Vibration and Airborne Sound in Repurposed Buildings: A Case Study of a Drum Kit in a Music Classroom

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This paper presents a case study of a space in a commercial building that was to be converted into a music classroom within a secondary school. Music classrooms, especially at the higher education level, often contain amplified or loud instruments, including acoustic percussion such as drums. Drums pose unique challenges due to the generation of both high airborne sound pressure levels and induced structural vibrations. Vibration and airborne sound from three critical drum components were measured to assess transmission through a suspended concrete slab and connecting masonry elements. The impact of using a resilient interlayer to reduce structural vibration and re-radiated noise was also evaluated. The tested resilient platform reduced airborne and structure-borne sound by approximately 5 dB in D_w measurements, particularly for the thinner slab. The study underscores the complexity of sound transmission in buildings, suggesting the need for further investigation. The results of these measurements for various slab thicknesses and mitigation strategies offer insights for treating airborne noise and structural vibration in drum kits and other loud instruments.

1 INTRODUCTION

This paper aims to provide acoustic data and quantify the effects that a resilient interlayer can have on airborne noise, impact noise and vibrations for instruments such as a drum kit that induces vibration and noise into the construction.

A literature review has been conducted and limited information concerning percussion and associated vibration has been found. One such study published by AAS in 2008 (Emslie & Hanson, 2008) can be summarized as follows: The paper discusses the design, construction, and acoustic performance of a private drum studio aimed at minimizing noise impact on neighbours while maintaining high sound quality within the studio. It details the use of lightweight partitions, vibration isolation and various sound absorption treatments to achieve significant noise reduction and optimal internal acoustics. The study concludes with the successful achievement of stringent noise criteria and an acoustically balanced environment suitable for both practice and recording purposes. However, the objective issue with this paper's scope is noise and vibration within the same building for a heavy concrete construction which the mentioned paper does not cover.

1.1 Criteria

The airborne sound insulation performance criterion for the project is D_w 45 dB in accordance with the design standards for education facilities for the South Australian Government (Department for Education, 2024). The criterion refers to internal walls separating music spaces with the note that acoustic requirements must be specifically determined by an acoustic engineer. Furthermore, the following text is included in the design standard: "Acoustic requirements in specialist spaces including design and technology workshops, performing arts, music, drama and assembly halls, and all other specific combinations of walls between noise-sensitive spaces, must be designed by an acoustic engineer with reference to the AAAC Guidelines."

Impact sound insulation performance has a criterion of $L'_{nT,w}$ 45 dB in accordance with the AAAC Guideline for Educational facilities (Association of Australasian Acoustical Consultants , 2018). The criterion refers to a source room with high sound levels to a receiver room with very low tolerance to noise disturbance. There are currently no formal criteria for vibration limits within educational facilities from percussive instruments. Measurements of RMS acceleration were performed which are shown with decibel units.

2 METHODOLOGY

2.1 Existing space and refurbishment

The current building is a commercial space with offices that is to be converted to a music classroom (Music GLA) within a secondary school. Music GLA, especially at the higher education level, often contain amplified or loud instruments, including acoustic percussion or drums. Based on the author's previous experience with both acoustic and digital drums in apartments it was important to convey the need for mitigation and have a listen. The author's previous experience was that even the digital bass drum could be heard through concrete structures in non-directly adjacent apartments.

The project was a perfect opportunity to measure noise/vibration levels on two different slab thicknesses within the same room and investigate how much the placement affected the outcome. Having the architect on site to listen was a great way of conveying the need for mitigation and understanding that no mitigation would cause disruptions. There was an opportunity to test a simple mitigation solution with a resilient layer. Drums present unique challenges due to the generation of both high airborne sound pressure levels and induced structural vibration. The existing office space has a concrete slab that varies in thickness between 180 mm to 450 mm for the studied source space as shown in Figure 1. The potential Music GLA (Source or SRC) is located on the first floor above a future teacher workspace and library on the ground floor (Receiver or REC). The transmission paths for airborne and structure-borne noise are complex; a drawing of the structural system is shown in Figure 2, with the stair not directly anchored in the concrete wall. Measurements on site for the sound insulating performance takes all these paths into account and is not aimed to discern between the different transmission paths.

