DOI: 10.61782/fa.2025.0188

FORUM ACUSTICUM EURONOISE 2025

CASE STUDY: REMODELING OF OPEN PLAN DUTCH SCHOOL – ACOUSTIC DESIGN AND OPERATIONAL CHALLENGES

Bianca Scherpenhuyzen[1*] **Colin Campbell**[2] **Jeroen Vugts**[3]
[1] Saint-Gobain Ecophon, Netherlands
[2] Saint-Gobain Ecophon, UK
[3] LBP Sight, Netherlands

ABSTRACT

This innovative learning environments case study examines the acoustic design and operational challenges of De Werkplaats, a progressive primary school in Bilthoven, the Netherlands. De Werkplaats was designed to integrate open learning environments to foster collaboration, inclusivity, and student agency. However, the design faced challenges in balancing the acoustic and spatial needs of diverse learning activities, due to non-traditional classrooms. Noise disturbances, largely due to mismatched activities between different groups in the same open space, prompted a decision to remodel the environment. This offered an opportunity to collect subjective and objective data before and after remodeling, providing insights into how these changes impacted functionality and user satisfaction. Key factors include insufficient acoustic zoning, overstimulation from open layouts, and challenges aligning spatial design with the school's educational philosophy. This study investigates whether conventional acoustic standards suffice in such settings or if broader considerations, such as activity coordination, privacy, and adaptable noise mitigation strategies, are required. Insights are drawn from acoustic measurements and user experiences. The findings underscore the importance of early-stage planning, tailored guidelines for open school environments, and integrating well-being-focused design principles. This research contributes to frameworks for creating sustainable, inclusive, and acoustically balanced learning environments. The findings underscore the importance of early-stage planning, tailored guidelines for open school environments, and integrating well-being-focused design principles.

*Corresponding author: colin.campbell@ecophon.co.uk

Keywords: Innovative learning environments, acoustic design, remodeling, activity-based, acoustic standards.

1. INTRODUCTION

De Werkplaats[1] is a progressive primary school in Bilthoven, the Netherlands, inspired by the educational vision of Kees Boeke[2]. The school embraces an open learning environment to foster collaboration, student agency, and inclusivity. However, the implementation of open learning spaces has posed challenges related to noise disturbance, spatial organisation, and the alignment of teaching and learning activities. This study examines the impact of these factors on the school's functionality, leading to a recent remodeling aimed at addressing these issues. By analysing subjective and objective data[3] before and after the remodeling, this paper explores how acoustics, spatial design, and educational methods interact in open learning environments.
The increasing shift from traditional classroom models to open learning spaces has raised questions about the acoustic feasibility of such designs. While openness fosters collaboration, it can also introduce excessive noise, distraction[10,12] and overstimulation[4], particularly for neurodiverse students[5] and teachers. Understanding the relationship between space and sound is crucial in creating environments that support various learning needs while maintaining flexibility and adaptability.

Over the past years, we see that trends in educational design have shifted from traditional classroom models to open, flexible learning spaces. These designs promote collaborative learning[6,7], but often lack sufficient consideration of acoustics, spatial organisation and insufficient attention is paid to the practical situation of the educational vision.

At De Werkplaats, noise disturbance and overstimulation became prominent issues. The initial open environment did not adequately support the diverse activities carried out by the different school years, prompting a re-evaluation of the school's spatial layout. Furthermore, the comparability of such spaces to open office environments is often made but remains questionable, as schools serve a fundamentally different purpose and user group.

1.1 The vision of De Werkplaats

De Werkplaats[1] is based on the progressive educational philosophy of Kees Boeke[2], which emphasizes independence, responsibility, and collaborative learning. The school's design aimed to facilitate these principles through open, flexible spaces that encouraged movement, group work, and autonomy. However, the absence of structured acoustic zoning led to challenges in sustaining productive learning conditions, necessitating adjustments to the school's spatial configuration (See image 1).

In 2015, adjustments were therefore made by applying acoustic wall solutions at strategic locations (See previous De Werkplaats Case Study[8]). Because the team works flexibly, people do not always stand in the same place and activities change, these solutions do not bring the desired result with regard to sound and acoustics.

