Investigation of impact isolation of flooring products and resilient underlays

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ABSTRACT

The majority of noise complaints by residents in multi-dwelling residences are caused by hard surface flooring. A common solution to curb the impact of hard floors is to install a resilient layer between the subfloor structure and the hard surface flooring. This study attempts to investigate the influence of various flooring products and resilient underlays on the impact sound isolation of several commonly used floor systems. The impact sound insulation of numerous combinations of flooring products and resilient underlays were tested on a concrete slab with a plasterboard ceiling. Four flooring products were tested including an engineered tile system, engineered timber, timber laminate and vinyl flooring products. The underlay products consisted of three rubber underlays with varying thicknesses, one underlay consisting of polyurethane foam granulates and cork and an underlay consisting of polyurethane-bound elastomers. Comparison of results between soft floor coverings and hard floor coverings indicate that the profile of the resilient underlay can have significant improvements in impact sound insulation, more so than the weight of the flooring or the thickness of the resilient material.

1 INTRODUCTION

As residential areas in major cities across the world become more densely populated, there is a greater focus on building taller, highly populated residential buildings. Surveys of residents in high density dwellings have indicated that occupants are almost always annoyed by foot fall noise, while other noise sources only cause annoyance at certain levels (Watters, Bolt & Beranek, 1976) and the majority of complaints by residents in multi dwelling residences are caused by impact noise (Jeon, Jik Lee & Sato, 2006).

Surveys have also found an increase in depression, anxiety, fatigue and insomnia was present in cases where low frequency structure borne noise is reported (Mirowska & Mroz, 2000). Further studies have also shown that the noise from apartments above is found to be more disturbing than noise from apartments below (Raw & Oseland, 1991).

In an effort to reduce the weight of taller residential buildings, pressure is put on building designers to achieve a high level of residential amenity with light weight construction. The demand brought on by impact noise regulations (Strata Schemes Management Regulation, 2010) has driven flooring manufacturer's and researches to develop underlay materials, to be installed between hard flooring products such as timber or tile and the building structure (Rushforth, Horoshenkov, Miraftab & Swift 2005), to reduce impact noise and vibration. These products can be quite expensive and difficult to install, therefore builders and designers may be reluctant to specify such "additional materials". It is therefore important to be able to design floor systems that provide adequate noise and vibration isolation with efficient use of materials and space.

The majority of vibration control methods in residential inter-tenancy floors involve the use of vibration damping and of flexible couplings and mounts in the form of intermediate flooring layers or flexible ceiling mounts. This paper compares the acoustic performance of various types of resilient underlays and floor coverings commonly used.

2 FLOOR IMPACT NOISE - REVIEW

A single degree of freedom system describes a vibration system by the spring stiffness and damping of a mass. To understand the effect stiffness has on the impact reduction performance of a floor system, Kim, Jeong, Yang and Sohn (2009) investigated the correlation between dynamic stiffness of resilient materials and heavy weight impact sound reduction level. The results of the testing found that as the dynamic stiffness of the resilient layer decreased, the resonance frequency decreased and the impact sound reduction level increased. For improved impact sound reduction, a dynamic stiffness of 8 MN/m^3 or less is preferred.

Yoo and Jeon (2014) carried out an investigation into the effects of different types of interlayers on floor impact sound insulation in box frame reinforced concrete structures. The impact sound insulation performance of a floating floor is mainly dependant on the dynamic properties of impact isolators used. Floating floor systems with resilient materials may be ineffective in reducing low frequency sound transmission from heavy weight impacts, where by the impacts excite flexural vibration resonances of the floor structure. Preventing such heavy weight impact sound transmission involves controlling the mode frequencies of the floating floor by inserting additional layers.

The results showed that resilient isolators were effective in reducing the floor impact sound level at higher frequencies but increased impact sound levels at lower frequencies, particularly near the natural frequency of the floating floor system. Modifications to the floating floor structure to increase available damping was however effective in reducing low frequency impact sound.

2.1 Identifying Construction Improvements in Impact Isolation

Schiavi, Gugliemone and Migietta (2011) discussed the effect of a static load on the dynamic stiffness and airflow resistivity of porous and fibrous resilient insulating materials used under floating floors. The research showed that the change in density and stiffness caused by the application of a static load altered the flow resistivity of the material and therefore the performance of the floor. Given that the results of the floating floor tests varied according to the load applied to the test sample, and that the measurement of dynamic stiffness is carried out under a known static load, Schiavi et al. suggest that airflow resistivity should also be carried out under the same static load as dynamic stiffness measurements.

2.2 Low Frequency Resonances

Theoretical models have shown the importance of the supporting structure's resonances in determining the low frequency response of the floor system. Cho (2013) used finite element analysis to compare laboratory and in-situ measurements and found that the impact sound transmission in the experimental method varied with floor dimensions. The study showed that frequency matched resonance must be considered for low frequency impact sound isolation of floating floors. Cho concludes that the accuracy of the standard single degree of freedom vibration isolation improves when frequency matched resonance is considered.

Hui and Ng (2009) conducted experimental modelling and practical measurements to investigate the reduction of low frequency vibration transmission. The study found, to reduce the low frequency vibration transmission, the isolator is best located at the nodal point of the flexural vibration mode of the concrete slab. The nodal point can be located by finite element method. Hui and Ng found, to reduce the flexural vibrations a stiffener should be placed near the centre of the slab.

In order to predict the noise inside the receiving room at frequencies from 20 Hz to 200 Hz, where the response is dominated by the room's modal characteristics, Neves e Sousa and Gibbs (2011, 2014) used analytical modelling with natural mode analysis of rectangular plates to represent the floor structure. The results were validated in the laboratory and in-situ. This research resulted in an expression to predict the room dimensions to avoid, depending on the concrete slab thickness and dimensions.

