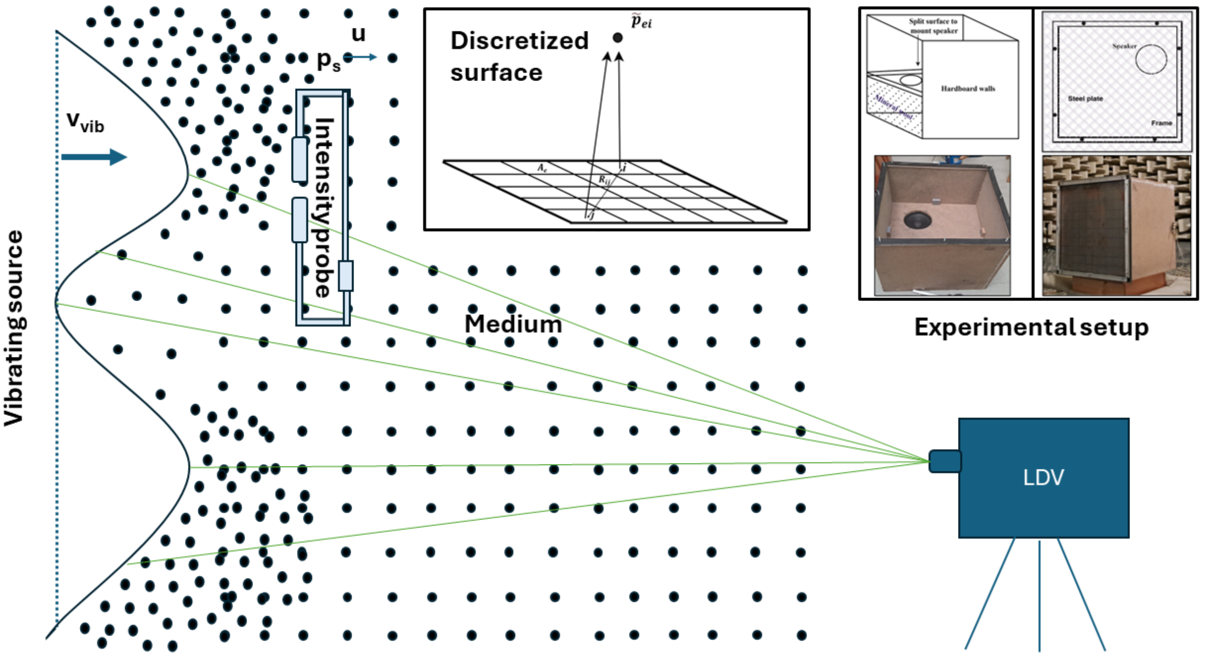

Figure 1. Sound pressure and surface velocity-based sound power determination.

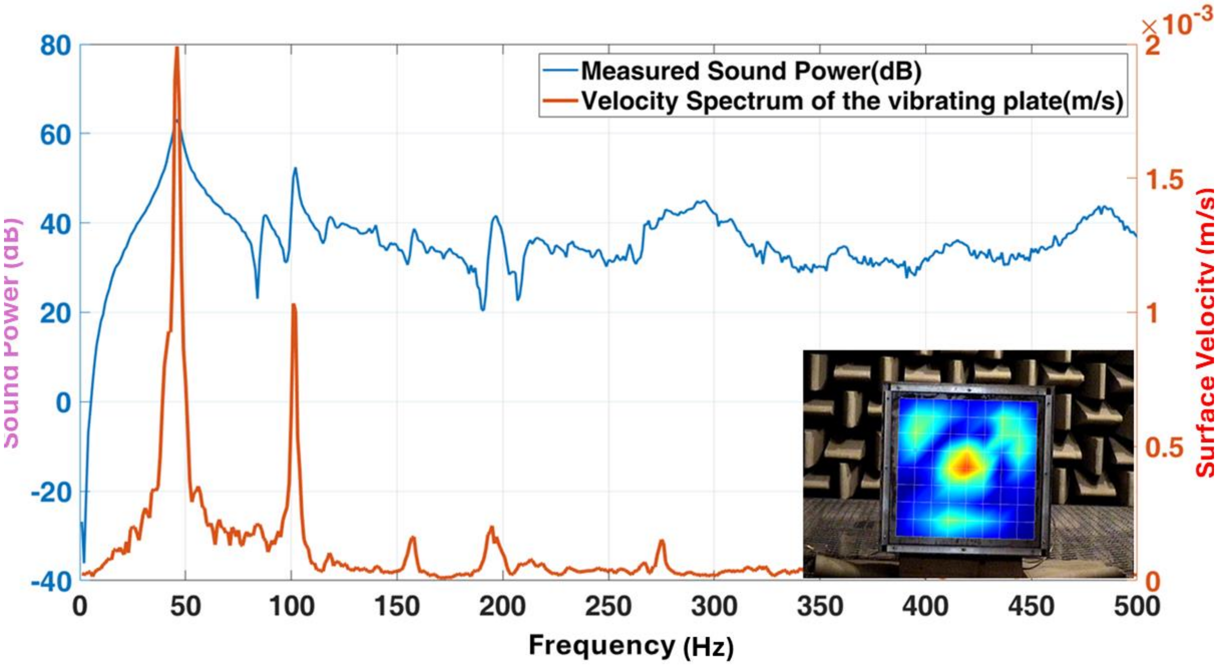

Figure 2. Prediction of sound radiation modes from structural modal analysis.

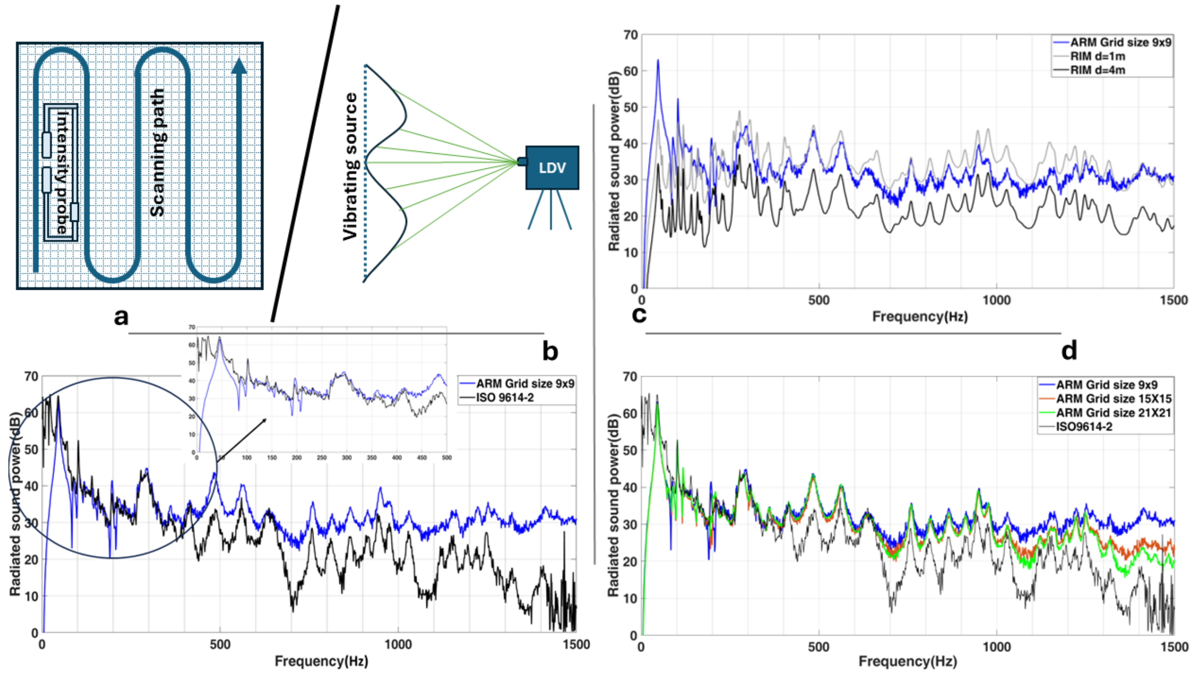

Figure 3: Sound power determination using acoustic pressure and surface velocity. a). Intensity probe and LDV measurement procedure, b). Comparison of ARM with ISO, c). Comparison of ARM with far and near field sound power using RIM, d). Effect of grid size on the accuracy of ARM.