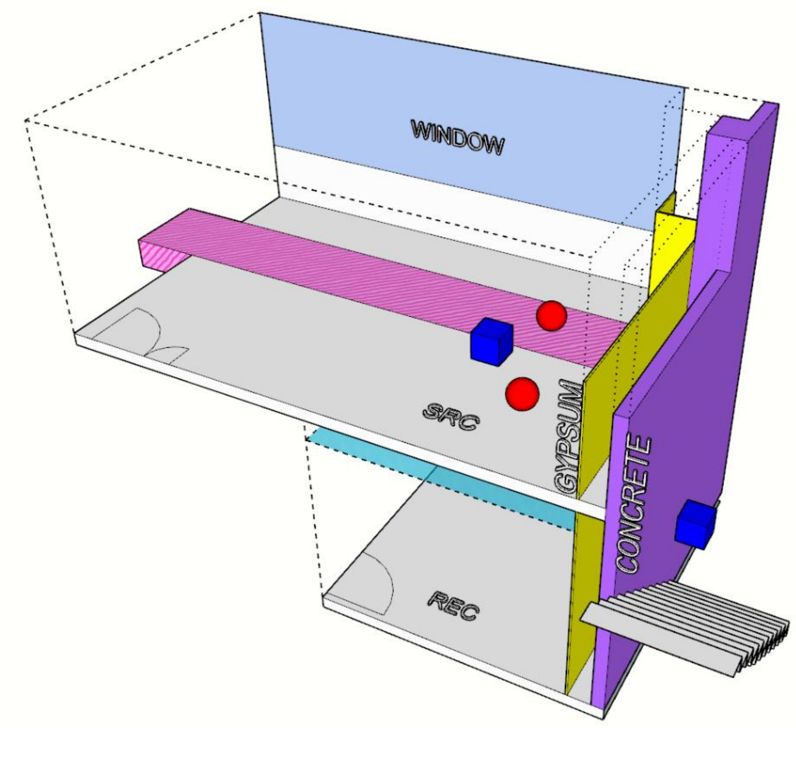

Figure 1 – The red sphere indicates drum location on 180 mm slab (grey) and 450 mm slab (pink hatch). The dark blue cube is the location of the accelerometers on the floor in the source room (SRC) and on the wall by the stair on the ground floor representing the receiver room (REC).

Attempts to move the Music GLA to the ground floor and away from sensitive areas were not an option but should always be attempted. Note that all windows were closed during the measurements and new ductwork is to be installed during the refurbishment allowing for closed windows on both the first and ground floor. The ceiling in the receiver room for the measurement was a plasterboard construction with penetrations for light fixtures and other installations, see Figure 3. Penetration such as these will affect the sound insulating performance from the source room to the receiver room.

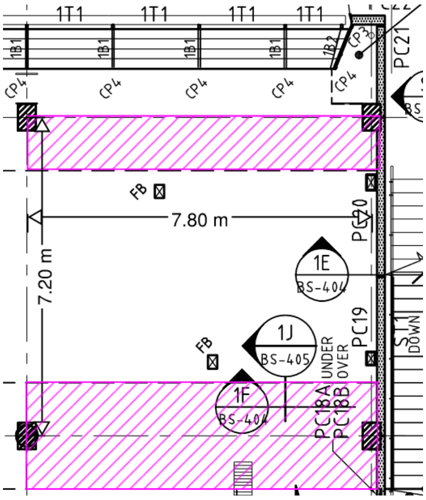

Figure 2 – Distance of structural system. Pink hatches are the beams or 450 mm concrete.

(BS EN 12354-5:2023) highlights several factors that can influence the structure-borne sound component:

Source Characteristics: The structure-borne sound power level of the source determines the potential maximum sound energy that can be transmitted into the building structure. This factor primarily depends on the characteristics of the equipment generating the sound.

Mounting Method and Location: The way equipment is mounted (e.g., direct fixing or use of resilient supports) significantly impacts the transmission of structure-borne sound. The coupling between the source and the structure (expressed through coupling terms) affects how much sound is transmitted into the building. The location of the source is also essential for the impact that the source will have on the structure.