Ford and Hothersall (1974) conducted research into the influence of the top floor covering and found that the resilient properties of the flooring, affect the mean squared velocity of the sound radiating into the supporting slab by modifying the force of the vibration pulse generated on the floor.

3 TEST PROCEDURE

3.1 Introduction

Impact insulation measurements were conducted in accordance with AS/NZS ISO 140.7-2006 (ISO 140-7:2006), on an existing floor / ceiling system of a commercial building to best replicate typical floor and ceiling construction. The base floor, on which all of the materials were to be tested, consisted of a 200 mm thick concrete slab with a 10 mm plasterboard ceiling suspended below the concrete slab using 35 mm furring channels. This construction is considered representative of common residential floor/ceiling systems, with a plasterboard ceiling suspended below.. Given the large number of tests conducted, the underlays were not glued to the concrete slab, nor were the flooring samples glued to the underlays.

3.2 Flooring Products

The impact sound reduction of combinations of five 'Regupol' resilient underlay flooring products (E48, 6010 BA, 6010, 4515 and Sound 12) and four flooring products (engineered timber, engineered tile, timber laminate and vinyl), were tested on top of the existing structural slab. These products were selected as collectively they represent a broad range of typical flooring products installed in residential buildings today. The five Regupol resilient underlay products were selected as they provide a range of underlays with varying materials, thickness and profiles, thus allowing the effect of these characteristics to be investigated.

The tested engineered timber flooring was a 15 mm thick "Boral Silkwood" product which consisted of 11 mm compact plywood with a top layer of 4 mm Tallowwood hardwood and an acrylic coating. The engineered tile sample consisted of a 9 mm ceramic tile fixed with a standard tiling adhesive to a 9 mm thick sheet of fibre cement, which is then glued to a second sheet of 9 mm fibre cement using a construction adhesive.

The timber laminate floor sample consisted of 8 mm Medium Density Fibreboard (MDF) with a 1 mm vinyl veneer (faux timber). The top side of the laminate flooring panel is wood grain textured, while the bottom side is flat. The timber laminate flooring sample consists of interlocking panels, which interlock by way of a tongue and groove joint along two adjacent sides of the panels.

For tiling installations with a resilient underlay, a problem occurs when the compression under foot of the resilient underlay causes a difference in height between adjacent tiles. These differences in height then cause cracks of the tile or grout. For this reason in situations where a resilient intermediate layer is required for vibration and impact isolation, two layers of sheeting with joints overlapped are introduced in between the tile and resilient elastic layers to prevent cracks.

The 4.5mm poly / vinyl chloride (PVC) flooring product was chosen as representative of a typical modern floor covering. The vinyl flooring sample consisted of interlocking panels, which interlock by way of a tongue and groove joint along two adjacent sides of the panels. The top side of the vinyl is textured to give the appearance of wood grain, while the bottom side is flat and slightly rough to allow adhesive to be applied to fix to the concrete or timber sub structure. To avoid an excessively elastic floor, vinyl floor systems which require a resilient underlay must be mounted above a relatively stiff structural layer (for example plywood or fibre-board) with the resilient underlay below this. To investigate the effect of the structural interlayer on impact noise reduction, the vinyl floor system was tested with and without the interlayer.

The thickness, surface density and density of the four flooring sample products is shown in Table 1.

Table 1: Flooring Product Specifications

Sample	Thickness	Surface Density	Density
Engineered Timber	15 mm	9.61 kg/m^2	640 kg/m^3
Engineered Tile	30 mm	53.49 kg/m^2	1783 kg/m^3
Timber Laminate	9 mm	7.78 kg/m^2	865 kg/m^3
Vinyl	4.5 mm	9.9 kg/m^2	2200 kg/m^3
Vinyl with structural layer	22.5 mm	20.7 kg/m^2	920 kg/m^3

3.3 Resilient Underlays

The E48 product is a styrene-butadiene rubber (SBR) bonded with a polyurethane binder. SBR is from a group of rubbers derived from styrene and butadiene and commonly used in car tyres. The profile of E48 is dimpled on one side and flat on the other, with its thickness varying between 8 mm and 4 mm. The E48 product is designed to be installed under cement screed for tiling situations.

The 6010 product consists of recycled rubber granules with elastic polyurethane binding. The sheet profile is flat on both sides, with a constant thickness of 10 mm. The 6010 product is designed to be installed under hard flooring products such as timber floorboards or plywood.

The 6010BA product consists of the same recycled rubber granules as the 6010 product. The main difference between the two products is that the profile of the rubber of 6010BA is dimpled on one side and flat on the other, with its thickness varying between 17 mm and 8 mm. The 6010BA product is designed to be installed under cement screed for wet area tiling situations.

4515 is an elastic prefabricated mat, made from polyurethane foam granules and cork, bound with polyurethane. The sheet profile is flat on both sides, with a constant thickness of 3 mm. The 4515 product is designed to be installed directly stuck beneath tiles in dry areas using adhesive without the need for screed.

Sound 12 underlay consists of polyurethane-bound elastomers. An elastomer is a polymer that has both viscosity and elasticity and makes Sound 12 the softest of the samples tested. The elastomer is laminated on the top side by a green aluminium foil. The profile of Sound 12 is dimpled on one side and flat on the other, with its thickness varying between 17 mm and 8 mm. The Sound 12 product is designed to be installed beneath cement screed for tiling situations.

The profile thickness, surface density, tensile strength, elongation at break and density of the five resilient underlay products is shown in Table 2.