CONCLUSIONS

In this study exploration of different sound power determination techniques provides perspective on different aspects such as the feasibility of surface velocity-based methods, the merits of ARM over the pressure-based methods, and its accuracy in the wide frequency range, etc. While results obtained from ARM show qualitatively good agreement with the standard measurement method discrepancies were found in the high-frequency region. Nevertheless, ARM estimates well in the low-frequency range which has been the major challenge with the pressure-based methods. This shows the potential of ARM for cases where background noise is the problem and makes it suitable for in situ measurements for the sound radiating surface. With these promising outcomes and by considering the potential of the ARM method in the future, this work will be incorporated with the change for the in-situ acoustic measurements of large building facades.

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SOUND ABSORPTION OF GRAPE STEMS – CASE STUDY

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Abstract

This paper presents the possibility of using grape stems as a sound-absorbing material. The objective is to determine if grape stems, sourced from the wine industry, can serve as a viable and eco-friendly alternative for manufacturing acoustic absorptive panels. The sound absorption coefficient (α) for grape stem materials with particle sizes of 0 – 0.7mm, 0.7 - 2mm, and 2 - 4mm showed a progressive increase across the analysed frequency range reaching maximum sound absorption values in range from 0.55 to 0.65 Hz. This integration of grape stems into acoustic materials enhances environmental sustainability and cleaner production in the materials sector, offering a sustainable and innovative solution that aligns with waste assessment standards and promotes environmentally friendly practices in acoustic.

Keywords: Acoustic material, Bio-based material, Grape stems, Sound absorption

Acknowledgements

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INTRODUCTION

Over the past twenty years, industrial operations and population growth have led to increased noise and global warming. Noise, which the World Health Organization (WHO) has linked to heart attacks (Van Kempen et al., 2012), has a significant impact on public health, with approximately 40% of the population suffering from noise-related problems, particularly in large urban areas (Rasmussen, 2018). Noise covers both outdoor and indoor environments, handling it indoors requires special solutions. The sound absorption plays important role in architectural acoustics in general. Beside room acoustic issues, sound absorptive materials are often used in design of building constructions with high insulation performance.

Studies on natural fibres like kenaf, wood, hemp, and others have demonstrated high sound absorption coefficients, influenced by thickness, density, and porosity (Berardi & Iannace, 2017). Materials like flax starch and date palm fibre are effective sound absorbers and eco-friendly alternatives to synthetic options (Alwaleed et al., 2014; Abd AL-Rahman et al., 2014). Reusing grape stems for acoustic materials offers an innovative and sustainable approach to finding sound-absorbing materials that are environmentally friendly and support environmental sustainability. Grape stems, classified as bio-based materials, have shown promise in applications due to their moisture buffering and sound absorption properties (Berardi et al., 2015; Raja et al., 2023). This study explores using grape stems, a by-product of the wine industry, to create sound-absorbing materials.

METHODS

The grape stem wastes were collected from private vineyards located within the viticultural enclave of the Nitra region in Slovakia. In order to obtain the by-product from the recovered waste, several steps were carried out, including cutting, drying, and sieving processes. Firstly, the material was chipped using a food chopper and then sieved to remove the finer fraction. The grape stems were then dried in a ventilated oven at 105°C (British Standards Institution [BSI], 2013) until they achieved a constant mass to avoid mould or insect infestation. Subsequently, the dried material was further sieved using 0.7, 2 and 4 mm sieves to obtain three fractions of by-products with different particle sizes and densities (see Figure 1), the characteristics of which are expressed in Table 1.


a)


b)

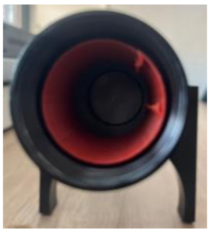

c)

Figure 1. Grape stem by-products obtained a) 0 - 0.7mm, b) 0.7 - 2mm, c) 2 - 4mm.

Table 1. Sample characteristics.

Name	Particle size	Density [kg/m³]
Grape stem A	0 - 0.7mm	212,7
Grape stem B	0.7 - 2mm	284,9
Grape stem C	2 - 4mm	162,6

Related to the particle size, the single fractions in following text are marked as 0.7, 2 and 4mm. For the measurement of the sound absorption coefficient of the grape stem by-product, the impedance tube method was used according to the ISO 10534-2:2023 (International Organization for Standardization [ISO], 2023).
This study evaluates the sound absorption coefficient (α) of various test specimens, focusing on loose grape stems. Initially, grape stems were tested in a horizontal impedance tube supported by a 3D printed holder with hight of 5cm and top cover with sock to prevent material loss. The same material was assessed without the holder and sock by positioning the tube vertically the specimen thickness 5cm, allowing comparison of the two sample mounting methods. Additionally, the sound absorption performance of grape stems in different particle sizes was analysed in before mentioned composition. This comparison aims to determine the efficacy of each installation method and the natural state of the samples, with mineral wool serving as a reference material for sound absorption performance. Figure 2 shows the holder, the holder with a sock, and mineral wool installed in the impedance tube.


a)


b)


c)

Figure 2. a) Holder b) Holder with sock c) Mineral wool.

Figure 3 shows an illustration of the set-up in which the grape stem sample is placed in the vertical impedance tube.

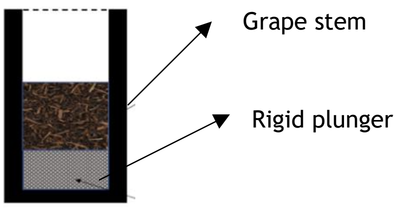


Figure 3. Illustration of the vertical impedance tube set-up.

RESULTS AND DISCUSSION

Figure 4 shows the sound absorption coefficient (α) in third-octave bands of the empty tube, holder, holder with sock, mineral, mineral wool with holder, and grape stem samples with varying particle sizes.

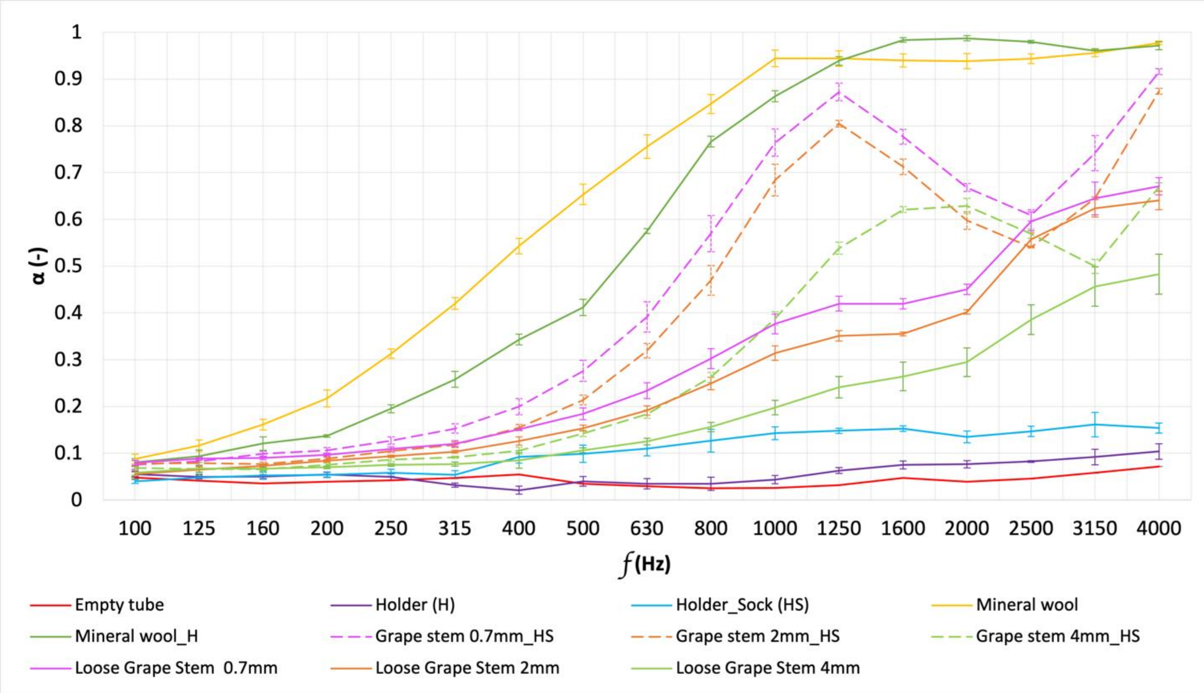


Figure 4. Comparison of frequency dependent sound absorption of tested variations.