Transmission Paths: Structure-borne sound can travel through multiple paths within a building. These include direct transmission through structural components (e.g., walls and floors) and flanking transmission through adjacent elements. Each path contributes differently to the overall sound transmission.

Figure 3 – Installations on walls and in ceiling for receiving room.

Figure 4 – Carpet in the source room at the 450 mm position with full drum kit and mounted vibration monitor on concrete.

2.2 Drumkit and platform

A full drum kit, as shown in Figure 4, was set up and measured at first to get airborne noise through the slab to the receiver room. The aim was to place the kit as (especially bass drum, tom and snare) on the 450 mm thick slab and not too far away from the adjoining concrete wall, please note that the gypsum lining limited the placement of the full drum set. However, the entire drum set did not fit on the test platform and therefore a bass drum, snare and tom were chosen to represent the different types of drums that are usually associated with a drum set. The bass drum is crucial due to the foot impact and low frequency thud, the tom was attached to the bass rum which made it possible to fit it on the platform. The hi-hat was too large and difficult to play comfortably and was therefore not used on the platform. The snare was natural choice because it fit and the platform and could be played comfortably.

The mass of bass drum with pedal, snare with stand and tom with stand is estimated at approximately 24 kg. Half a wooden pallet was used as platform with approximate dimensions of 1200 mm x 500 mm x 130 mm and weighed around 15 kg. Nine pieces of yellow Sylomer® SR11/25 (25 mm) with dimensions of 100 mm x 100 mm were placed under the platform. The drum platform and the chosen drum pieces are shown in Figure 5. The size of the platform did not allow for the drummer to sit on it.

Figure 5 – Position on 180 mm of concrete with platform.

2.3 Measurements

2.4 Airborne sound insulation performance

In accordance with the latest international standards, measurements (ISO 16283-1:2014) and evaluation (ISO 717-1:2020) for airborne sound insulation were carried out. Airborne sound insulation equipment used (calibrated in accordance with the latest calibration certificate) was as follows:

- Rion Sound Level Meter – Serial number 785237 – Source room
- NTi XL2 Sound Level Meter – Serial number – A2A-13461-E0 – Receiver room
- Behringer B115D Speaker – located in the corner of the 180 mm drum position for representative location of the source that was away from the window.

2.5 Impact sound insulation performance

In accordance with the latest international standards, measurements (ISO 16283-2:2020) and evaluation (ISO 717-2:2020) for impact sound insulation were carried out. Impact sound insulation equipment used was as follows:

- Norsonic NOR277– Serial number 2776363 – Tapping machine – Source room
- NTi XL2 Sound Level Meter – Serial number – A2A-13461-E0 – Receiver room

2.6 Vibration

The drums were played for a duration of 2 min and vibration data was extracted during a 30 s period for the accelerometer locations according to . The drummer was asked to play at steady intensity which the drummer describes as “medium intensity, basic rock beats with fills”. The drummer recollects choosing the song "You Get What You Give" by New Radicals which is listed as a pop band. The source room accelerometer was mounted with beeswax directly on the concrete slab under the existing carpet tile. The receiver room accelerometer was mounted using epoxy on a metal plate and attached to the vertical wall. The most movement was detected on the z-axis channel which was perpendicular to the surfaces in both the source and receiver rooms. Evaluation was done for RMS acceleration (μm/s^2). The accelerometer was checked for calibration according to the sensitivities of the latest calibration certificate. The accelerometer was set to high sensitivity and a capability of measuring vibration levels over 1 Hz in 1/3 octave bands at 1 second intervals. Vibration equipment used is as follows:

- SVAN 958A (blue) – Serial number 45586 – Triaxial accelerometer – Source room
- SVAN 958A (black) – Serial number 45591 – Triaxial accelerometer – Receiver room wall (stairwell)

3 RESULTS AND DISCUSSION

3.1 Airborne sound insulation performance

Airborne sound insulation results are shown in Table 1 and Table 2. Note that the airborne noise level in the source room is a combination of direct airborne and re-radiated noise from the room structure.

