Konferenzbeiträge / Atti / Proceedings

Building Simulation Applications BSA 2022

5th IBPSA-Italy Conference
Bozen-Bolzano, 29th June –1st July 2022

Edited by
Giovanni Pernigotto, Francesco Patuzzi,
Alessandro Prada, Vincenzo Corrado, Andrea Gasparella

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Bozen-Bolzano University Press, 2022
Free University of Bozen-Bolzano
www.unibz.it/universitypress

Cover design: DOC.bz / bu,press

ISSN 2531-6702
ISBN 978-88-6046-191-9
DOI 10.13124/9788860461919

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Smart Sensors and Auditory Sensitivity: Acoustic Optimization of Dedicated Spaces for Autistic Individuals

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Abstract

This work deals with the design of an indoor environment dedicated to autistic individuals, who may suffer from hypersensitivity to acoustic stimuli. Specifically, in this volume customized pieces of furniture are included, containing smart sensors, designed to help people with cognitive deficits to live an independent life. Among the indoor comfort aspects, the acoustic requirements have been investigated, in order to guarantee both the optimal functioning of the acoustic sensors and the acoustic occupants' well-being. The optimal indoor acoustic levels are based on a literature review. Measurements are performed in order to calibrate a 3D acoustic model. Then diverse scenarios are analysed, and an optimized configuration is proposed and realized. The model is then validated with the final acoustic measurements, which confirm the designed results.

1. Introduction

Many autistic individuals show particular sensitivity to noise disturbance, both indoors and outdoors, often to a greater extent than neurotypical people, thus exhibiting acoustic hypersensitivity (American Psychiatric Association, 2013).

In a recent study conducted in Canada involving 168 families with an autistic child (3-16 years old) 87 % of the respondents reported that their children were very sensitive to noise (Nagib & Williams, 2018). Specific studies carried out on school environments (Tronchin et al., 2018) with autistic children have shown that the application of interventions aimed at reducing noise coming from outside the classroom (from corridors, or neighboring classrooms), have permitted them to reduce behavioral temperaments (self-stimulatory behavior), such as obsessive behavior, specific for each child, including head-banging, biting their hands and rocking (Kanakri et al., 2017). These results are also confirmed by the first analysis of the SENSHome Interreg Project research, which features an investigation of Italian and Austrian families. In this case too, acoustics were found to be the greatest source of stress for autistic people and their relatives and caregivers. Many papers, institutional programs, manuals and documents related to acoustic individuals explained that acoustics are of paramount importance when designing dedicated spaces (Ahrentzen & Steele, 2015; Braddock & Rowell, 2011; Mostafa, 2014).

For all these reasons, during the construction and setting up of an environment dedicated to a full-scale reproduction of living environments for autistic people and their families, the acoustic aspect was analysed beforehand and verified on site. Specifically, the SENSHome environment is located inside the Building Physics Laboratory at the Free University of Bolzano. It hosts the furniture specifically designed for autistic people by the University of Trieste and integrated with the smart sensors system that make up the early warning system, specifically developed for the SENSHome project.

2. Setting Up The SENSHome Laboratory

As formerly pointed out, the determination of acoustic quality parameters is of paramount importance (Tronchin, 2021). The reverberation time R_T, clarity C_{50} and definition D_{50} for environments dedicated to autistic people are the most commonly used parameters to qualify an indoor environment both for indoor comfort and for the use of microphone sensors (Griesinger, 2013; Marshall, 1994; Tsilfidis, 2013). These factors were then considered as reference for the acoustic optimisation of this environment.

Fig. 1 – Starting conditions of the building physics laboratory at UNIBZ

The interior design included a frame structure of vertical wooden panels and some fake windows covered with a white acoustic-transparent membrane (Fig. 2). Featuring this configuration, the space included three areas: an entrance, a kitchen and a living room (quiet space). Each area is then filled with furniture specifically designed for the project (Fig. 3).