Five different specimens were measured from each type. The standard deviation presented by error bars in Figure 4 indicates the variation in obtained result. The results deviation gives important information related to reproducibility of the specimens. From figure 4 indicates that grape stem performance is significantly influenced by the holder and sock. The effect on absorption for empty tube is up to $\Delta\alpha \leq 0.1$. For specimens including grape stems, the improvement in sound absorption was recognized in range up to $\Delta\alpha \leq 0.45$. This effect was influenced mainly by interaction of the holder and sound absorptive membrane (socks in this case). This caused the significant improvement of absorption in specific frequency region. On the other hand, effect of holder only was negative on the resulting sound absorption. This effect can be recognized in frequency range below 1kHz for mineral wool specimen and for empty tube below 630Hz. The efficiency of the smaller grape stem particles (0.7 mm and 2 mm) as durable sound-absorbing materials, especially for high-frequency depending on the sound thickness of absorptive layer. Relatively uniform improvement of sound absorption was recognized by decreasing the size of specimen particles. It must be mentioned here, the density of specimen was not determined in the meantime during measurements.

CONCLUSIONS

This study underscores the potential of grape stems as an effective and sustainable sound-absorbing material. The research demonstrates effect to particle size on resulting sound absorption. Interestingly for chosen fractions of the grape stem by increasing the size of particles and density of specimen as well the sound absorption was decreased. The maximum obtained for loose grape stem material without holder and socks was in range 0.3 to 0.65 in frequency region from 800 - 4000 Hz. This not only contributes to sustainable building materials but also promotes efficient biowaste management. Future research should explore combining grape stems with other natural fibres or binders to enhance their acoustic properties. Additionally, investigating optimal densities and thicknesses can lead to more specialized sound-absorbing materials. Furthermore, treating grape stems to improve their durability will expand their applicability in building materials.

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CLOSED ORGAN PIPES LENGHT LIMITATION

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Abstract

Study examines the limitations of tuning height for wooden closed organ pipes, specifically the Copula stop, which has undergone significant retuning and intonation adjustments in the past. By using a gradual retuning method, the research analyses the sound's frequency spectrum to determine the optimal tuning range. The results show that significant changes in tuning height can lead to substantial degradation in sound quality. The research emphasizes that ill-considered restorative modifications to the air column length of these organ pipes lead to undesirable and permanent changes in the instrument's sound characteristics.

Keywords: Organ pipes, wood, sound, tuning, restoration

Acknowledgements

The contribution was created as part of the VEGA project no. 2/0134/23 "Influence of materials on acoustic properties of historical single-manual pipe organs in Slovakia, Solved at the Institute of Materials and Machine Mechanics of Slovak Academy of Sciences.

INTRODUCTION

The tuning of historical organs and the associated intonation of pipes is among the most serious issues in the restoration of historical organs. In the past, these instruments have been tuned to various pitches, making it impossible to speak of a uniform standard. Since these instruments were often rebuilt over the centuries, these changes also affected their tuning and intonation. To properly assess this issue, it is important to know the historical and musical-aesthetic context of the stylistic period as well as the acoustic possibilities of the stops and pipes (Štafura et al., 2022).

A fundamental problem is whether the change in tuning results in an undesirable change in the original sound quality of the modified instrument. Our previous research on the wooden pipe organ revealed a clear finding that the wooden organ pipe works optimally (from the perspective of sound spectrum) for a certain height of the air column. This height can be changed (while maintaining sound quality) only within a relatively narrow range. Exceeding this range in either direction leads to a significant impoverishment of the spectrum and thus to an undesirable change in the sound quality of the generated tone. The study captures the development of the spectra of generated tones with extreme changes in the height of the air column. We focused on the wooden Copula stop, which was significantly retuned and intonationally modified in the past, including in Slovakia (Štafura et al., 2018).

METHODS

For the purposes of the experiment, we created a wooden organ stopped pipe with an overlength, which was subsequently gradually retuned. This tuning modification aims to provide information on the actual range of possible tuning within the context of the specific scale of the given pipe. This simulation aims to answer the question of whether there was a change in tuning at the turn of the 19th and 20th centuries that fundamentally affected the sound character of wooden stopped organ pipes. We retuned the experimental organ pipe in one-centimetre increments, measuring the sound frequency spectrum at each step. For recording the sound frequency spectrum of the pipes, methodology developed by our research team was used. The method for recording the sound frequency spectrum is based on two main parts of the technological equipment (Figure 1).

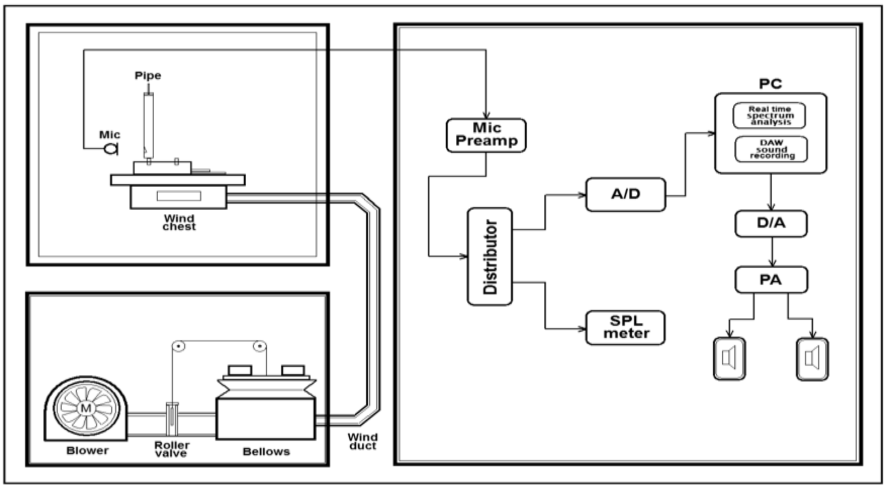

Figure 1. Measurement apparatus scheme.

The primary part consists of tone excitation of individual pipes, provided for by the experimental wind-chest connected to bellows, pressure regulator and blower (Laukhuff). The secondary part is used for evaluating the sound frequency spectra in the real time using the acoustic software ARTA. DAW software Samplitude 11 is installed to the PC a well, and its task is to record and edit signals from individual pipes that are being processed. Such configuration enables us to match every evaluated sound spectrum to the corresponding sound signal. The signal from the measurement microphone (Mini SPL), recording the sound of the organ pipe in question, is amplified in the microphone preamplifier, and from its outlet it proceeds to the distributor, where it is divided into two ways. The first one leads to the A/D converter, and the signal digitalised this way is subsequently evaluated in the acoustic software. The signal is then recorded in the sound programme, and a corresponding sound file is created to the analysed sound spectrum. The second signal way leads from the distributor to the acoustic analyser used for evaluating the sound pressure level (SPL).

During the experiment, following parameters were set for the RTSA: sample frequency 44.1 kHz; the number of samples in the measured window 8,192; weighting window "Hanning" and linear averaging from 100 samples. During the entire experiment, a constant pressure of 60 mm H_2O (1mm H_2O = 9.8 Pa / 62 mm H_2O = 607.6 Pa) was kept in the experimental organ wind-chest. Lenght of the air column of experimental pipe was 57 cm and area of pipe was 6,5 cm^2 (2,1 x 3,1 cm). The measurement was carried out from the 55-centimeter mark with a 1-centimeter increment down to 5 cm (Figure 2).

Figure 2. Experimental organ pipe.

FINDINGS AND ARGUMENT

Based on the measurement results, we have identified several locations that represent significant sound changes (Figure 3).

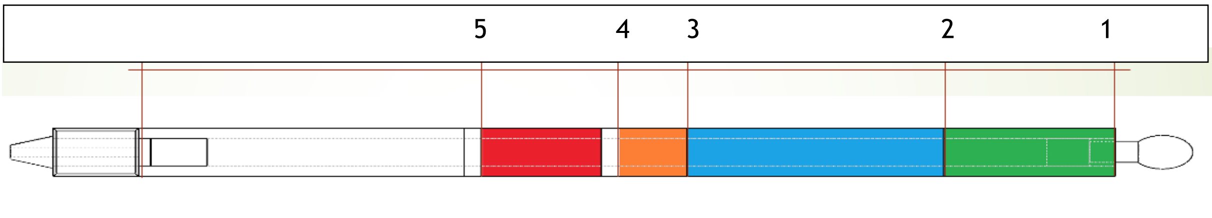

Figure 3. Locations with significant sound changes.