1.2 The Role of Acoustics in Learning Spaces

Acoustics play a crucial role in cognitive processing[10], communication[7], and overall well-being[11&12]. Poor acoustic environments can lead to increased cognitive load[10], stress[13], and reduced engagement[12]. Research suggests that excessive noise impairs concentration[12], particularly for younger children and those with auditory sensitivities[14]. In open learning environments[19], speech intelligibility[15] and background noise management become paramount to ensuring effective teaching and learning experiences[11].

2. METHODOLOGY

This case study employs a mixed-methods approach, combining quantitative and qualitative data to assess the impact of remodeling efforts at De Werkplaats. The research process includes:

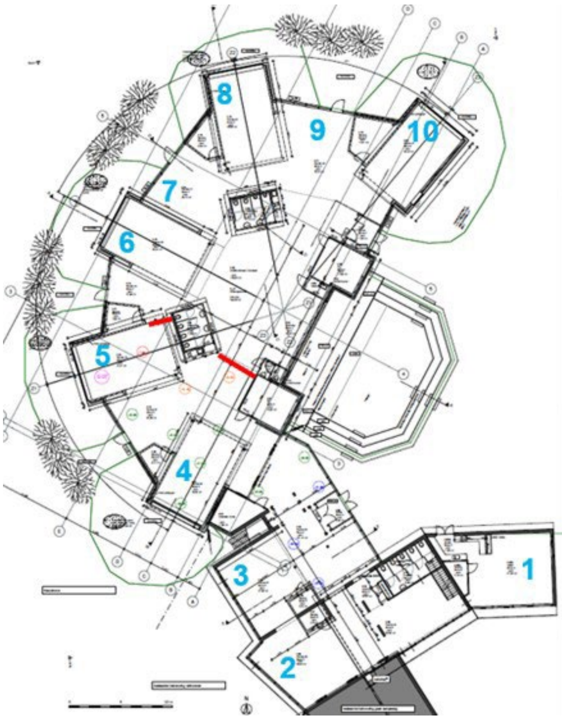

Image 1. Open school plan (1-10 classes marked in blue) with re-modelling design new partitions in red Typology of space D (ILETC) [9].

- **Objective Measurements**[3]**:** Impulse response measurements using the Dirac 6.0 room acoustics program were used to determine a number of relevant room acoustic parameters. Although the main focus of the research was on free field noise reduction, measurements of reverberation time (RT), speech intelligibility (STI) and overall noise levels before and after remodelling were carried out (see previous Case Study[8]).
- **Subjective Feedback**[16]: Surveys, interviews and workshops with teachers to evaluate perceived acoustic comfort and teaching effectiveness. With a focus on the vitality of the teachers. They were also given the opportunity to take a hearing test. This will be covered in more detail in a further paper.
- **Observations**: Documentation of behavioral and spatial use patterns.
- **Comparative Analysis:** Evaluation of changes resulting from remodeling efforts, identifying improvements and persisting challenges.

The study also examines how the school's learning environment compares to open office spaces, questioning whether similar acoustic strategies can be applied to both settings.

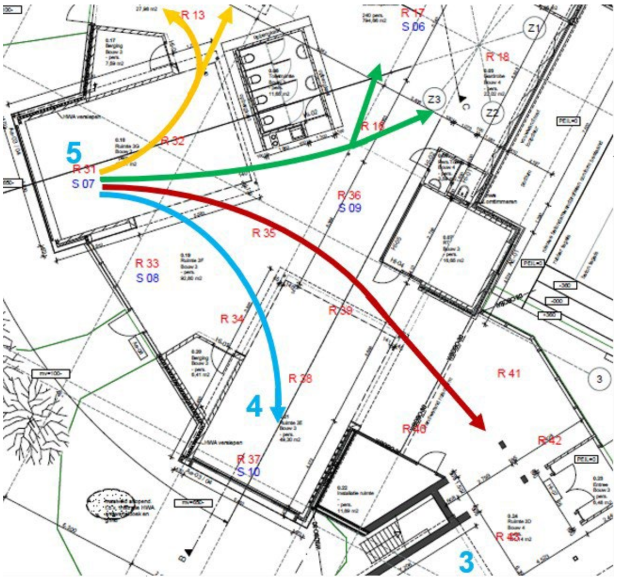

Image 2 Sound paths all from Class 5, S07/R31 source position into all adjacent teaching domains (Classes 6, 4 & 3) and their respective learning spaces before the partition walls.