Fig. 2 – Interior covering provided in the laboratory for the preparation of the SENSHome scenario. Vertical wooden panels

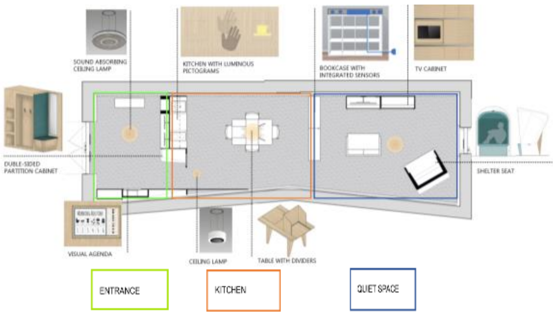

Fig. 3 – Layout of the internal distribution of spaces and location of various pieces of furniture

From an acoustic point of view, it was possible to act directly at the design phase, considering the issues related to indoor acoustic comfort described. Going into detail, many elements of the designed furniture were implemented with sound- absorbing materials (Fabbri et al., 2021) or systems. In particular, the coverings of the entrance furniture (Fig. 4a) and the quiet place armchair (refuge space, Fig. 4b) were produced using soft, sound-absorbing materials, (specifically a polyurethane foam), featuring a thickness of 5 cm.
Interestingly, inside the refuge space, both the high performance of the sound-absorbing interior coating and the huge presence of exposed surface area permitted a very special acoustic field for those sitting inside. This was highly appreciated by the autistic individuals, who liked this special feature of the refuge space, lying inside it many times and for significant time spans.

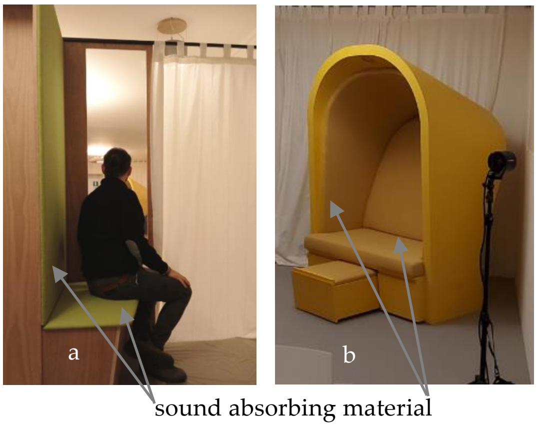

Fig. 4 – a) entrance furniture with sound-absorbing coating; b) dedicated armchair (refuge space) with sound absorbing coating

Another piece of furniture which included sound-absorbing characteristics is the kitchen table. It is equipped with special panels, which could be used to separate every single person sitting around it. Indeed, some autistic individuals cannot stand someone else's food or smell. For this reason, the panels include active carbon layers and sound-absorbing elements. This provides a customized local environment where an individual can experience her/his own personal requirements, but still maintain a social breakfast/lunch/dinner. In Fig. 5, the panels are shown. It is possible to detect the perforated internal surface, where both odors and noise could enter and be absorbed.
Moving onto the suspended ceiling lamps, 4 elements were included. Specifically, a round-shaped wood panel was used and filled with microphone sensors, LED strips and sound-absorbing polyurethane foam, 7 cm thick. The lamps are 65 cm in diameter and suspended where the highest noise levels are supposed to be. Accordingly, one was suspended over the lunch table (Fig. 5), another one over the sofa where the television is seen, a third one in the entrance were people gather before entering and the last one over the kitchen space.

Fig. 5 – Detail of the kitchen table with sound-absorbing dividers and ceiling lamps with sound-absorbing coating

In addition, between the wooden frame of the casing and the cladding, a hollow space is left to be filled with sound-absorbing panels, usable to reduce internal reverberation (Fig. 6).

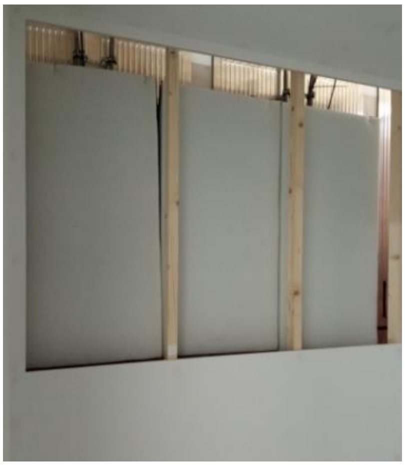

Fig. 6 – Detail of the suspended sound-absorbing panels layered between the wooden structure and beyond the acoustic-transparent membrane

The sound-absorbing foam used to cover furniture complements and the sound-absorbing panels on the wall are characterized by the frequency sound absorption coefficients reported in Figs. 7 and 8. It is possible to notice how the two selected layers are characterized by a very good acoustic performance.