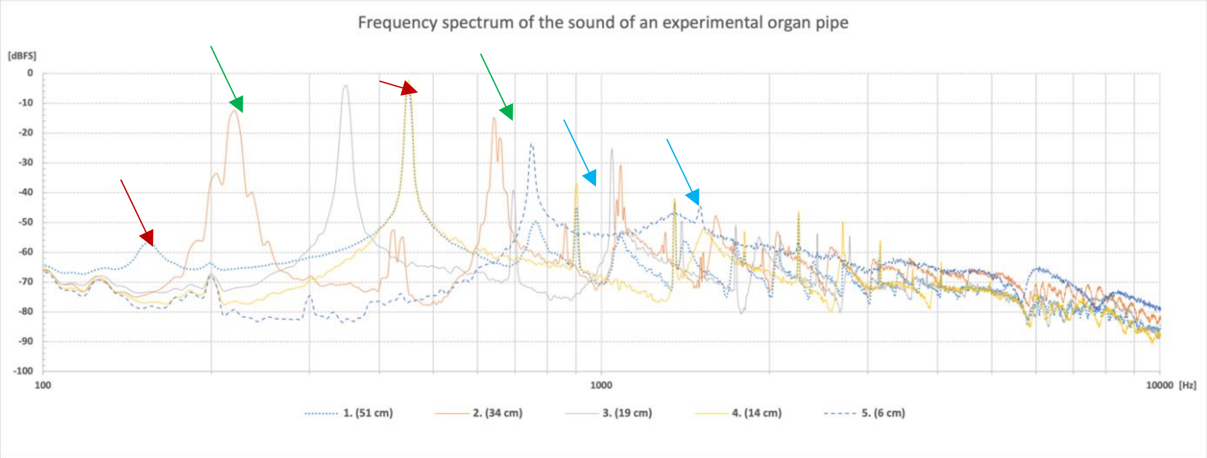

Figure 4. Frequency spectrum of sound of an experimental organ pipe.

Measurement Point 1 - Measurement at air column height of 51 cm: After analysing the frequency spectrum of the sound, we see that the fundamental component is significantly suppressed, and the third harmonic component dominates the sound (see the red arrow in Figure 4).

Measurement Point 2 - Measurement at air column height of 34 cm: At this measurement stage, there was an increase in the first harmonic component, balancing with the third (see the green arrow in Figure 4).

Measurement Point 3 - Measurement at air column height from 19 to 15 cm: The pipe operates in an optimal mode, as evidenced by the largest representation of higher harmonics in the spectrum, with this range being approximately a major third (for our experimental pipe, this range is 350 – 450 Hz, which represents 435 cents).

Measurement Point 4 - Measurement at air column height of 14 cm: The pipe no longer operates in an optimal mode, and the second harmonic begins to even prevail over the third harmonic component. The second harmonic is significantly suppressed in closed pipes operating in an optimal mode (see the blue arrow in Figure 4).

Measurement Point 5 - Measurement at air column height of 6 cm and lower: In this range, the pipe has lost the ability to generate a real tone (compare the spectrum).

CONCLUSIONS

The study clearly showed that wooden closed organ pipes with a given cross-section cannot be shortened or lengthened arbitrarily without negatively affecting their sound quality (FLETCHER, ROSSING, 1993). Tuning adjustments of these pipes must be performed within a very narrow range (interval) of a major third to avoid significant deterioration of the sound spectrum. Ill-considered interventions in the pipe organ for tuning changes can lead to a fatal degradation of the instrument's sound quality, potentially causing irreversible damage. The study provides important insights into the acoustic principles crucial for the proper restoration and tuning of historical organ pipes (ČULÍK, 2013).

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ON THE OBJECTIVE ASSESSMENT OF IMPACT SOUND INSULATION WITH HEAVY AND SOFT IMPACT SOURCES

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Abstract

It is important to determine the required values for the maximum impact noise level in residential buildings. While the standard outlines a procedure for determining this level, there are no specific requirements for ceiling constructions related to heavy excitation sources. This study compares four different approaches for rating noise levels in the frequency range of 50 to 630Hz based on L_{AFMAX}. A linear correlation was observed in the ISO-defined procedures. The comparison between ISO and JIS evaluations revealed that the results depend on the noise spectrum's shape and on the reference curve type used in the JIS evaluation. The ISO's proposed single number ranking generally yields higher values, but this does not necessarily mean it correlates better with human perception. Addressing this issue in the future is recommended.

Keywords: Impact sound insulation, heavy impact source, assessment

Acknowledgements

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INTRODUCTION

The topic of objective evaluation of ceiling constructions is being reopened, both in relation to developments in the construction industry and the increased number of complaints from users of living spaces. The common denominator is often disturbance, especially noise in the area below 100 Hz. In connection with this, some countries introduce requirements placed on ceiling structures not only in connection with SNQ but also with the value of the so-called mass spring mass resonant frequency of the floor. Nowadays, when measuring and evaluating the quality of ceiling structures, we use excitation devices and procedures defined in standards ISO 10140-3(ISO1,2021), ISO 10140-5(ISO2,2021), ISO 16283-2 (ISO1,2020) and ISO 717-2 (ISO2,2020). Standardized impact noise sources are the standard tapping machine, modified tapping machine and heavy/soft impact source — rubber ball. The objective parameters that are the usual output of measurement procedures according to ISO are $L_{nT,w}$ (Weighted standardized impact sound pressure level), $L_{n,w}$ (Weighted normalized impact sound pressure level), $L'_{iA,Fmax}$ (A-weighted maximum impact sound pressure level - usually no requirements defined), $L'_{iA,Fmax,V,T}$ (Standardized A-weighted maximum impact sound pressure level - usually no requirements defined). However, in scientific publications dealing with the subjective perception of impact noise and determining permissible values for maximum noise levels, we often encounter other evaluation parameters (Jeon, 2006). This motivated us to take a look at the standards JIS A 1418-2 (JIS, 2019) and JIS A 1419-2 (JIS, 2017), which are focused on this issue. In this contribution, methods of single-number assessment of impact noise insulation based on heavy soft source excitation are gradually compared.

METHODS

In order to compare the single-number evaluation procedures recommended by ISO and JIS standards, the set of noise level spectra was created (figure 1). A total of 8400 spectra were subsequently evaluated for individual SNQs. The comparison was gradually focused on:

- Evaluation of floor impact sound insulation performance of buildings using grade curves
- Evaluation of floor impact sound isolation performance of buildings based on A-weighted sound pressure level value
- Evaluation of floor impact sound insulation performance of buildings using inverse A characteristic curve

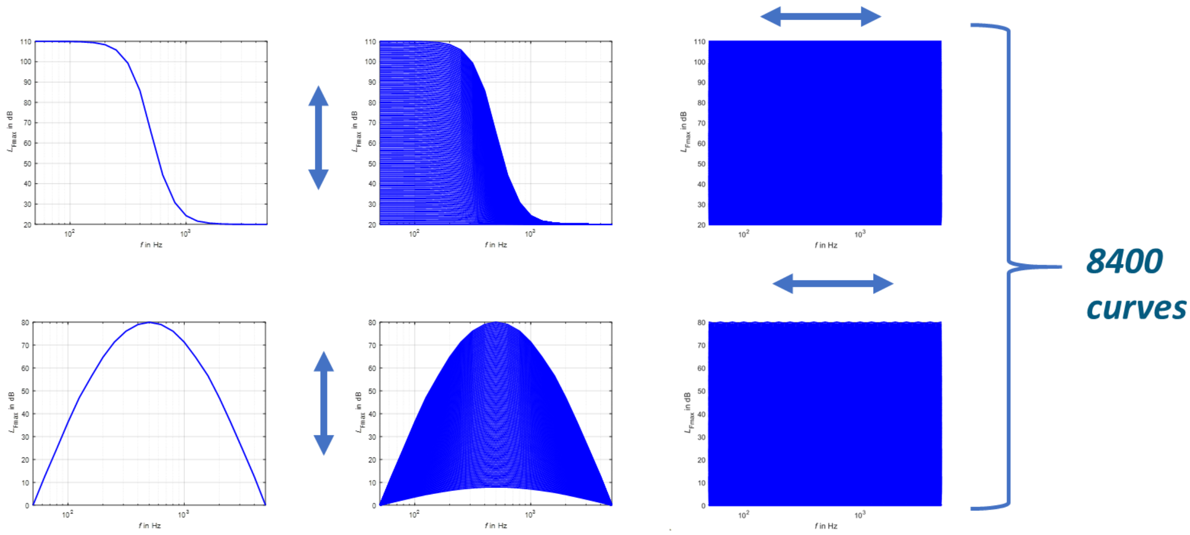
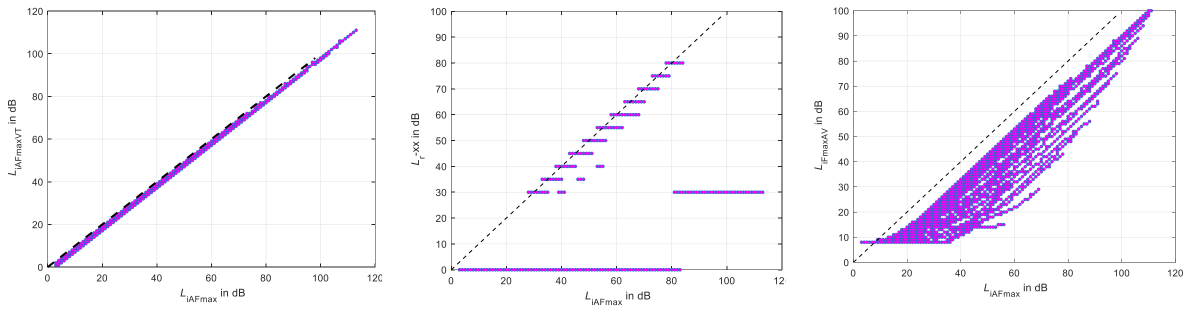


Figure 1. Scheme of L_{max} spectra generation.