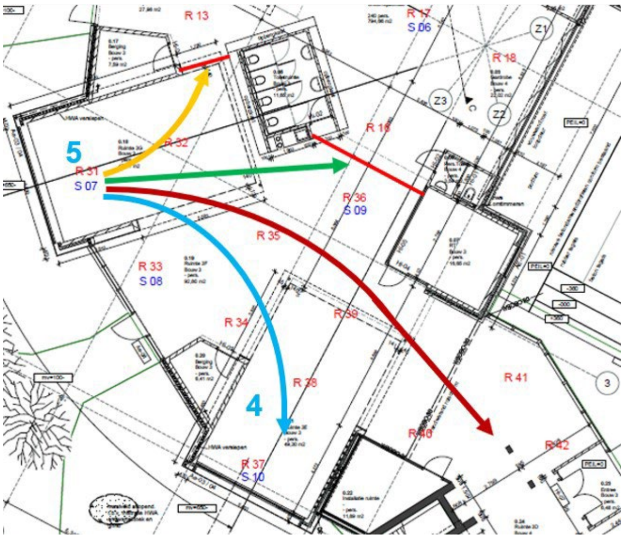

Image 3 Sound paths all from Class 5, S07/R31 source position into Class 4 and 3 teaching domains (R32-43 in red text) and their respective adjacent learning spaces after the partition walls(marked with the two red lines).

3. MEASUREMENTS

3.1 Reverberation Time (T30)

The measurements show that the average reverberation time in the Class teaching domains is approximately 0.4 s (between 0.40 and 0.43 s). The average reverberation time is relatively short, and compared to the results of previous reverberation time measurements (see previous study[8]), (0.43-0.48) the reverberation time is now shorter. This may be a combination of the presence of more furniture in the teaching domains and a reduction in the overall volume.

3.2 Speech Transmission Index (STI)

STI values relate to the quality of speech intelligibility[15]. The following can be concluded from the STI measurements: - At a short distance from the source, speech intelligibility is naturally good. However, comparatively elevated STI values have also been measured at greater distances from the source. The STI values recorded were not less than 0.50 vs what would be recommended values[17] for these spaces (see chart 1). Within the core Teaching domain, in which the source is placed, speech intelligibility is generally 'good' at all positions, with STI values higher than 0.70.

Furthermore, the measurements conducted in the adjacent learning spaces reveal that there are no positions relative to the source positions used where the STI is smaller than 0.20. This finding suggests that there are no positions between the group spaces where there is technically sufficient acoustic privacy.

It is acknowledged that the STI values were determined in an environment without sound generated by talking and playing children and teachers. The background noise from the HVAC system was included in the determination of the STI values. During operation, the background noise level is expected to be elevated with occupied activity noise, thereby further diminishing speech privacy. As most of the teachers were still disturbed by the noise after the acoustic panels had been installed, it was decided to install a partition between groups 5/6 and 7/8. The disturbance was mainly due to the different teaching and learning activities being out of sync. The timetables could not be coordinated because the nature of the learning task activities was too different for the two groups, although both groups were of course following according to the same vision, disturbances from other tasks put teachers and students off task, disrupting them from their specific task.

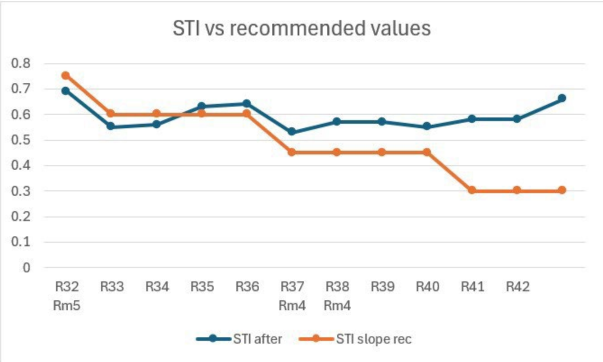

Chart 1. STI from Source S07/R31 in Class 5 to Class 4 & 3 and their respective adjacent learning spaces (Data from Table 1.)

