Floor airborne and impact sound insulation performance of cross laminated timber vs. timber joist and concrete systems

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ABSTRACT

Cross laminated timber (CLT) is a modern building material which is gaining increasing application in Australian and New Zealand building developments. It is used as a structural wall and floor element, and has certain advantages over traditional building methods utilising concrete floors, particularly relating to the speed with which CLT structures can be constructed on-site. One disadvantage of CLT is that the base timber floor panel has less mass per square meter than concrete. Therefore, CLT typically requires additional layers of material (ceilings and raised floors) to achieve airborne and impact sound insulation performance similar to that of concrete floors and, indeed, to meet Building Code requirements. This paper explores a range of on-site test results obtained from two similar CLT apartment buildings. Standard airborne and impact sound insulation results ($D_{nT,w}$, FSTC, $L_{nT,w}$ and FIIC) are presented, as well as heavy impact results obtained using a "Japanese ball drop" method ($L_{iA,Fmax}$) to assess the low-frequency performance of the CLT floors. Various flooring upgrades were tested with the aim of improving the sound insulation performance of the floors. Test results from other apartment buildings with a mixture of concrete floors and timber joist floors are also presented and compared to the CLT floor results.

1 INTRODUCTION

Cross Laminated Timber (CLT) is a modern building material produced by glue-laminating planks of timber together and layering these in perpendicular directions to form a highly rigid, multi-layered, panel (akin to large-scale plywood). The CLT panels can be easily machined in the factory with a high degree of accuracy to form structural wall, floor, facade and roof elements. Prefabrication of such elements is one significant advantage of CLT over more traditional construction methods utilising concrete structural elements, which leads to reduced construction times on-site.

Compared to concrete, however, CLT has relatively low surface mass (kg/m^2). This is a key material property which dictates the sound insulation performance of a dividing element (wall, floor, etc.). The thickness of CLT in apartments is typically 100-200mm, with a surface mass of between 40 and 100kg/m^2; compared to that of a concrete apartment floor's surface mass, which is normally between 240 and 480kg/m^2. The CLT, however, is significantly heavier than the layer of plywood or particle board typically found as the structural flooring membrane on other "lightweight" apartment timber joist floors.

The primary aim of this paper was to assess the relative airborne and impact sound insulation performance of CLT versus concrete or timber joist floors, and to determine the type of flooring upgrades which would be required to obtain Australian and New Zealand Building Code compliant results for each floor system. A further aim was to determine whether the lightweight (CLT and timber joist) floors can achieve similar low frequency impact insulation performance to that of concrete floor systems.

2 TESTED APARTMENT FLOOR TYPES

This study focussed on the comparison of in-situ acoustic performance of floors separating apartments in four apartment buildings that contained varying floor constructions. Two of the buildings were largely identical and constructed with CLT as the primary structure (internal walls, floors, roof and facade). The third and fourth buildings contained both concrete floors and timber joist floors.

In all tested floor samples, the separating floor area and receiving room volume were relatively large, i.e., greater than 23m^2 and 61m^3, respectively, and therefore deemed suitable to assess the low-frequency performance of the floors with reasonable accuracy.

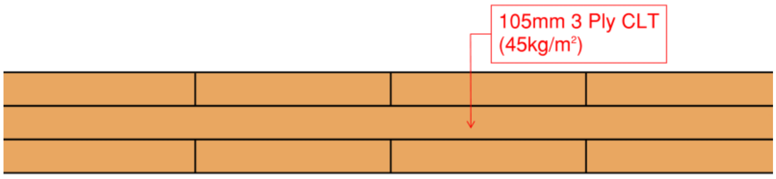
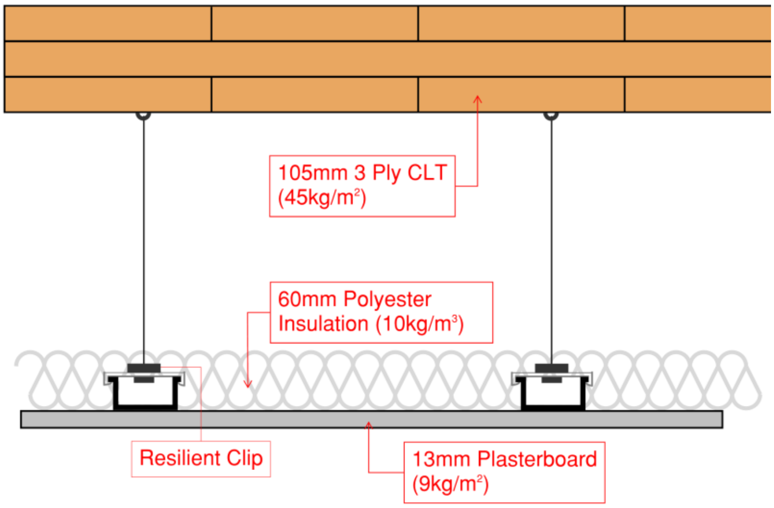
3 CONCRETE VS LIGHTWEIGHT APARTMENT FLOORS