FINDINGS AND ARGUMENT

As expected the correlation between L_{iAFmax} and $L_{iAFmaxVT}$ is linear. For L_i-xx ranking based grade curves the correlation is affected by the fact, the grade or reference curves are in step of 5dB. Also the fact the grade curves are for values from 30 to 80dB, higher and lower spectra get to the out of range groups.



a) b) c)

Figure 2. Correlation between single number rating approaches. a) L_{iAFmax} / $L_{iAFmaxVT}$; b) L_{iAFmax} / L_i-xx; c) L_{iAFmax} / $L_{iFmaxAV}$.

Involvement of inverse A characteristic curve results in the spread of correlation curves. That is related to the shape of the inverse A curve but also to the shape of sound pressure level shapes generated for this investigation.

CONCLUSIONS

There must not be neglected the need to determine the requirement values in relation to the maximum Impact noise level in dwelling houses. Despite the fact that the standard provides the procedure of determining the maximum level of impact noise, there are no requirements determined for excitation with standardized source. In total four approaches of single number rating based on L_{AFMAX} for the frequency band from 50 to 630Hz were compared in this contribution. For case of ISO defined procedures, a linear deviation has been recorded. The comparison of ISO and the JIS evaluation has shown the dependence of the result on the shape of a spectrum of noise. This is caused by the use of reference curves in the JIS evaluation. ISO proposed single number ranking provides higher values in general. However, this does not mean that this method is better correlated with the human perception. It is desirable to deal with this issue in the future.

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JIS A 1418-2:2019 Acoustics - Measurement of floor impact sound insulation of buildings - Part 2: Method using standard heavy impact sources

INDOOR ENVIRONMENTAL QUALITY EVALUATION OF REFERENCE OFFICE

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Abstract

Currently, renovations of the buildings from the renovation plan are underway in order to preserve the original character and at the same time to improve the energy efficiency of the buildings. In addition to improving the thermal protection of the building, such as the replacement of openings or the insulation of the outer shell , there is a possibility for the renewal of the building's technology to get notable improvement in energy efficiency. By using advanced types of opening´s elements, the availability of natural ventilation will be reduced due to higher air tightness. Building´s interior spaces need to be ventilated naturally by users and/or by environmental technology with properly regulation. In addition to evaluating energy efficiency of the building, it is necessary to evaluate other internal environmental attributes of the buildings. The assessment of the internal temperature rise in the summer season, thermal stability during the heating season and daylighting of interior spaces with natural light are the most important ones, that interact between each other.

Keywords: Acoustic comfort, thermal comfort, daylight comfort, thermal temperature, indoor quality

Acknowledgements

We would like to thank the organizers of the conference that we could be part of a pleasant and friendly conference.

INTRODUCTION

Indoor environment quality (IEQ) of a reference office significantly affects the satisfaction and productivity of employees. To analyse the environment, in addition to internal boundary conditions (input technical data), it is also needed to specify the nature of the work that the employee performs. An employee in such an office environment can perform administrative work (continuously sitting in one office room during a working day), teaching (variable work tied to a change of the environment in time intervals), research (variable work tied to one office environment). For an administrative worker, lighting is a priority factor that affects his productivity and work efficiency. In teaching and research activities, thermal and acoustic comfort is an important factor for achieving productivity and work efficiency. For high-quality indoor operation, it is necessary to take into account all attributes that have an impact on indoor environment. It is mainly about thermal, light and acoustic comfort. For the user, an indoor work environment must be comfortable enough so that his activities do not deteriorate. That is why this contribution focuses on these attributes from the point of view of the quality of indoor environment. In terms of current requirements, it is necessary to assess the internal temperature rise of the indoor air. In order for the interior space to meet the current requirements, it is necessary to fulfil the requirement that the internal air temperature must not exceed 26 °C.

METHODS

According to European directives, it is necessary to design buildings in such a way that the main passive elements of cooling are used and active elements that increase the energy consumption of the building are minimized. Therefore, in this contribution, we deal with passive shading elements/ devices that reduce the heat load during summer days. Although shading improves the quality of the internal environment in terms of internal temperature, it negatively affects natural daylighting into the interior. In order to meet all requirements for the internal environment, it is necessary to assess the internal environment comprehensively and include in the analysis all demands in terms of current requirements. In this article, a typified reference office located in the building of the Faculty of Civil Engineering was selected. The selected reference office is located on the 6th floor. The office is occupied by users from 8:00 a.m. to 4:30 p.m., which is the working time of the employees. A building envelope which separates the interior from the exterior is based on a lightweight façade construction with an insulated window sill structure and transparent upper part represented by insulated triple glazing system. The other interior vertical constructions of the office (partitions) are made of reinforced concrete with a high storage capacity.

Strategically deployed shading systems mitigate glare on display screens, minimizing visual discomfort and associated reductions in productivity. This can lead to demonstrably improved occupant well-being and performance. Furthermore, shading protects interior furnishings and finishes from UV degradation, extending their lifespan and reducing long-term maintenance costs. In essence, effective shading fosters a visually ergonomic and thermally comfortable workspace, promoting occupant health and overall office efficiency.

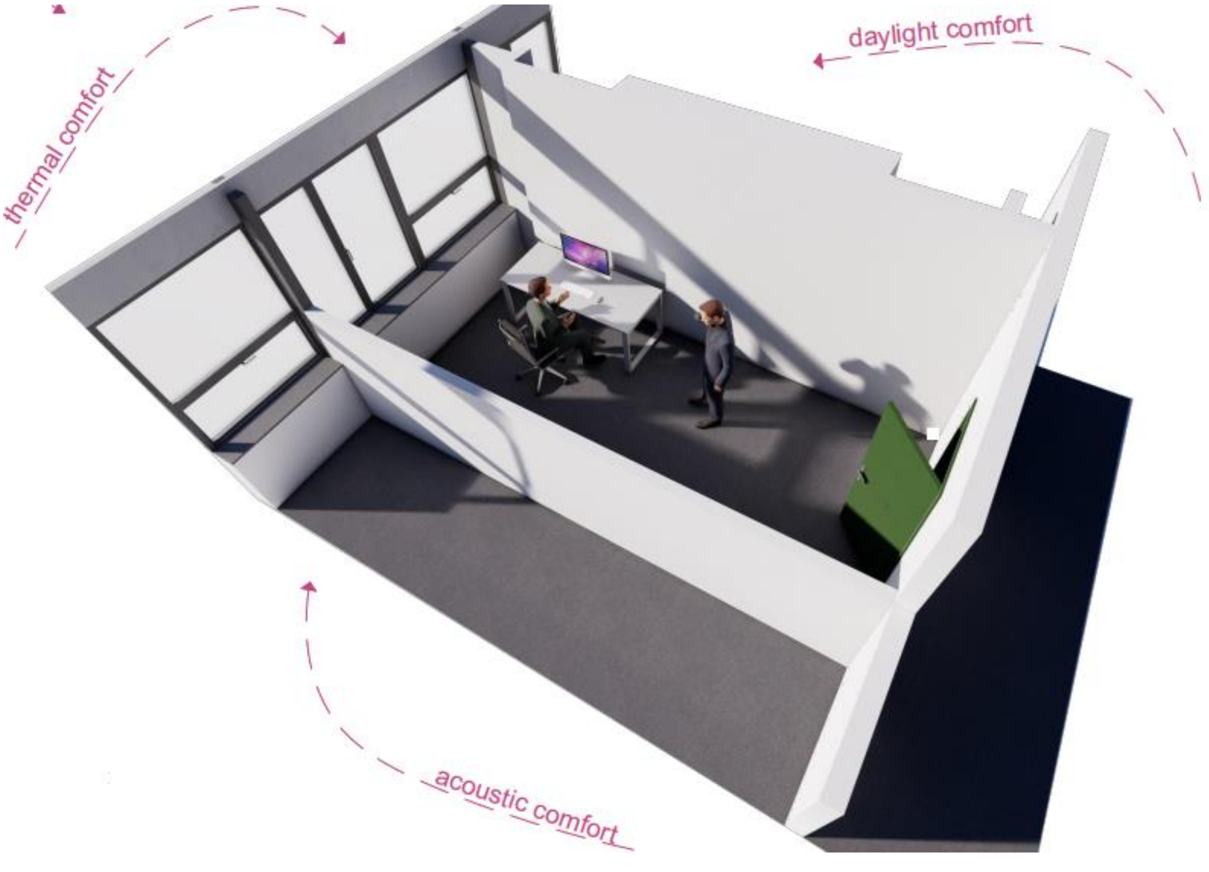

Figure 1. 3D representation of a simulated office.