Table 1. STI data from Source S07/R31 in Class 5 to Class 4 & 3 and their respective adjacent learning spaces illustrated above in Chart 1.

STI values	R32 Rm5	R33	R34	R35	R36	R37 Rm4	R38 Rm4	R39	R40	R41	R42	R43
STI after	0.69	0.55	0.56	0.63	0.64	0.53	0.57	0.57	0.55	0.58	0.58	0.66
STI slope	0.75	0.6	0.6	0.6	0.6	0.45	0.45	0.45	0.45	0.3	0.3	0.3

3.3 Sound decay (DA)

In order to gain an understanding of the variation in sound levels between the different spaces in the wings, the sound levels at various receiving positions were measured in comparison to a fixed source position, utilising a constant source with a known level. The resulting data were then utilised to calculate the difference in sound level (LAeq) between the source and receiving positions. The following conclusions can be drawn from the sound reduction measurements:

Specifically, within a overall class spaces including the adjacent class learning spaces, the maximum recorded sound reduction was found to be approximately 32 dB.

Furthermore, within a teaching domain in which the source is placed, the sound reduction is generally limited to a maximum of 12 dB. This is despite the shielding effect of existing cabinets in the transmission path.

It is evident from the findings that clear shielding or a considerable distance from the source is necessary to observe a reduction in sound levels of more than 15 dB.

Furthermore, the sound reduction in the room is also limited at greater distances. It is evident that the sound reduction in a room is subject to limitations, primarily due to the partial shielding effect of walls. In many instances, there exist direct lines of sight between the source and the receiver, which further complicates the issue. The presence of sound reflections via the facades, the hard floor and the hard interior walls has been detected. Consequently, sound from a given source can also reach the receiver via these reflections amplifying those sound paths.

Specifically, the noise level resulting from a person speaking at a normal conversational tone is approximately 60 dB(A) at a distance of 1 m, whereas the background noise level in an open educational space is approximately 35 dB(A). This indicates that a noise reduction of more than 25 dB (60-35) is necessary to no longer be able to understand the speaker. This reduction has been observed in a number of the measured situations. However, this is not observed at short distances. In practice, the background noise level in the school is higher. The presence of masking ambient activity noise contributes to the maintenance of privacy, and it is therefore possible to achieve sufficient speech privacy with a smaller noise reduction.
A comparison of the measurement results with those from a previously conducted study reveals that the sound reduction is comparable in both instances. However, at several locations, there is a variation of 1 to 2 dB, which can be attributed to minor variations in the source and receiving positions.

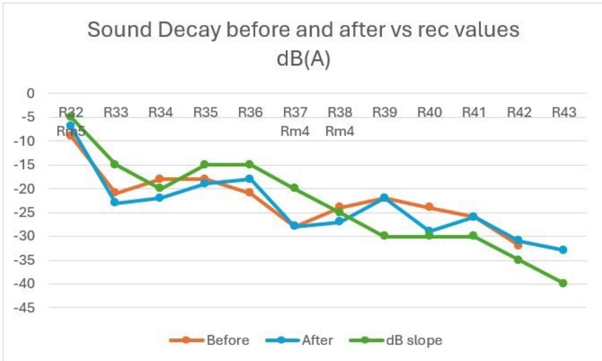

Chart 2. Sound decay dB(a) before and after from Source S07/R31 in Class 5 to Class 4 & 3 and their

respective adjacent learning spaces vs the recommended sound decay slope (Data from Table 2.)

Table 2. Sound Decay from Source S07/R31 in Class 5 to Class 4 & 3 and their respective adjacent learning spaces illustrated in Chart 2. above.

Sound decay	R32 Rm5	R33	R34	R35	R36	R37 Rm4	R38 Rm4	R39	R40	R41	R42	R43
Before	-9	-21	-18	-18	-21	-28	-24	-22	-24	-26	-32	
After	-7	-23	-22	-19	-18	-28	-27	-22	-29	-26	-31	-33
dB slope	-5	-15	-20	-15	-15	-20	-25	-30	-30	-30	-35	-40

3.4 Noise levels (LAeq)

Over a period of 11 working days, noise levels in the space were measured during working hours (8:00 to 17:00). During these measurements, the average noise level, the maximum and minimum noise levels were recorded at a number of locations within the space. The measurement results provide insight into the noise levels that occur when the building is in use, i.e. when students and teachers are present.