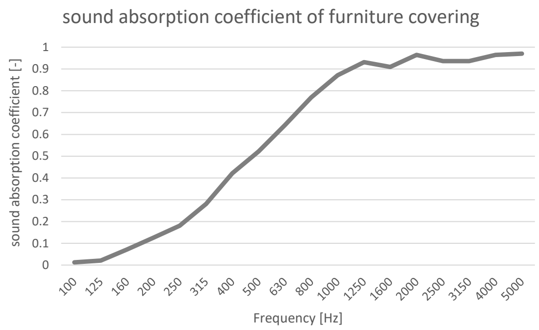

Fig. 7 - Sound absorption coefficient frequency trend of the cover furniture

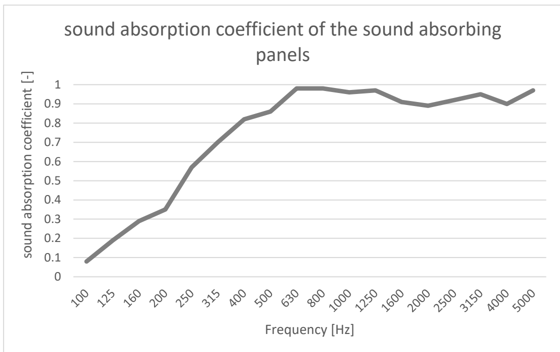

Fig. 8 - Sound absorption coefficient frequency trend of the internal panels

The main aim of the acoustic analysis was to obtain an indoor average reverberation value of between 0.5 and 0.7 s (Griesinger, 2013; Marshall, 1994; Tsilfidis, 2013). These values represent the right compromise for the achievement of optimal conditions both for the use of the environment by autistic people and for the use of the microphone sensors.

3. Acoustic Analysis of Various Scenarios

Since it is acknowledged that acoustic models should be calibrated using reverberation time (Karjalainen & Järveläinen, 2001; Suárez et al., 2005, Tronchin, 2005), only this parameter was considered in the following dissertation.

The general criteria of the ISO 3382-1 were considered when performing acoustic measurements. The microphone height was 1.6 m, while the source height was 1.9 m in all cases (Tronchin et al., 2021). The measurement was set by placing the source in 2 different positions and the 8 receivers all along the void space (Tronchin & Bevilacqua, 2022). The source played a sinusoidal sine sweep having a frequency of between 50 Hz and 12000 Hz and a duration of 20 seconds (Tronchin & Knight, 2016). Measurements were performed in an unoccupied configuration.

The average reverberation time of the laboratory in the empty condition was measured and was 3.5 s. The average was computed considering the range 500 Hz – 1000 Hz – 2000 Hz. Since the aim is to obtain an average reverberation time on the same frequency range of 0.5-0.7 seconds (Griesinger, 2013; Marshall, 1994; Tsilfidis, 2013), some actions should be considered.

Therefore, the correct amount of sound-absorbing panels had to be calculated in order to achieve the target reverberation values. For the acoustic optimisation of the laboratory environment, it was necessary to provide a quantity of sound-absorbing materials of approx. 45 m² (i.e., an amount equal to 22.5 % of the total reflective surface of the room). Figs. 8-10 show the virtual models of the three configurations of the laboratory analyzed: i) empty, ii) with furniture and iii) with furniture and sound-absorbing panels.