FINDINGS AND ARGUMENT

Indoor comfort quality observed by indoor air temperature rise was assessed for the selected reference office. All structural elements, materials composition of structures and their physical properties were taken into account in the simulation model. An important parameter when designing the interior environment are mainly: the thermal storage capacity of the included materials, the ventilation rate of the premises and the optical and energetical properties of the transparent material. Two orientations of the transparent structure were chosen for the analysis. Orientation was analysed for South and West orientation as the orientation which are exposed to the maximal energy loads from the sun. An important parameter for assessing the rise in air temperature is also the engagement of the shading devices, which have a positive effect on the rise of heat but can negatively affect the availability of natural daylight into the interior. Therefore, in the given simulation with hourly steps, we chose the hottest day of the year and analysed different modes of activation of the shading elements. The most ideal mode of shading is adjustment according to the intensity of sunlight.

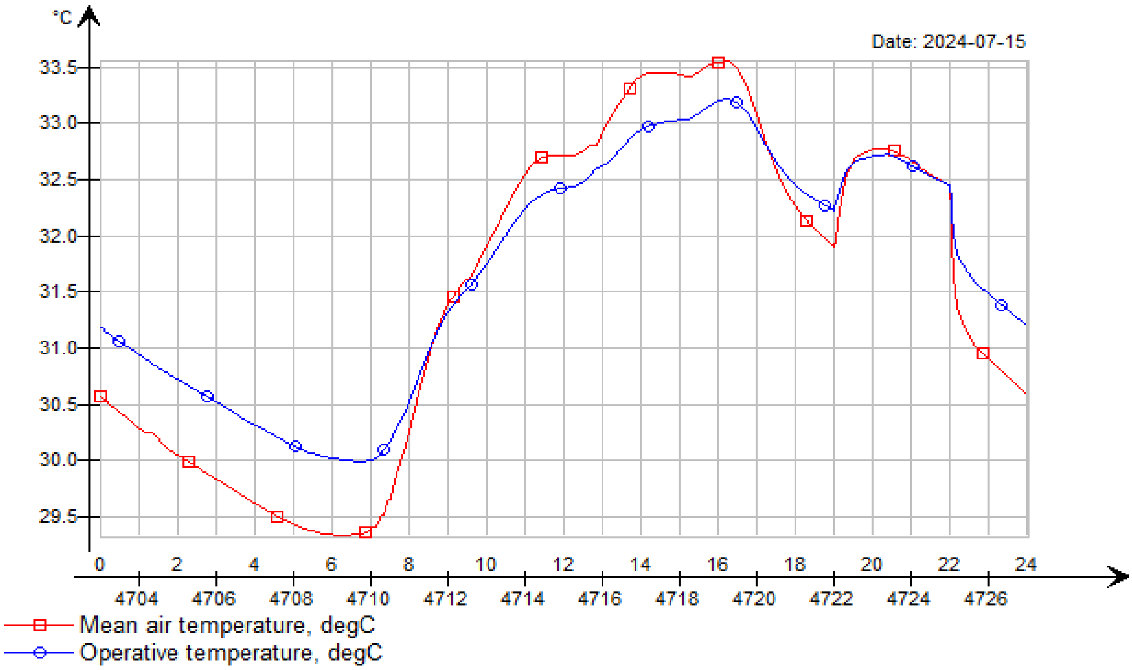

Figure 2. Main temperatures.

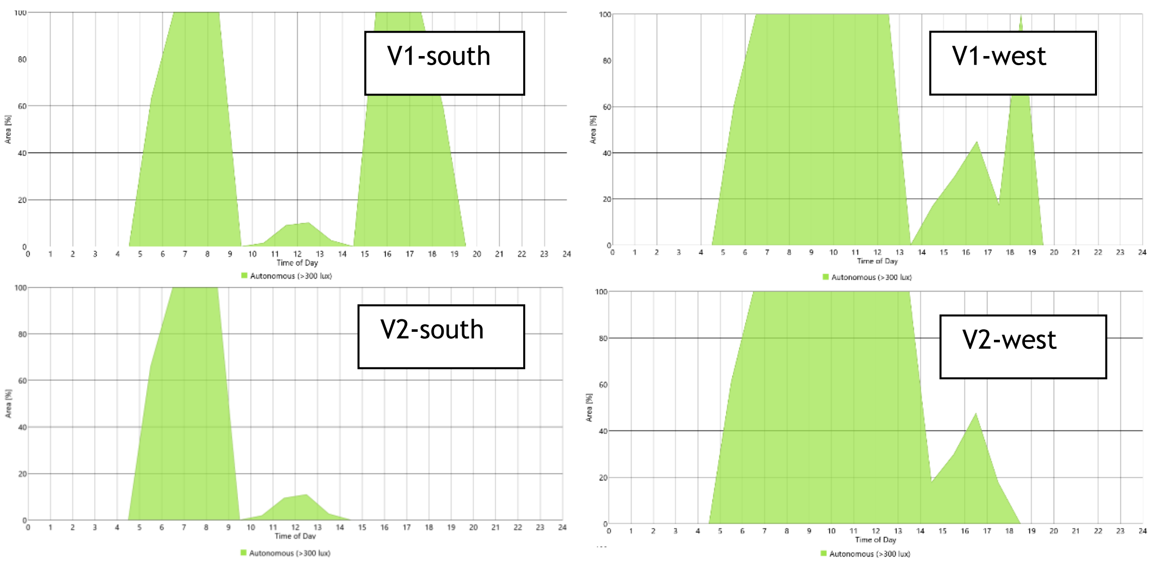

Figure 3. Calculation of sDA; comparison of the two strategies for different orientations (south and west), a percentage of the floor area excessing 300 lux is shown.

In the field of daylighting also two shading scenarios were investigated. The first scenario implemented shading activation based on the LEEDv4 2% rule, a common industry standard. The second scenario employed a data-driven approach, utilizing shading activation strategies derived from the results of the initial thermal simulation. The simulations employed key metrics to assess daylighting performance: Spatial Daylight Autonomy (sDA) to evaluated the percentage of floor area receiving sufficient daylight (300 lux) for at least half of occupied hours. Also mean Illuminance, which provided an overall picture of average light levels within the office. And Useful Daylight Illuminance (UDI), that quantified the distribution of illuminance levels throughout the space. These metrics were compared for two shading control scenarios (LEEDv4 2% rule vs. data-driven thermal simulation schedule) and two facade orientations (west and south) in Figures 1-3. Therefore, a total of four outputs are presented for each measure, allowing for a comprehensive evaluation of the impact of shading strategies on daylight availability, occupant comfort, and visual well-being.

CONCLUSIONS

In order to achieve a high-quality environment in indoor spaces, it is necessary to take into account all attributes which have an impact on the indoor environment. It is mainly about acoustic, thermal and light comfort. Only with such an assessment and a balance of all parameters can a quality environment be achieved, in which the user spends almost more than 90% of his life. The shading device itself reduces the internal air temperature in the summer season but does not ensure the temperature as prescribed in the standard. Therefore, in conclusion, from the point of view of the rise in indoor air temperature, it is necessary to design active cooling devices for such spaces. Without these devices, we cannot meet the current requirements. the daylighting simulations revealed significant differences in daylight availability and illuminance levels between the shading control scenarios and facade orientations. The second shading strategy (based on the activation of shading devices by thermal simulation) resulted in a substantial reduction in daylit area (around 50%) compared to first scenario (using LEEDv4 rule), particularly for the south-facing facade. This trend was also observed in the UDI and mean illuminance metrics, suggesting lower overall daylight penetration. Interestingly, the west-facing facade showed minimal variation between the two scenarios. These findings suggest that the data-driven shading strategy may be overly restrictive for south-facing offices, potentially compromising occupant access to natural light.