Table 1 – Measured airborne sound insulation performance

Test number	Source	Source SPL (dBA)	Receiver SPL (dBA)	Construction	D_w (dB)	ΔD_w (dB)
001	Full drumkit	101	53	450 mm	45	11 dB
006	Kick, snare and tom	100	46	450 mm + Sylomer® + platform	56	
008	Kick, snare and tom	99	47	180 mm	50	5 dB
013	Kick, snare and tom	99	46	180 mm + Sylomer® + platform	55	
019	Speaker	103	44	180 mm	60	

Table 2 – Spectral values of sound insulation D_w tests per 1/3 octave band [Hz]

Test number	100	125	160	200	250	315	400	500	630	800	1k	1.25k	1.6k	2k	2.5k	3.15k
001	58	59	61	55	52	52	49	45	45	42	41	40	46	49	48	53
006	54	57	59	52	51	53	52	52	52	54	56	57	59	59	59	58
008	53	49	61	56	53	51	52	52	48	51	50	51	51	49	50	51
013	54	49	61	55	54	52	51	51	51	53	55	56	58	59	58	58
019	54	58	59	58	54	55	59	59	56	58	62	58	59	60	63	63

Test *001* gives the D_w with a full drumkit as a source on the 450 mm thickness slab position. Part of the structure-borne sound is output as radiated sound. Test *006* shows the difference in putting three critical instrument components that would fit on the Sylomer® platform. The ΔD_w *= 11 dB and ΔSPL Rec = 7 dB* between the mentioned measurements.

Test *008* gives the D_w between the rooms with critical components as a source place in the 180 mm thickness slab position. Test *013* shows the difference in putting three critical instrument components that would fit on the Sylomer® platform. The ΔD_w *= 5 dB* between the mentioned measurements which means that the critical components make a difference of 5 dB when placed on the resilient interlayer platform as opposed to directly on the floor. Great care was taken attempting to put the equipment in the same spot, however the contact points between separate drum components and a platform will be different. It is noted that the D_w for Test *008* is significantly lower between 630 Hz to 3150 Hz than Test *013.* This could indicate that the position and presence of the resilient platform influences the mid to high frequency sound insulation performance.

The ΔD_w *= 1 dB* between Sylomer® platform on the 450 mm thickness slab versus the 180 mm thickness slab which is within the measurement tolerance. This indicates that the same reduction was achieved for airborne noise for both concrete thicknesses with the resilient interlayer. A greater difference was expected due to the different placements on the beam vs mid span between beams with regards to the rigidness of the structure. However, the difference is small when comparing D_w and only a large difference is noticed at 125 Hz between the measurements.

Test *019* is a standard airborne sound insulation test that shows the measured D_w is 60 dB. The speaker was still placed in the source room that was located above the receiver room which may still transfer structure-borne sound to the lower receiver room. Note that the drums were audible in the receiver room and would most likely be disturbing in the library and workrooms below the suggested Music GLA. D_w 60 dB is above the criteria and is still not enough sound insulation to the future library.

Drums were clearly audible throughout all the measurements. Flanking paths included slab, façade wall and internal lined wall adjacent to structural concrete wall. Note that a future raised floor will act as a lining and further reduce the sound transmission path through the slab. The tested platform had no such reduction present due to that the area covered was small and that it was open to air.

3.2 Impact sound insulation performance

The impact sound insulation performance was tested for the two slab thicknesses on top of the existing carpet tiles. A total of 3 positions with different angles of the tapping machine above the receiver room was chosen per slab thickness. The difference between the two slab thicknesses is marginal in terms of the single number rating. L'_{nTw} *38 dB* for the 450 mm thickness concrete and L'_{nTw} *37 dB* for the 180 mm thickness concrete. For both concrete thicknesses, the levels are low which implies that the impact sound insulation is excellent for the current structure with carpet tiles and well below the strictest criterion of L'_{nTw} 45 dB. However, the impact noise measurement is typically not valid below 100 Hz from an impact hammer stimulus as noted in the article:

> The characteristics of the pistons' impact are dissimilar to the impact of a human foot in this lower range. This may cause low signal-to-noise ratios in field measurements and the test data may also be less representative due to the test objects' possible structural nonlinearities affecting impact sound transmission. (Olsson & Linderholt, 2020)

Impact sound insulation testing is a poor criterion to rate the perceived impact noise levels from drums.