The following conclusions can be drawn from the noise level measurements:
Specifically, during class hours, the lowest recorded noise level was found to be 41 dB(A) LAeq. Conversely, the highest recorded noise levels attained 79 dB(A).
Conversely, after class hours, a marked decline in noise levels becomes evident. However, a notable increase in noise levels was observed around noon. This can be explained by reference to the lunch break.
During class hours, an increase in noise levels to 79 dB was observed in the Teaching domain.

It is noteworthy that the average noise levels LAeq and the maximum noise levels LA,5 exhibit a discrepancy of up to 1 dB on occasion. This finding suggests that the average noise levels in the room are nearly equivalent to the maximum noise levels.

Table 3. Overview of acoustic measurements (values averaged) in Remodeled classes 3, 4 & 5 in comparison to the appropriate recommended guideline.

LBP Sight previous acoustic data typical spaces (vs rec values)	Werkplaats Recommended	Classes 2-5
Sound decay between teaching domains	>20dB	20-28dB
Sound decay in primary and secondary domain	20dB	11-16dB
Overall background noise (unoccupied)	<45dB	41dB
Speech intelligibility in own primary domain	>0.6 (STI)	0.69
Speech intelligibility to same secondary domain	>0.45 (STI)	0.64- 0.55
Speech intel. to other teaching domain	<0.20 (STI)	0.53
Reverberation time	<0.5s	0.41

4. FINDINGS

4.1 Pre-Remodeling Challenges

- **Misalignment Between Teaching Methods and Space Usage**[16]**:** The open layout failed to accommodate diverse range of learning activities, leading to frequent disruptions.
- **Noise Disturbance:** Without adequate acoustic separation, teachers experienced difficulties due to excessive noise, which had a negative impact on concentration and engagement[12].
- **Overstimulation:** The absence of enclosed, quiet areas contributed to sensory overload[5].
- **Team Teaching Difficulties:** Teachers found it challenging to coordinate lessons effectively without disrupting adjacent activities[23,25].

4.2 Remodeling Interventions

To address these challenges, the school implemented several modifications:

- **Enhanced Sound Absorption:** The installation of sound-absorbing materials, such as acoustic panels and carpets, was initiated to improve the overall sound quality. (Previous Study[8]).
- **Partial Enclosure of Learning Areas**: Introducing semi-enclosed spaces to minimise noise transmission. This was done by using a full-height separation wall with a revolving door. In addition, a number of walls were extended horizontally over the full height. In a number of

places, this horizontal extension was carried out to a height of approximately 1.6 meters.

- **School Building Guidelines**: Addition of guidelines on sound and acoustics in the Risk Inventory and Evaluation documentation[20].
- **Workplace Health and Comfort**: Normalising sound and sound perceived disturbance as a topic in teacher well-being and broader soundscape[26]. discussions.

Table 3. Overview of acoustic measurements (values averaged) in Remodeled classes 3, 4 & 5 in comparison to the appropriate recommended guideline.

De Werkplaats new extension 2015	Before (9-12yrs)	Remodelled (9-10yrs Class 2-5)	Remodelled (11-12yrs Class 6-10)
Number of classes in shared space	10	4	5
Number of Students	300	112	140
Number of students/ class	28	28	28
Number of teachers/ class	2-3	2-3	2-3
Overall m2	1000	400	500
M2/student	3.5	3.5	3.5
Typology of learning space	D	C/D	D

4.3 Post-Remodeling Experiences

Post-remodeling evaluations indicate that, even though an adjustment was made to the layout by separating learning spaces 1-5 from 6-10, this has not been sufficient to provide a comfortable learning environment. While some sound propagation issues have been resolved, almost two-thirds of the teachers continue to be regularly disturbed by noise in the teaching and learning soundscape[25].