Table 2: Intermediate Resilient Product Specifications

Sample	Thickness (mm)	Surface Density (kg/m^2)	Tensile Strength (N/mm^2)	Elongation at Break (%)	Density (kg/m^3)
E48	8/4	3.3	0.3	50	550
6010	10	5.8	0.5	70	580
Sound 12	17/8	5.7	0.12	40	410
6010 BA	17/8	7.69	0.5	20	550
4515	3	1.25	0.9	30	430

4 RESULTS

The receiving room impact sound levels, background noise levels and reverberations times were measured and processed using Brüel and Kjær instrumentation and software. The flooring samples were all tested on the bare concrete without any underlay to determine the effect of the flooring samples on the impact sound isolation of the floor system.

These tests were then compared with impact sound testing of the bare concrete floor slab to determine the relative effectiveness (if any) of each flooring product in reducing impact noise. The comparisons were graphed across the frequency spectrum and are shown in Figure 1.

The frequency results for the engineered hardwood floor, engineered tile, timber laminate and vinyl are shown in Figures 2, 3, 4 and 5 respectively, with the results of the vinyl floor system without a structural underlay shown in Figure 6 to demonstrate the effect of the stiff structural layer on the impact isolation.

In each case the normalised, weighted field impact sound isolation $L'_{nT,w}$ was calculated and these results are included with the graphs. In this relation, the impact sound insulation performance of a system as defined in ISO 140.7 and is denoted by a single value descriptor, the weighted impact sound insulation $L_{n,w}$ (for laboratory tested rating) or $L'_{nT,w}$ (for field tested rating). The lower the number, the better the impact sound insulation performance. The single value descriptor allows for easy comparisons between different systems and has therefore been used throughout this study.