3.3 Vibration

Table 3 shows the difference between drums directly on concrete/carpet as opposed to the resilient interlayer platform. It includes the difference between measurement of vibration at the source on the first floor and on the receiver wall on the ground floor, see Figure 6. A negative value indicates an amplification of the vibration, and a positive value indicates a reduction of the vibration. The frequency with the highest amplification and reduction has been highlighted with **bold** text in Table 3. Note that vibration levels are not independent of the source location and structures impedance/mobility. Due to time restrictions vibration levels were only tested in two locations with and without the resilient platform in locations that were considered for the actual placement of the drums.

Figure 6 – Accelerometer mounted on the wall in the ground floor lobby, close to the stairwell.

The total reduction and amplification are summed up for the entire frequency range which indicates that the total reduction with the Sylomer® platform is approximately 16 dB for the 450 mm thickness concrete versus 23 dB for the 180 mm thickness concrete when summed over the 1/3 octave-band range. This suggests that the platform with the 25 mm resilient interlayer is more effective on the 180 mm concrete. Even though a reduction is seen from 4 Hz for certain 1/3 octave bands, this does not align with the theoretical calculations where a 25 mm resilient layer platform with the current load should have a natural frequency of around 30 Hz with reduction of vibration starting at 50 Hz. The 450 mm slab with the platform indicates amplification above 50 Hz where as the 180 mm slab with the platform sees a reduction.

Table 3 - Measured vibration performance for Sylomer® platform compared with concrete and carpet tile in decibels for RMS acceleration.

Frequency 1/3 octave band (Hz)	450 mm concrete with Sylomer® platform (dB)	180 mm concrete with Sylomer® platform (dB)
3.15	**5.2**	3.6
4	2.1	0.3
5	3.2	-3.5
6.3	1.2	2.1
8	0.9	1.1
10	3.0	4.8
12.5	3.1	2.6
16	2.9	0.2
20	-0.3	-0.1
25	0.9	0.6
31.5	0.2	0.8
40	0.2	-0.3
50	0.9	3.5
63	-0.9	3.0
80	1.1	**-3.7**
100	**-3.3**	**5.0**
125	-2.5	4.0
160	-1.6	-0.7
Total	**16.4**	**23.2**

The reduction between source and receiver accelerometer for each tested construction is shown in Figure 7. Generally, the resilient interlayer effectively dampens vibrations in the tested configurations. The 450 mm thick concrete slab with Sylomer® platform exhibits an amplification of measured vibration around 125 Hz, the cause of which remains unidentified and does not correspond with the estimated resonance frequencies of either the individual slab thicknesses or the combined construction. A possible explanation could be outside interference (plant starting and inducing vibration) at these frequencies during the measurement with Sylomer® platform; however, nothing was noted during the measurement.