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THE MAIN SOURCES OF VIBRATION AND NOISE OF TANK WAGONS

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Abstract

The research, of which this article is a part, deals with the design, implementation and verification of the methodology of measuring the transmission of vibro-sound energy from the contact of the tread profile with the rail through the primary suspension blocks, side bearers, bogie pivot and brake system to the tank shell and measuring the generation of sound energy by the wagon bogie. It analyses the frequency distribution of vibro-sound energy of individual blocks (components) of the tank wagon and the intensity of vibration transmission by these blocks until the mounting of the tank shell. Vibro-acoustic measurements were performed on an accredited test circuit in motion at different speed of the tested tank wagon prototype. Prior to the in-motion measurements, a modal analysis was carried out on the bogie and tank shell of the tank rail vehicle to determine the Eigen frequencies of the Eigen modes of the individual components of the bogie and tank shell. For each bogie block, time-frequency-amplitude diagrams of the vibration acceleration square depending on the wagon speed are given, as well as the results of the bogie and braking system noise analysis, which clearly characterize the dependence of the dynamic load of the bogie and components connecting the tank wagon on the operating speed. Using frequency spectra, the transmission loss of individual bogie blocks and tank at a maximum speed of 120 km/h is displayed. The measurement methodology, measured amplitudes and frequency distribution of vibrations and noise in motion are the basis for reducing the vibro-sound energy not only of the developed prototype tank wagon, but also of railway wagons with a similar bogie. As part of scientific research, the proposed methodology was also successfully applied to solving the dynamic load of high-speed spinning headstocks used in the textile industry.

Keywords: tank rail vehicle, bogie, kinematic excitation, vibration transmission, noise

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INTRODUCTION

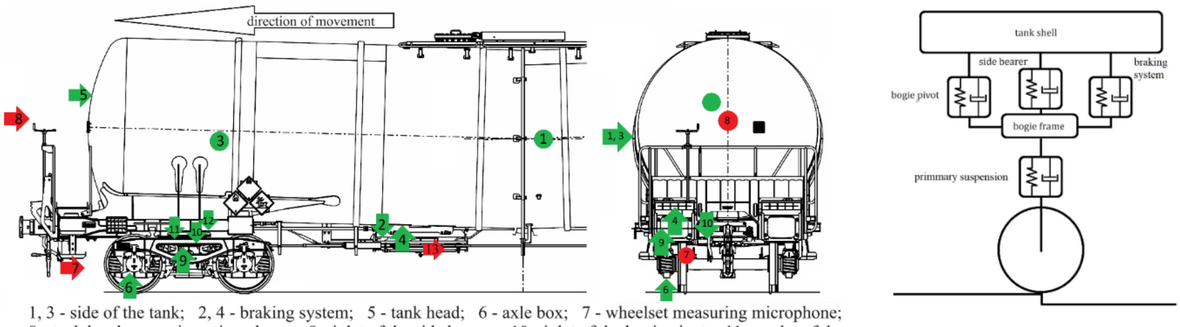
The wagon wheels and the construction of their mounting (bogie) in relation to the wagon (superstructure) of a freight railway wagon is predominantly made of metal components, which are a very good conductor of vibro-sound energy from the source (contact of the wheel with the rail) to the superstructure of the wagon. If the superstructure is a cistern, this energy is also transferred to the metal body of the tank shell, thereby increasing the area of radiation of sound energy to the surrounding environment, which is most pronounced when the natural frequencies of the tank shell match the excitation frequencies. Thus, the individual components of the wagon, from the wheel to the superstructure itself, are characterised by natural frequencies which, when matched with the excitation frequency component, cause resonance of the component and thus increase the noise emission into the surrounding area (Thompson, 2009). The reduction of the vibro-sound energy generated by the rolling of the wheelset on the rail transferred to the bogie structure and radiated into space as unwanted noise required theoretical, numerical, structural, material and experimental analysis of the generation, transmission and radiation of this energy into the surrounding space. In order to reduce the vibro-sound energy of rail vehicles, it is important to analyse the frequency-amplitude loading of the individual bogie blocks of these vehicles from the primary excitation source, which is the contact of the tread profile and the rail, directly on the components (blocks) of the tank wagon in motion. The aim of the proposed methodology and frequency analysis is to obtain transmission loss values by applying accelerometers and measuring microphones on the blocks (components) of the bogie from the primary source to the inputs to the tank shell, at the operating speed of the rail vehicle.

Efforts to reduce mechanical vibration and noise are aimed at reducing the sound power of the source itself, reducing the sound energy radiated by the source into the open space and preventing the propagation of vibro-sound energy through the mechanical system, i.e. the bogie and the tank wagon shell itself. This is necessarily preceded by the design and verification of the optimal measurement methodology at rest in determining the Eigen frequencies of the Eigen modes of selected components of the rail vehicle and especially in motion by measuring the amplitude-frequency attenuation characteristics of individual blocks of the rail vehicle bogie. The article only mentions the transmission of vibro-sound energy through the primary suspension.

METHODS

The goal of vibro-acoustic measurements of the developed tank wagon prototype in motion was to verify the proposed methodology for obtaining reliable vibro-acoustic signals at different operating speed, to verify and confirm the results of previous measurements at rest in determining the natural frequencies of the basic structural blocks (ŽIARAN AT AL., 2020) and to analyse the transmission loss of these tank wagon blocks, namely the primary suspension with the axle box and the axle guide stay, the bogie formed by the longitudinal beam and bogie main cross member, the side bearer, the bogie pivot and the braking system from the real kinematic excitation under the defined operating conditions of the tank wagon. The obtained vibro-acoustic results together with the results from previous measurements are the basis for the design of measures to effectively reduce the noise of the developed tank wagon prototype of a given mass, length and volume with a universal bogie usable for most types of railway vehicles (ŽIARAN AT AL., 2022).

The tank wagon was applied 11 vibration acceleration sensors to predefined measurement points on the bogie, on the mounting of the shell of the wagon tank and on the shell itself (DARULA, 2011). Three measuring microphones were used to measure the sound pressure level generated by the wheelset, to measure the noise at the bottom of the tank shell, including the braking system, and to measure the noise generated by the head of the tank shell. When applying the sensing elements to the tank wagon and their connection to the evaluation equipment stored in the measuring wagon, the maximum speed of 120 km/h of the measuring train had to be taken into account of the measuring train so as not to interrupt and affect the sensed signals from the defined measuring points and damage to the connecting cables and sensing elements, shown in Figure 1.



1, 3 - side of the tank; 2, 4 - braking system; 5 - tank head; 6 - axle box; 7 - wheelset measuring microphone; 8 - tank head measuring microphone; 9 - inlet of the side bearer; 10 - inlet of the bogie pivot; 11 - outlet of the side bearer; 12 - outlet of the bogie pivot; 13 - tank bottom measuring microphone

Figure 1. View of the distribution of accelerometers and microphones and schematic diagram of the transmission of vibration from the contact of the wheel with the rail to the shell of the tank.

The measurement of noise levels in accordance with the corresponding ISO standard (ISO 3095) was performed at the stationary measuring point of the reference noise track section and at the same time the signal of the generated noise was also recorded on the tank wagon. The measurement started at a speed of 120 km/h, which gradually decreased by 10 km/h. In addition to measuring at defined constant speeds, a signal was also recorded when the measuring train was started and braked. The results obtained from numerous vibro-acoustic measurements, at a large range of speeds, made it possible to more thoroughly verify the effectiveness of the measurement methodology capable of recording the range of dynamic loading of the tank wagon, and thus more effectively take noise reduction measures of the analyzed tank wagon prototype. The methodology and measurement results will also be used in the implementation of tests of the proposed and implemented measures aimed at reducing the noise of the tank wagon (Žiaran at al., 2022).

FINDINGS AND ARGUMENT

The intensity of vibration-sound energy generation of the primary source depends on the roughness of the contact surfaces and the irregularity of the rail shape and the tread profile of the wheel, which generates the kinematic excitation of the rail vehicle, dependent on the load, resp. contact pressure (Hertzian pressures), rail vehicle speed, but also from the turning radius or track slope and lateral loading of the wheel flange with the rail during random transverse movement of the wagon, transverse slope of the rails and in the curve with predominant centrifugal force prevails over the horizontal component of the gravity force or vice versa.