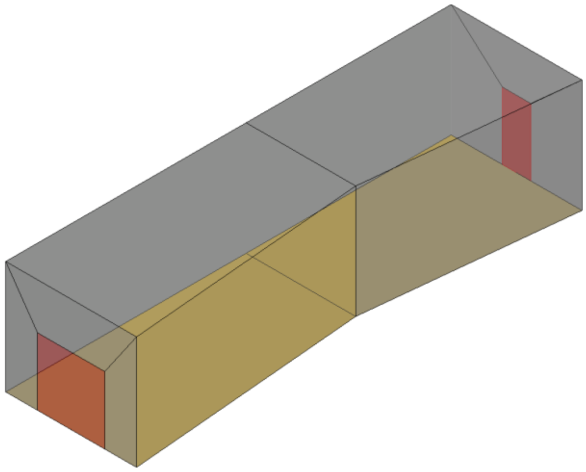

Fig. 8 – Virtual model of the laboratory: configuration i) empty

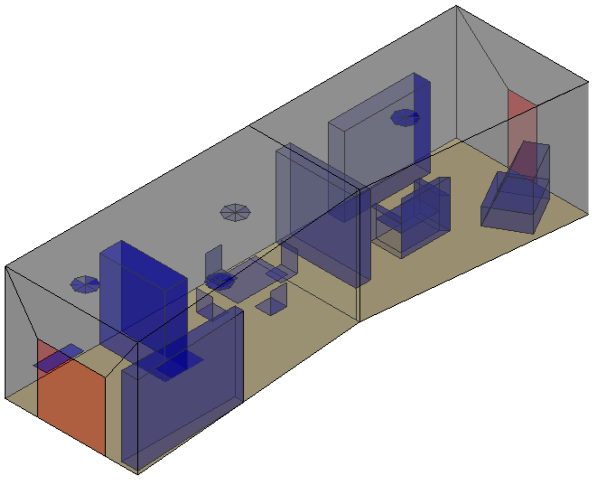

Fig. 9 – Virtual model of the laboratory: configuration ii) with furniture

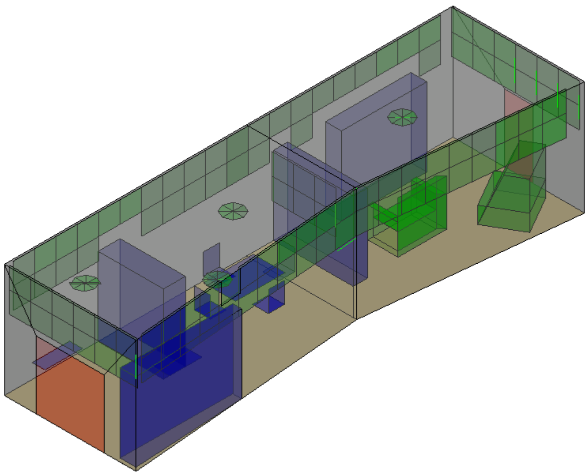

Fig. 10 – Virtual model of the laboratory: configuration iii) with furniture and sound-absorbing panels

In Table 1, we can see that, for the empty scenario, the simulation provides good results compared to the measured ones. In Fig. 11, the indoor sound field simulated at 1000 Hz is represented. It is interesting to notice how its distribution it is almost symmetrical. Since the calibration is positive, it is possible to proceed with the other two scenarios reported in Figs. 9 and 10.

Table 1 − Calculated averaged reverberation time for different scenarios

Lab configuration	Scenario (i)	Scenario (ii)	Scenario (iii)
Average reverberation time [s]	3.49	1.49	0.61