A different approach to designing Open Learning Environments is needed:

- **Parameters For Sound Measurement:** Measuring the reverberation time alone is not enough. When designing a healthy sound environment in an open learning concept, it is necessary to measure multiple parameters[21,22]. Speech Transmission Index, Speech Clarity, Room Gain/ Sound Strength, Spatial Decay, Background Noise, etc.
- **User engagement:** More attention should be paid in design to engage the user in understanding the risks of an open learning environment. Good acoustics in terms of requirements for short reverberation time, high or low STI and sound decay does not say enough.
- **Human Perception:** Sound perception is a highly subjective experience influenced by various factors of the interior soundscape[26], including auditory sensitivity, personality profile[27]. and the surrounding context.

5. DISCUSSION

5.1 Lessons Learned from the Remodeling Process

The remodeling at De Werkplaats underscores the importance of co-design[24] approach aligning spatial design with pedagogical goals[25]. While open environments can support collaboration, they must also incorporate acoustic strategies to minimise disruptions. Key takeaways include:

- **The Need for Acoustic Zoning:** Flexible learning spaces require designated areas for different activities to balance openness with functionality.
- **Early Integration of Acoustic Planning:** Acoustic considerations should be incorporated at the earliest stages of school design to prevent costly retrofitting.
- **Balancing Flexibility and Structure:** While adaptability is crucial, completely open layouts often fail to support diverse learning styles effectively**.**
- **Human Perception and User group:** It is of great importance to incorporate human perception into the design process, as comfort is significantly influenced by user behaviour. The basis upon which a satisfactory sound environment can be realised is based on the activities of the users in question.

5.2 Comparability to Open Office Environments

The comparison between open learning environments and open office spaces reveals key differences:

- **User Needs:** Students have different cognitive and developmental[14] requirements compared to office workers, making direct comparisons inappropriate.
- **Noise Tolerance:** Unlike adults, young students are less capable of self-regulating[14] their environment and require structured acoustic management.
- **Purpose of Space:** Schools facilitate a wide range of dynamic activities, whereas offices generally focus on productivity and efficiency in a more predictable manner. It must be taken into account that elementary school students will not work as quietly as office workers or older students. Furthermore, occupancy (people/m2 ratio) and volume is an important aspect. In a large volume (for example, an atrium with office floors) with comparatively lower occupancy, noise levels will likely be lower and more self-regulating than in a smaller, higher occupancy space such as De Werkplaats.

6. CONCLUSION

The development of specific guidelines for open educational spaces does not guarantee their ability to support diverse teaching and learning methodologies while maintaining acoustic comfort. It is important to note that open learning environments are not standard cookie-cutter layouts[9]. These environments are always different in form, and furniture layouts and are designed to be agile.

It requires dedicated experts who are involved at an early stage and an understanding of the human factors. It is advisable to involve the end user from the beginning[24]. and explain the acoustic implications and risks of using an open learning environment.

Schools should approach open-space designs with a strategic framework that incorporates acoustic, psychological, and educational principles to optimise learning environments for all users.

By addressing these challenges, educational institutions can create more inclusive, effective, and adaptable learning environments that align with evolving pedagogical trends while prioritising student and teacher well-being.

Future research could focus on how an open learning environment in primary education connects to the environment in secondary education, enabling a seamless transition.
Future studies could focus on investigating the impact of specific factors, including behavioural aspects; Socio-emotional development aspects, motivation, culture, and expectations, on sound perception in educational settings.

7. ACKNOWLEDGMENTS

We would like to extend our special thanks to the following: Annemiek Bulters and Roos d'Haen, De Werkplaats Kindergemeenschap. Judith Veen, Heart2Hear. Pien Schravesande, LBP Sight. Jeroen Goes, Delta de Bilt. Helena Lennerhov & Per Hiselius of Saint-Gobain Ecophon AB. Johanna Westera, Saint-Gobain Ecophon NL. Emma Greenland, Anderson Acoustics. Amanda Robinson, Aercoustics Engineering LTD. Bodil Hovaldt Bøjer, Royal Danish Academy. Mie Guldbaek Broens, LOOP.bz. Wes Imms, University of Melbourne. Their tireless work, advice and insights have supported and inspired deeper investigations around how this evolving learning environment can better inform other educators, designers acoustic engineers and policy makers to create learning environments with incorporated sound comfort.

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