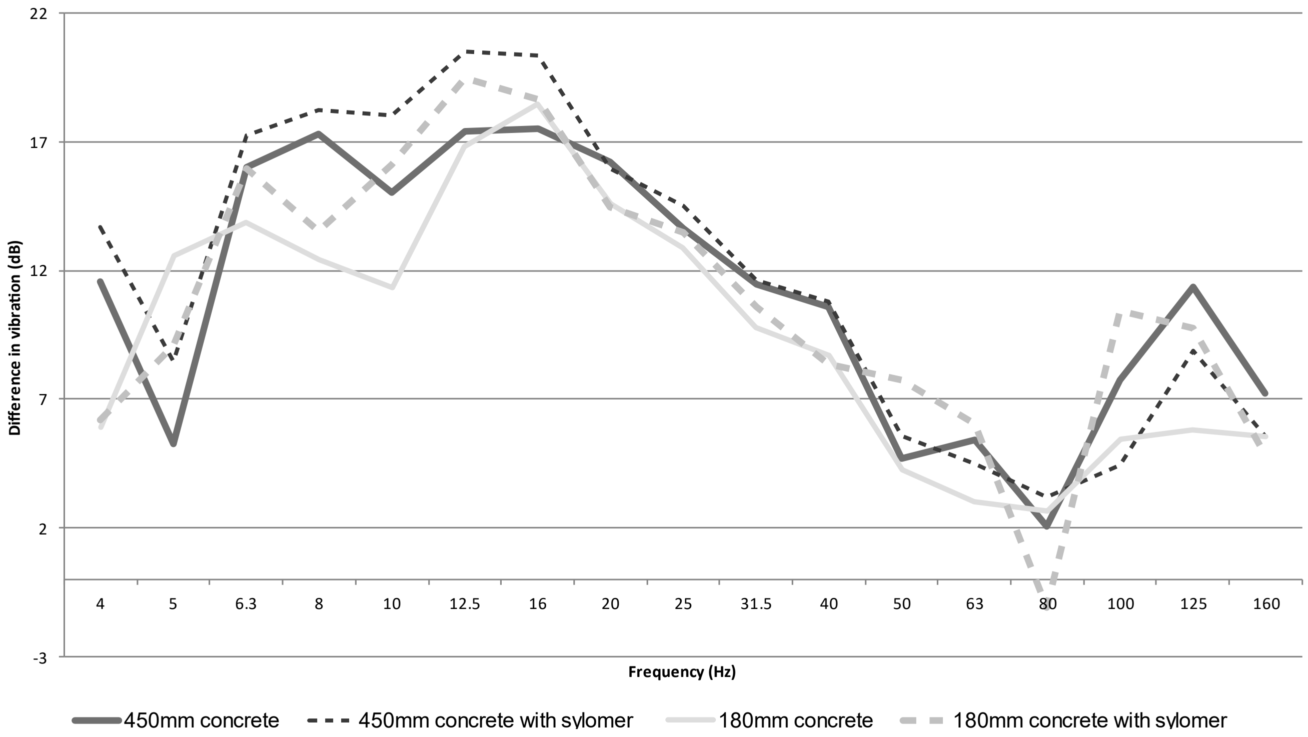

Figure 7 – Reduction between source and receiver accelerometer for all configurations per 1/3 octave band.

Subjectively, the vibration could be felt in the slab on the first floor through feet in the source room. At the accelerometer position on the ground floor, the vibration could be felt through the hands in the connecting concrete wall. The drums were also just audible in the lobby which was the location for the vibration measurements on the ground floor.

4 FURTHER INVESTIGATION

In order to further understand the measurements it is suggested that source and slab mobility should be investigated. The placement of the drums and the platform even without the resilient layer could also cause changes to reduce the sound and could be investigated further to isolate the cause of the presented results.

5 CONCLUSION

In conclusion, a resilient interlayer platform reduced the D_w of about 5 dB for the 180 mm positions. This is a simple view of a complex system but may still give an indication of the usefulness reducing mid to high frequencies. There is a great complexity to determine the airborne and structure-borne sound transmission in a building with intricate structural elements and the method for doing so could be improved by further testing. If a platform acting as a lining is also built, further reduction from the slab and flanking elements is anticipated.

The listening test on site was crucial in order to inform the client necessary measures and understand that the current state of the office sound insulation is not enough for a Music GLA and that a location directly above sensitive spaces is not ideal. Drums is a good example of instruments that will require additional considerations in these types of projects due to the high airborne noise and impact from playing.

The measurement results of the impact noise performance were well below the most onerous criteria which indicates that it is not a good measurement parameter and methodology (i.e. tapping machine as source) for these types of spaces to restrict disturbances.

Regarding vibration, the resilient interlayer provided an improvement for both the 180 mm and the 450 mm thicknesses of concrete. However, there were frequencies with both amplification and reduction. Across the entire frequency range, there was more overall reduction than amplification, with about 16 dB for the frequency range in 1/3 octave-bands for the 450 mm thickness slab and 23 dB for the frequency range in 1/3 octave-bands for the 180 mm thickness slab for the studied frequency range. Even though a reduction is seen from 4 Hz for certain 1/3 octave bands, this does not align with the theoretical calculations where a 25 mm resilient layer platform with the current load should have a natural frequency of around 30 Hz with reduction of vibration starting at 50 Hz.

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