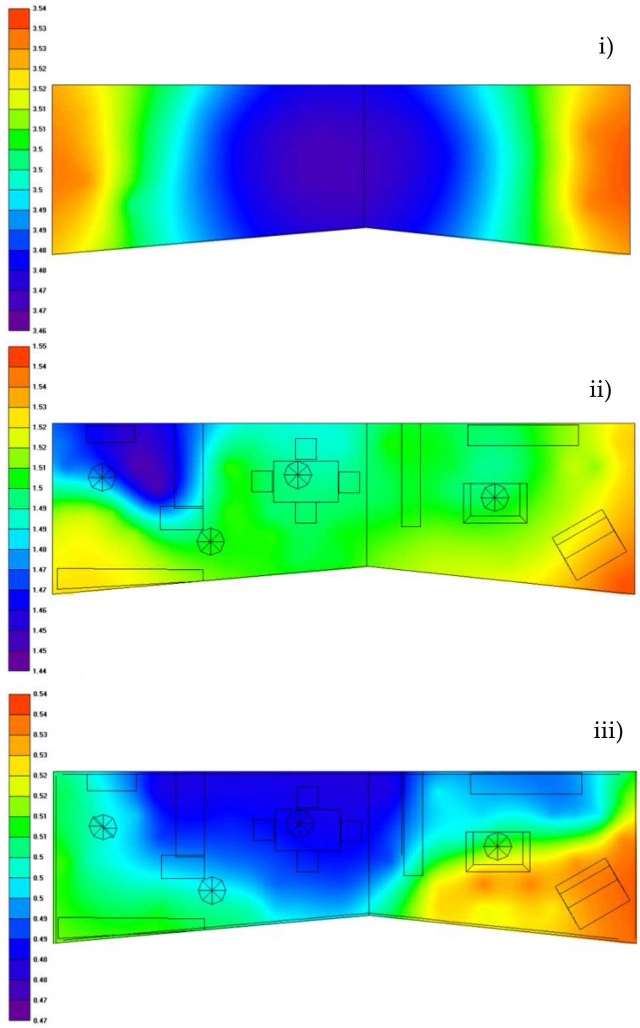

Fig. 11 − spatial reverberation time distribution for different scenarios: i) empty room, ii) furnished room and iii) furnished room with sound absorbing panels. Frequency plot: 1000 Hz

In Table 1, the average reverberation time values are reported, while in Figs. 12 and 13 the average reverberation time values at 1000 Hz are reported, for the analysed configurations.

4. Model Validation

The validation of the 3D model was developed when the SENSHome laboratory (scenario iii) had been set up (Fig. 12).

Fig. 12 − Two views of the SENSHome environment

The results obtained in terms of reverberation time agree strongly with the simulated ones. Indeed, the measured average reverberation time value is 0.63 seconds. Fig. 13 shows the frequency trend of measured results.

These values permit the next phase of the SENSHome laboratory to proceed, which concerns testing of the operation of the microphone sensors and the validation of the SENSHome scenario by hosting autistic individuals and their families and caregivers within it. This will permit an understanding of the effectiveness of the indoor sound field designed.

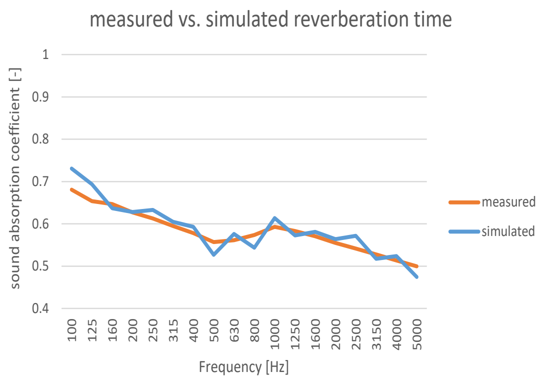

Fig. 13 − Reverberation time frequency trend of furnished room with sound-absorbing panels: in situ measurements

5. Conclusion

Acoustics are an indoor comfort aspect of paramount importance, especially for autistic people featuring auditory hypersensitivity. Taking care of the sound field of indoor environments could mean creating hospitable and non-discouraging living conditions. Using a robust procedure to design the SENSHome environment by means of measurements, 3D acoustic simulation and final validation also permitted the reverberation time of different scenarios to be optimised. This was also aimed at creating the best operating conditions for the microphone sensors that are part of the smart system included in the SENSHome environment. The acoustic properties of the sound-absorbing coverings were investigated. This led to the calculation of the surface area of the sound-absorbing panels to be used. The final measurements performed in the SENSHome environment built permitted an assessment of the effectiveness of the design developed. Future developments include validation of the microphone sensor operation conditions and of the internal acoustic quality perceived by autistic individuals, their relatives and caregivers.

Acknowledgement

This study was supported by the Interreg Italy-Austria project "SENSHome" ITAT 1088 CUP: I54I18000310006.

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