The aim of the primary suspension of the bogie is to reduce the intensity of vibro-sound energy from the primary source, i.e. the contact of the wheel and, in the case of transverse movement, also the wheel flange with the rail (EN 13715). The primary suspension connects the axle box with an axle guide stay firmly connected to the longitudinal beam and the bogie main cross member, which is the outlet but also the input measuring point for the side bearer and moved along the bogie main cross member for the bogie pivot, shown in Figure 2-left. The vibration transmission through the primary suspension, which contains two interposed parallel springs on the sides of the axle box and the axle guide stay, is analysed at the axle box location – primary suspension input, sensor 6 shown in Figure 2 and at the upper axle guide stay firmly connected to the longitudinal beam and bogie main cross member – the output of the primary suspension where the vibration acceleration was sensed, sensor 9 shown in Figure 2. The primary suspension dampens vibrations in the entire frequency band. Friction plates are also applied to the axle box and axle guide stay in the discontinuity at which the power flow is attenuated. By applying a material with a higher transmission loss in the contact surfaces of the axle box and the axle guide stay a greater reduction of the power flow from the primary source will occur.

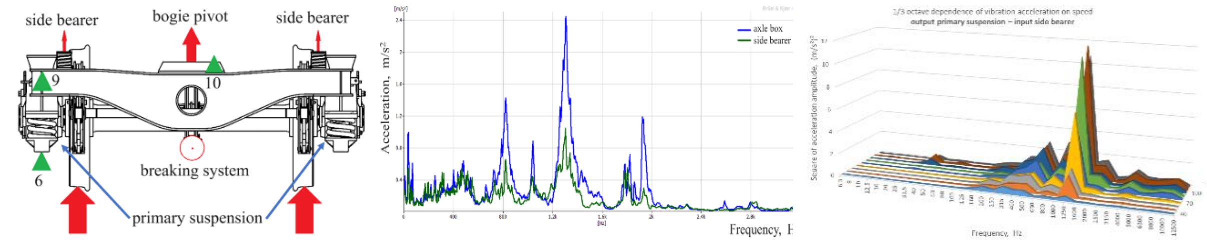


Figure 2. Frequency spectrum at the input and output of the primary suspension block (left) of the kinematic excitation at a speed of 120 km/h (midle) and amplitude changes in the speed range (right).

From the auto-spectrum of modal analysis, more pronounced amplitudes of discrete frequencies at the input of the primary suspension were obtained, in the vicinity of 500 Hz, 820 Hz, 1.05 kHz, 1.8 kHz, 2.1 kHz and 2.9 kHz (Žiaran at al., 2020). Similar frequency spectra with significant amplitudes at the measured frequencies at rest also represent the vibration of the primary suspension block in motion. In addition to the frequencies already mentioned, a significant discrete value of the vibration acceleration amplitude is at a frequency of 1.3 kHz, which is not significant in the auto-spectrum of modal analysis, due to the tank wagon providing a brake that attenuated the bogie's natural frequency amplitude. From the amplitudes of the frequency spectra, the value of the attenuation of the vibration acceleration by the primary suspension can be seen in Figure 2-midle.

The intensity of the frequency distribution of the excited vibration of the primary suspension connected to the axle box at the entrance and the axle guide stay firmly connected to the longitudinal beam and bogie main cross member is also confirmed by the speed and time-frequency-amplitude diagram in Figure 2-right. It can be stated that only the amplitude of the vibration acceleration changes with the speed of the wagon. This means that these discrete frequencies with significant amplitudes represent the Eigen frequencies of the Eigen modes of the individual components of the primary suspension block and the following components to the primary suspension.

CONCLUSIONS

The vibro-acoustic measurements of the tank wagon prototype in motion focused on the analysis of the frequency and amplitude distribution of the vibro-acoustic energy transmitted by the tank wagon bogie, including the braking system. During the kinematic excitation of the wagon, the frequency-amplitude transmission of vibro-acoustic waves to the tank shell and the emission of acoustic energy from the bogie to the surrounding area were monitored. From Figure 3 shows the frequency coincidence of the vibration and noise generated by the bogie. The maximum values of A-weighting levels in the third-octave bands near the middle frequencies of 1.25 kHz and 2 kHz coincide with the maximum vibration amplitudes, the values of the noise and vibration amplitudes being dependent on the wagon speed. Lower values of A-weighting sound levels and vibrations were achieved at the middle frequencies of the third-octave bands from 315 Hz to 800 Hz. In this frequency band, the tank superstructure of the wagon was mainly manifested.

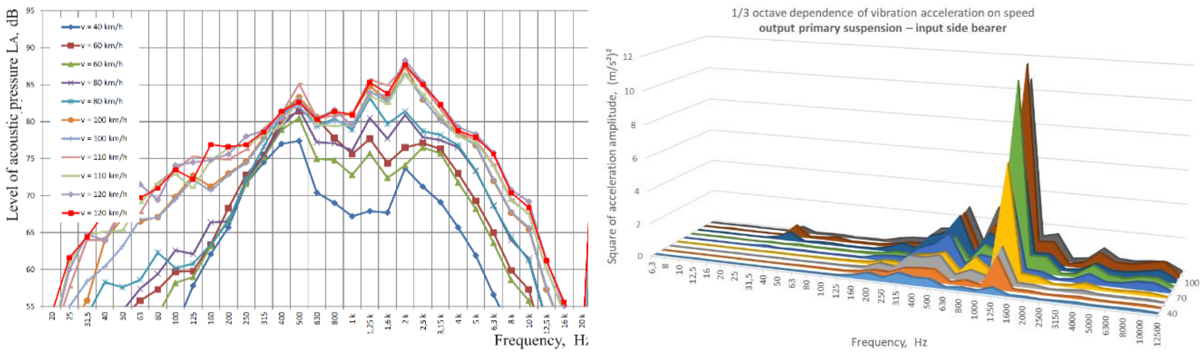


Figure 3. Third-octave analysis of the bogie noise (left), and bogie main cross member vibration (right).

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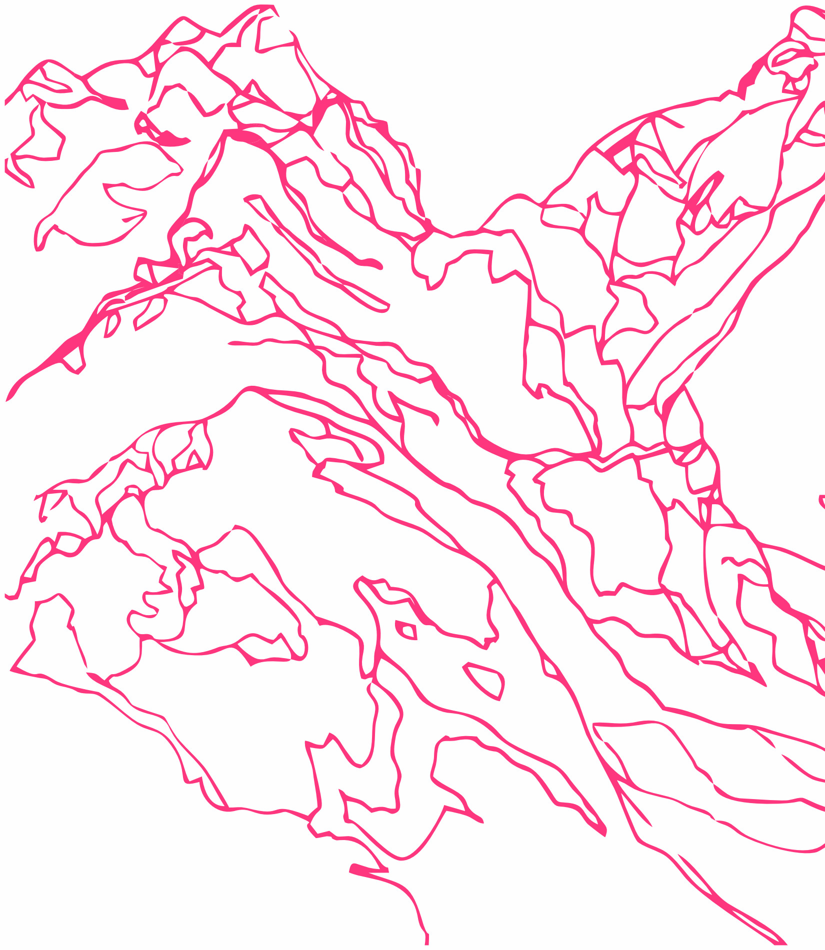

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