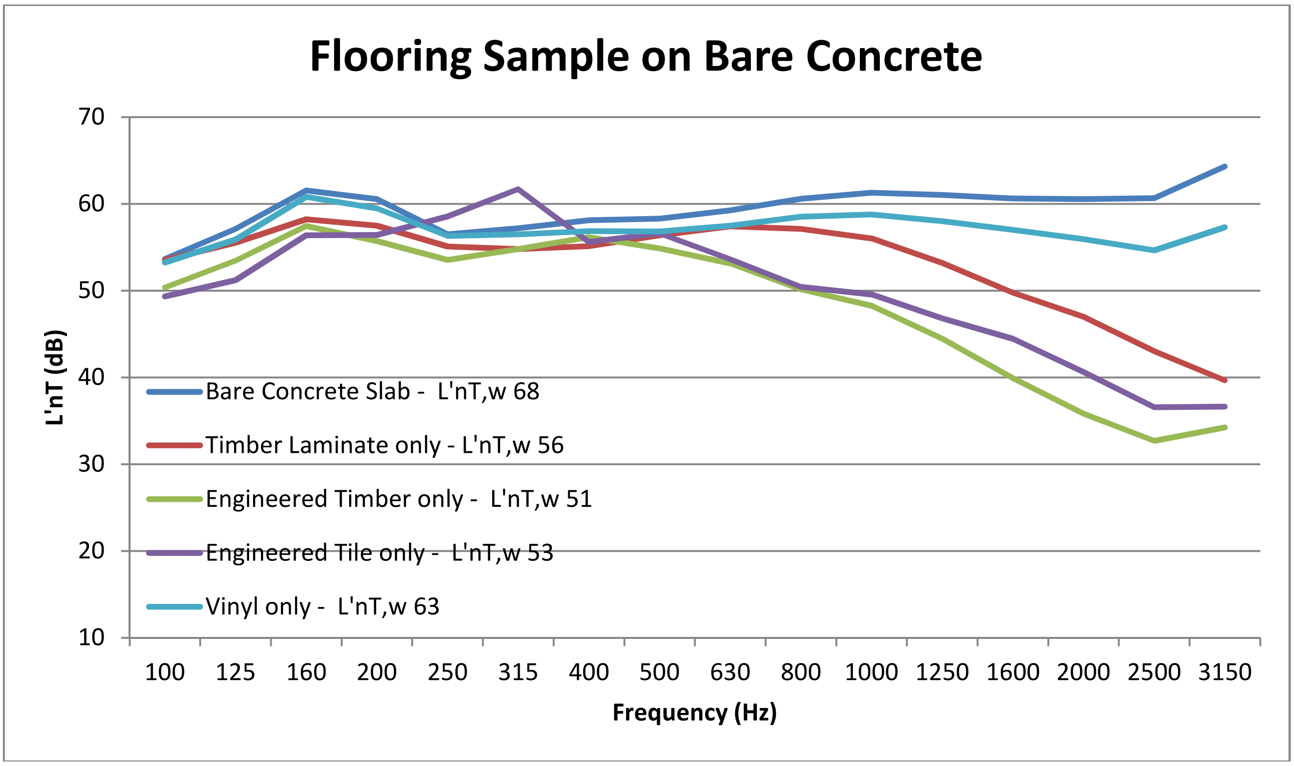

Figure 1: Flooring impact sound isolation comparison

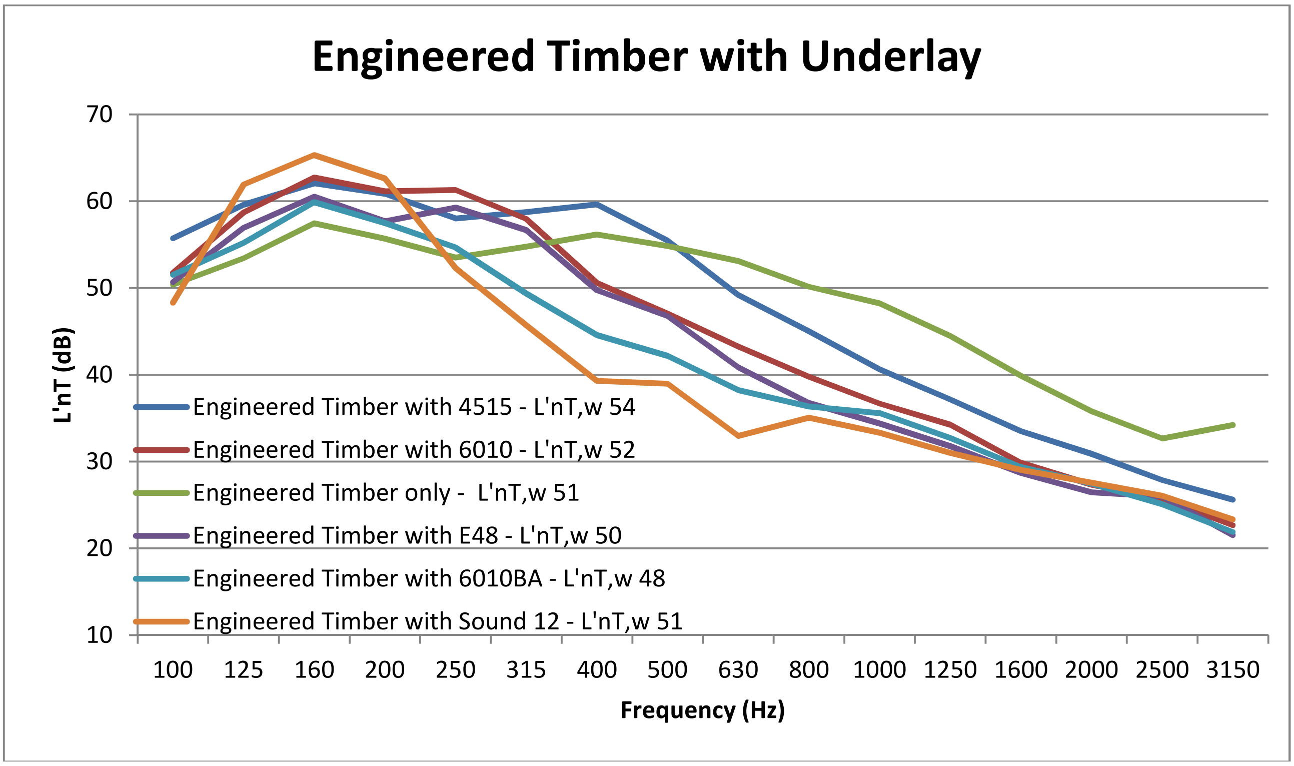

Figure 2: Engineered timber impact sound isolation

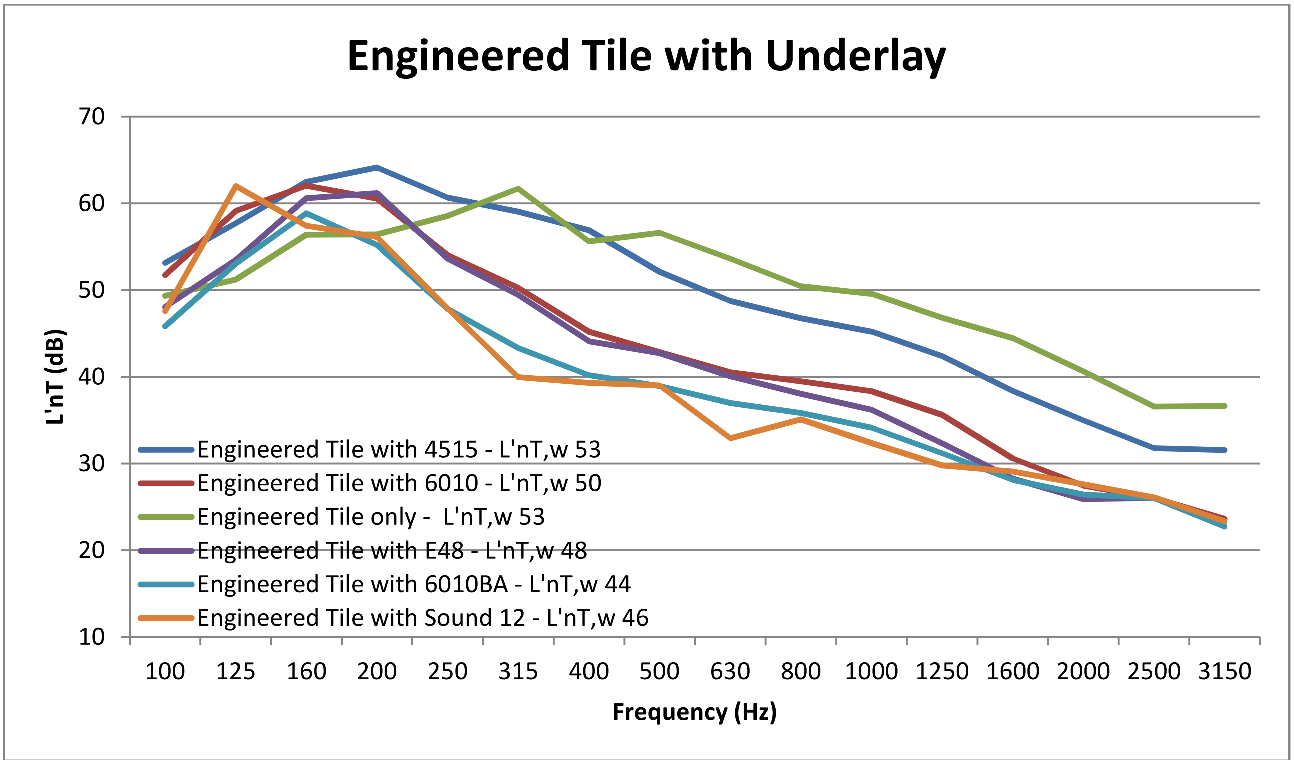