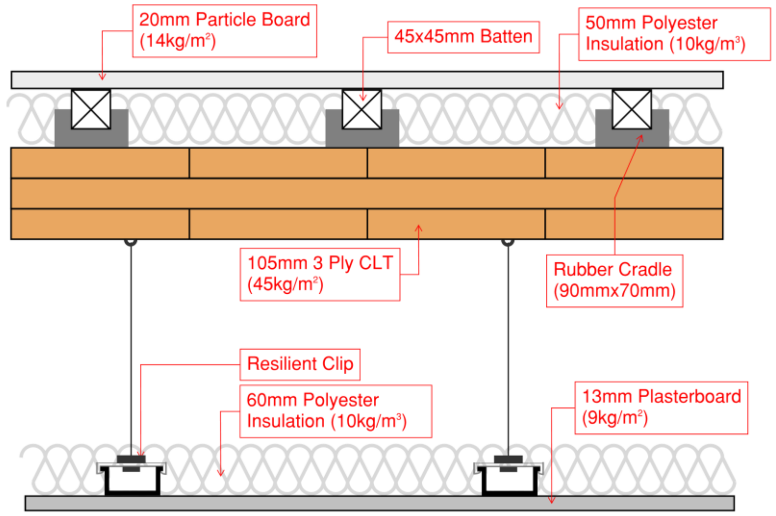
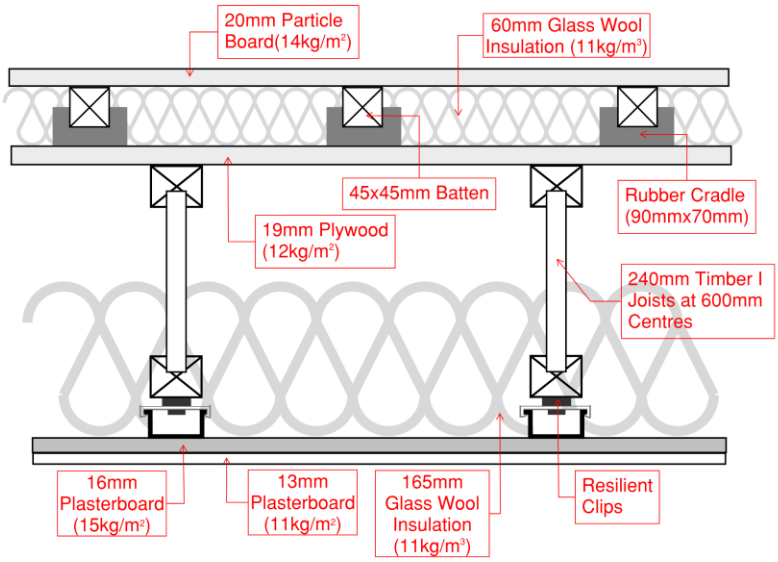
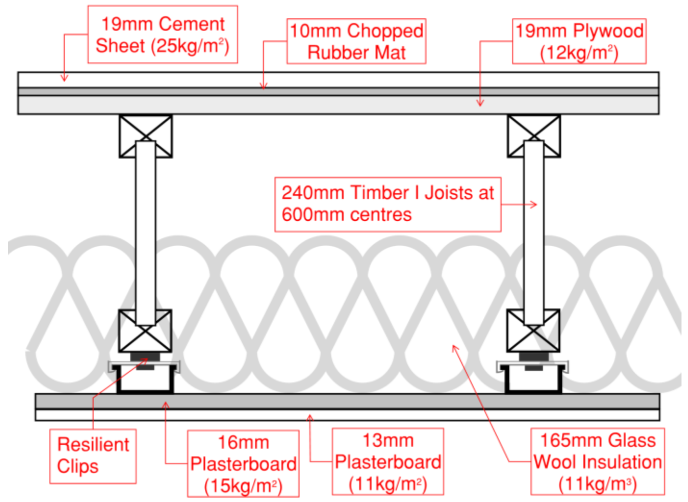
In the context of this study, the concrete floor system tested was taken to represent the benchmark of acoustic performance in apartment buildings, since this is historically the most common floor structure used in Australian and New Zealand apartments. Ideally, CLT or timber joist floors would be designed and constructed such that their performance was no worse than that of concrete, however, achieving good low-frequency performance from relatively lightweight floor systems often proves costly or impractical.