Figure 3 : Engineered tile impact sound isolation

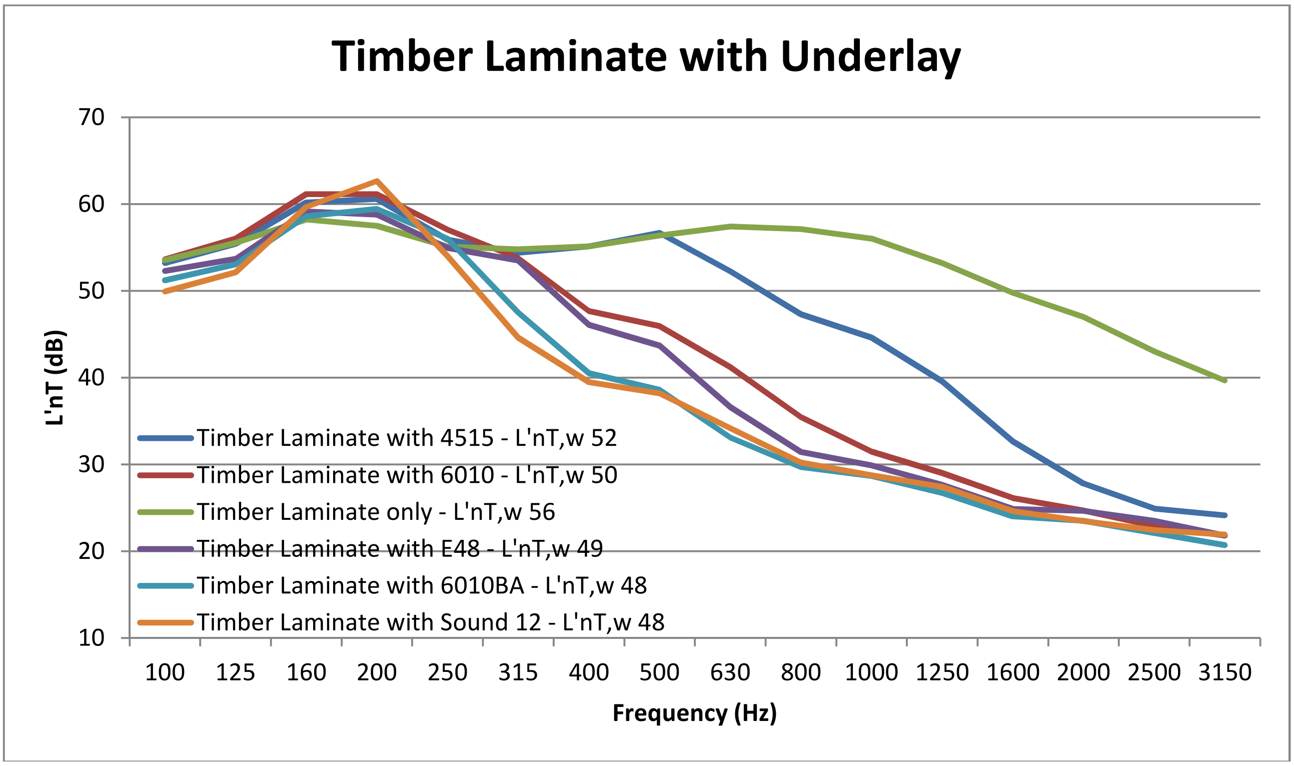

Figure 4: Timber laminate impact sound isolation

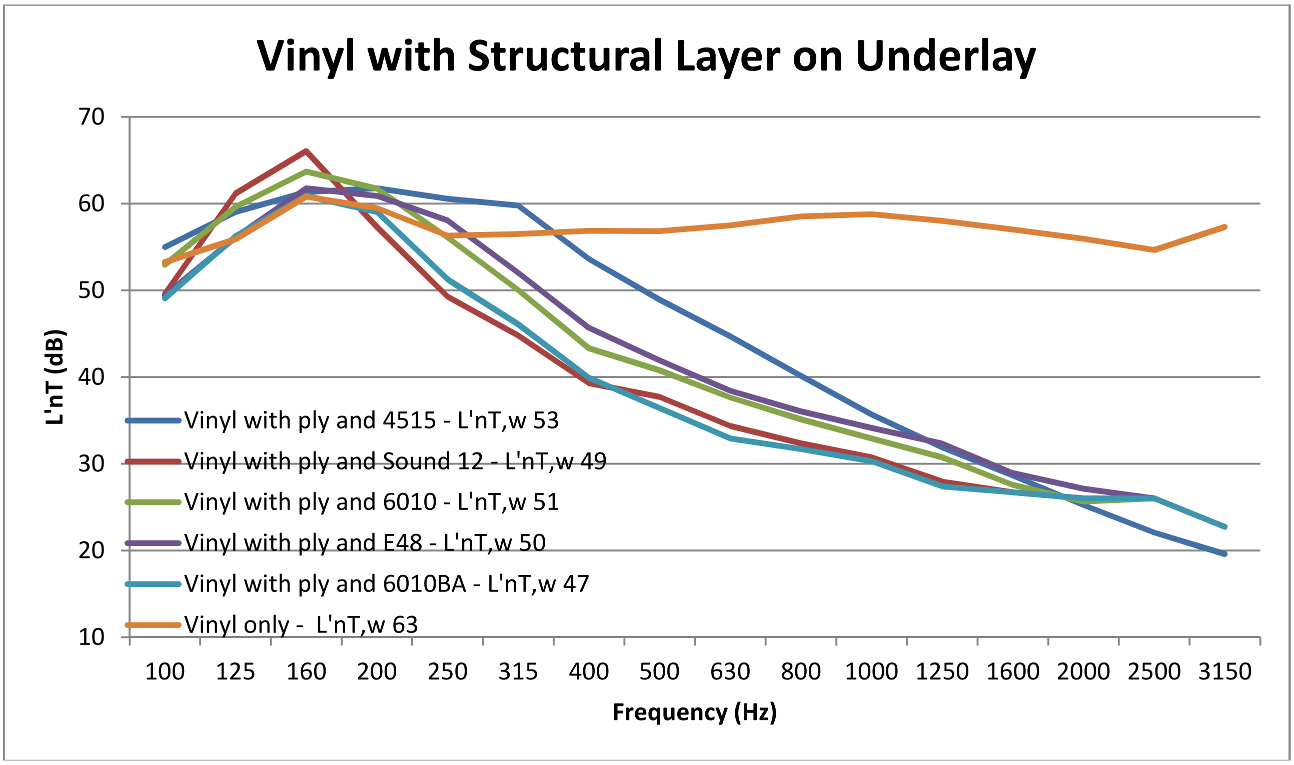

Figure 5: Vinyl impact sound isolation with structural layer

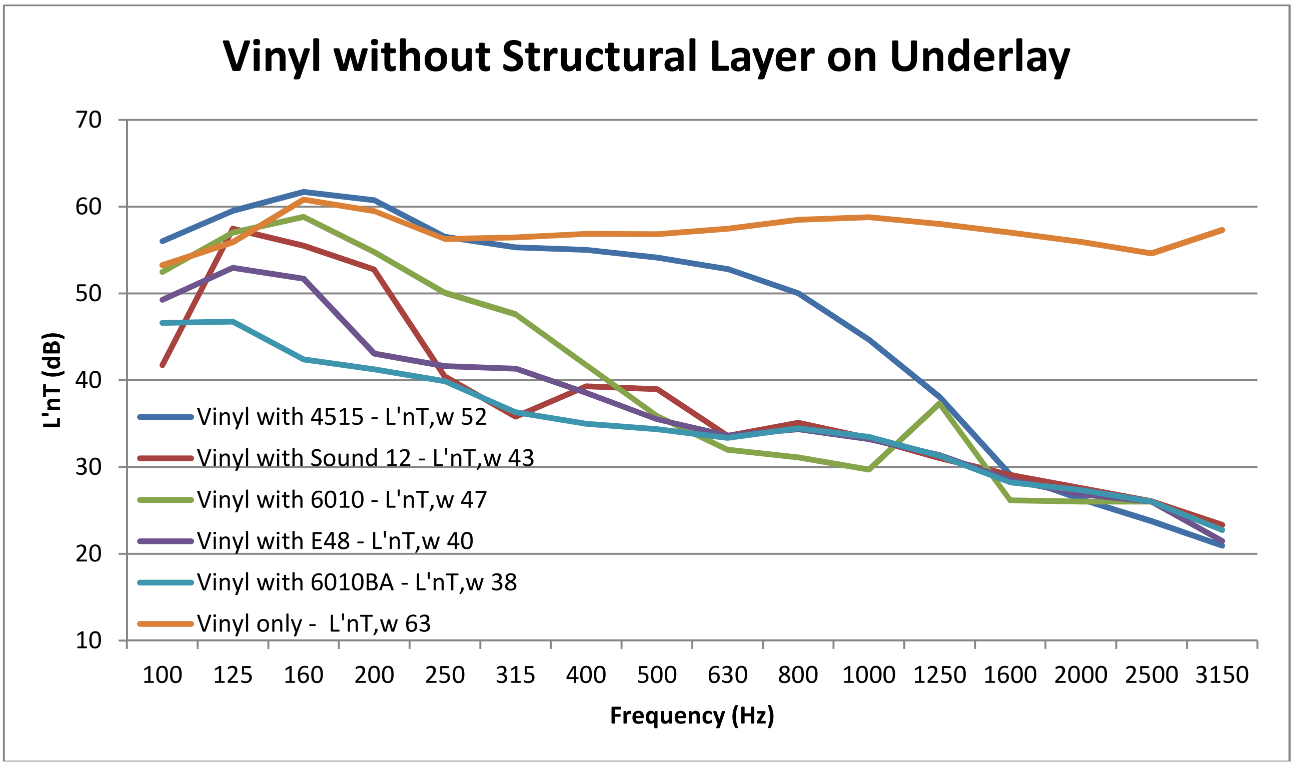

Figure 6 : Vinyl impact sound isolation without structural layer

The results of the timber laminate, engineered timber and engineered tile, with and without resilient underlay, in the frequency range from 100 Hz to 250 Hz is shown in Figure 7.

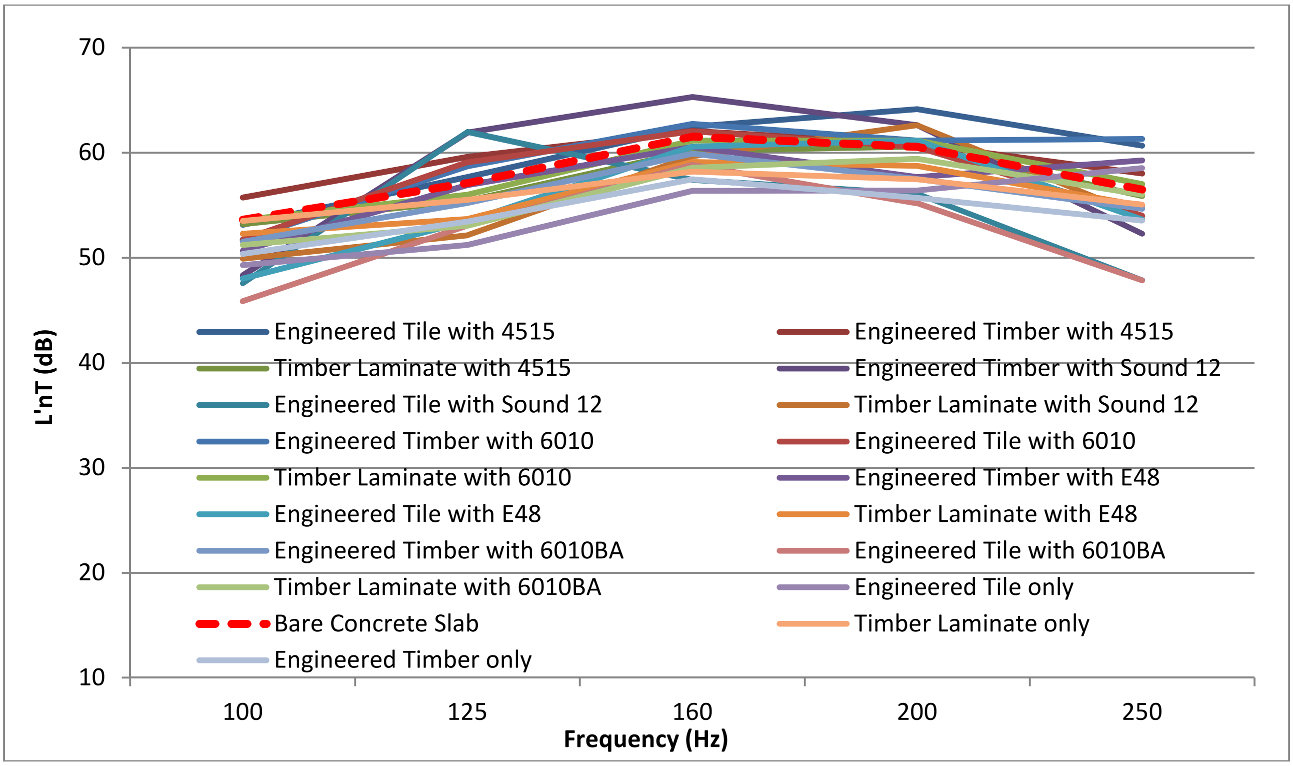

Figure 7: Comparison of low frequency performance

5 DISCUSSION OF RESULTS

5.1 Flooring Products without Underlay

The results of the flooring product impact tests (without resilient underlay) are shown in Figure 1. As may be seen, the most effective overall impact isolation was provided by the engineered timber product ($L'_{nT,w}$ 51) while the vinyl was least effective ($L'_{nT,w}$ 63), an improvement of 5 dB on the concrete slab ($L'_{nT,w}$ 68).

There is a maximum of 5 dB separating the flooring results in Figure 1 at 250 Hz, while the greatest difference between the tests results is shown to be above 630 Hz, with the results ranging by up to 30 dB at 3150 Hz. The $L'_{nT,w}$ third octave spectra show little difference below 500 Hz, with the exception of a peak at 315 Hz for the engineered tile results. In contrast to the low frequencies, the mid to high frequencies above 500 Hz show a clearly noticeable difference in the $L'_{nT,w}$ results of each flooring product.

5.2 Flooring Products with Underlay

With the exception of Regupol 3 mm 4515 and 10 mm 6010 underlay, all the flooring products performed better with the addition of a resilient underlay. The most effective impact isolator on the concrete slab with a resilient underlay is vinyl with the 6010BA underlay with $L'_{nT,w}$ 38, however due to the lack of a structural layer this is not a practical option. The least effective combination was the engineered timber with the 4515 resilient underlay, $L'_{nT,w}$ 54.

After the vinyl products, the second most effective flooring product is engineered tile with the 6010BA underlay, which achieved $L'_{nT,w}$ 44 . The least effective resilient underlay with engineered tile is the 4515 with $L'_{nT,w}$ 53, which is no improvement on the $L'_{nT,w}$ of the engineered tile system with no underlay.

When comparing the impact isolation performance across the frequency spectrum of the engineered tile system with and without 4515 underlay in Figure 3, it can be see that the addition of 4515 underlay decreases the impact isolation at low frequencies. It can also be seen that the addition of 4515 underlay marginally improves the impact isolation at frequencies above 400 Hz. This would suggest that the resonance of the mass and spring system with the 4515 underlay decreases the impact isolation around 200 Hz, while the region of isolation of the mass and spring system with the 4515 is above 400 Hz. The minimal increase (low frequency) and decrease (high frequency) in impact isolation provided by the 4515 underlay cancel each other to result in an identical $L'_{nT,w}$ result ($L'_{nT,w}$ 53) as that of the engineered tile system without any underlay.

When comparing the performance of each underlay with the various flooring samples, on average the 6010BA resilient underlay with the various flooring products achieved the best impact isolation results, with an average of $L'_{nT,w}$ 45. The 4515 resilient underlay achieved the worst impact isolation results with an average of $L'_{nT,w}$ 52.

The results suggest that the profile of the resilient underlay has a significant effect on the transmission of impact noise and vibration. For example the E48 product which has a dimpled profile and a thickness varying between 8 mm and 4 mm, out performs 6010, which has a flat profile and is 10 mm thick.

When comparing the performance of each flooring product with the various underlay samples, on average the engineered tile flooring systems, with the various resilient underlays, achieved the best impact isolation results with an average of $L'_{nT,w}$ 48. In contrast, the engineered timber flooring product with the various resilient underlays achieved the worst impact isolation results, with an average of $L'_{nT,w}$ 51.

5.3 Low Frequency Performance

All the flooring products results with and without a resilient underlay, with the exception of vinyl without a structural layer, displayed little difference in the low frequencies. This point is highlighted in Figure 7, which displays the 100 Hz to 250 Hz results of all the tested samples. The uniformity of the results, and the inability of the various types of floor systems to affect the low frequency impact sound isolation, would support the research of Neves e Sousa and Gibbs (2011, 2014), Hui and Ng (2009), and Cho (2013), as mentioned in Section 2.2. The results discussed may indicate that the low frequency performance of a floor system is governed by the characteristics of the supporting concrete slab, which is unaffected by the flooring and resilient underlay sample.

The fact that the majority of the results below 250 Hz in Figure 7 are lower than the bare concrete slab results, while still maintaining the same shape, may be explained by Ford and Hothersall's (1974) research as discussed in Section 2.2. The results validate the damping provided by the flooring product and its reduction in the force characteristics of the tapping machine.

The exception to this trend is shown in the results of the vinyl flooring with a resilient underlay and no structural layer. Comparing Figures 5 and 6 demonstrates that floor systems without rigidity have the greatest low frequency impact isolation and that the introduction of a structural layer nulls this effect.

5.4 Similar Results between 6010BA and Sound 12

From Figures 2 to 5. It can be seen that the L'_{nT} spectra for each flooring sample, with either 6010BA or Sound 12 underlay are very similar. The L'_{nT} results of the engineered tile and timber laminate across the frequency spectrum in Figures 3 and 4 respectively for Sound 12 and 6010BA, are almost identical. However, on the bare concrete the L'_{nT} results of engineered tile and timber laminate in Figure 1 have few similarities, which would suggest the similar results in Figures 3 and 4 are due to the properties of the underlay.

The similarities across the frequency spectrum of the vinyl and engineered timber with 6010BA and Sound 12 are almost replicated with the exception of the differences in the low frequency range below 250 Hz, which are shown in Figures 2 and 5. The similarity in results is hard to explain when the parameters of the materials are compared in Table 1.

Both 6010BA and Sound 12 have dimpled profiles, with their thickness varying from 17 mm to 8 mm, but this is where the similarities end. 6010BA is significantly more dense than Sound 12. Sound 12 has more elasticity than 6010BA, as its elongation at break is double that of 6010BA. Sound 12 has a tensile strength of 0.12 N/mm^2, while 6010BA has a tensile strength of 0.5 N/mm^2. As discussion previously, resilient underlays with a dimpled profile outperform those with a flat profile despite thickness. This thickness and profile of 6010BA and Sound 12 may explain the correlation between the results, regardless of the material composition.

5.5 Loading Test Samples

The 4515 resilient underlay's best performing system is with timber laminate with an impact sound insulation of $L'_{nT,w}$ 52, and its worst performing system is with engineered tile with an impact sound insulation of $L'_{nT,w}$ 53. Due to the results of the engineered tile with 6010BA or Sound 12, it would be expected that the more dense engineered tile would provide greater isolation. A possible explanation of the engineered tile poorer results with 4515, is the effect of the weight loading of resilient samples during tests and its effect on the stiffness of the material, which would agree with the research by Schiavi et al. as discussed in Section 2.1. Further testing of the same sample floor systems with varying amounts of load may demonstrate this point.

Although the vinyl flooring systems without a structural layer may not be practical, the floor systems achieved the most favourable results with all the underlay samples. The vinyl results are conflicting, as the vinyl on the bare slab was the worst flooring product while the vinyl directly on top of the resilient underlays performed the best. The vinyl flooring is the thinnest and most flexible of the samples and would be expected to achieve good impact isolation due to its elasticity. However, results would indicate that due to the flexibility and thickness of the vinyl flooring sample, the pulse generated from the tapping machine is efficiently transmitted through the vinyl and results in poor impact isolation performance of systems without a resilient underlay.

6 SUMMARY AND FUTURE WORK

6.1 Summary

Five resilient underlays were tested, with thicknesses varying between 3 mm and 17 mm. Three of the resilient underlay's consisted of rubber material, one of the resilient underlays consisted of a combination of polyurethane foam granulates and cork and the remaining resilient underlay consisted of polyurethane-bound elastomers. The four flooring products tested were an engineered tile system, engineered timber, timber laminate and vinyl.

The impact sound insulation results confirm previous work in studies of vibration transmission at low frequencies suggesting the concrete slab dimensions determine the amount of energy transmitted at low frequencies. Two of the resilient underlays, 6010BA and Sound 12, achieved very similar results despite having largely different material compositions, with the exception of an identical thickness and profile. This comparison has led to the conclusion that the profile of resilient underlay has a significant impact on the product's performance.

6.2 Future Work

The question of the effect of loading on the stiffness of the resilient underlay raised in Section 5.5 may be further investigated by the authors conducting follow up testing with samples under various loads and observing the results.

The similarity of the resilient underlay 6010BA and Sound 12 results despite their lack of common properties, discussed in Section 5.4, could further be investigated by gathering more data on the characteristics of each sample. Only the five tested characteristics presented in Table 2 were offered by the manufacturer. Numerous measurement points are available to quantify these resilient underlays.

The effect of profile of the resilient underlay as discussed in Section 5.4, could be further investigated by the authors, through testing of resilient underlays with identical thickness and varying profiles.

The acoustic measurements detailed in this paper where conducted without any adhesives between the concrete sub structure, the resilient underlay or the flooring sample. To eliminate any large differences between this series of testing and results expected onsite, the samples should be retested with all underlays and flooring samples glued as per manufacturers' specifications.

Lastly, the vinyl product displayed excellent results when tested without a structural layer between the vinyl and the underlay. Vinyl without a structural layer is not preferred in practice as the flexibility of the vinyl sheet on top of a resilient underlay, allows for too much compression underfoot. The vinyl product may be redesigned to be more practical by incorporating a stiff honeycomb skeleton integrated into the design of the vinyl sheet. Under load such as foot fall, the skeleton structure will spread the weight across the entire sheet, reduce compression and remove the need for an additional structural layer.

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