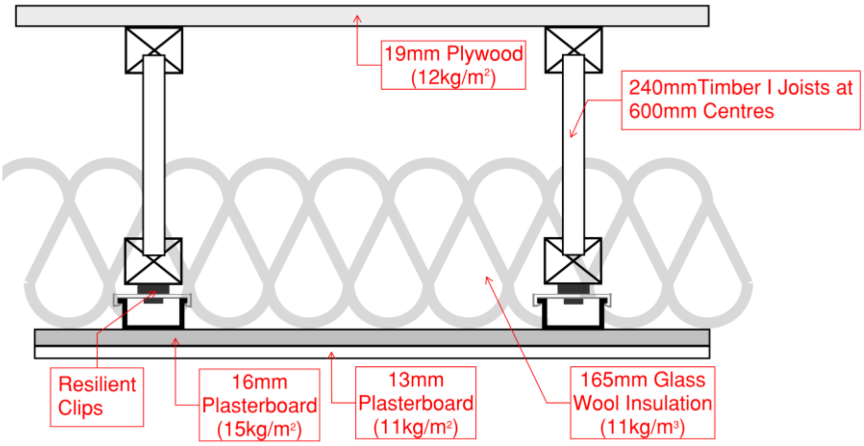
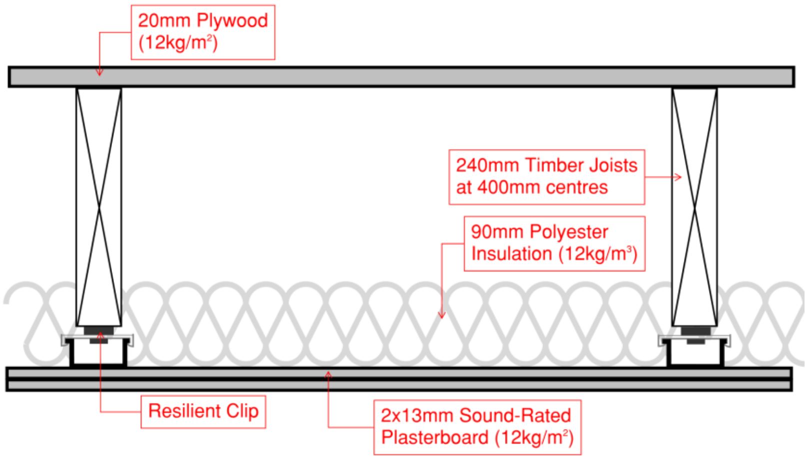
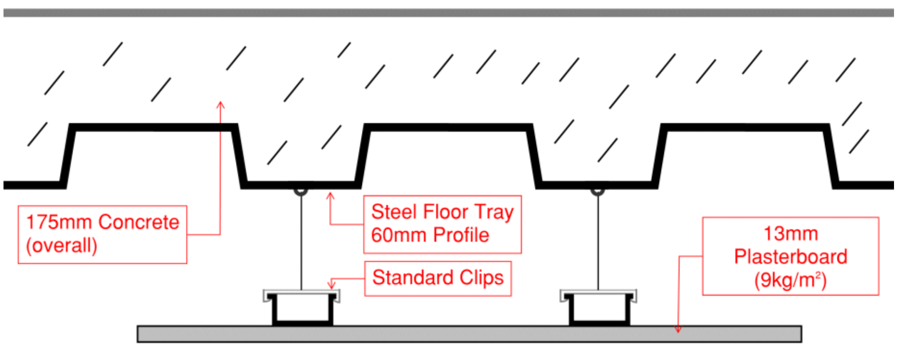
4 FLOOR CONSTRUCTION DETAILS

The diagrams below outline the key elements which make up each of the tested floor constructions.
Flanking of the CLT floors via the structural CLT walls was not considered to be a limiting factor in these tests since all CLT walls were lined with separate plasterboard layers.

Table 1: Construction diagrams for the eight tested floors

Test ID	Construction Details
① 105mm CLT (no ceiling)	
② 105mm CLT + suspended PB ceiling on resilient clips	

Test ID	Construction Details
③ 20mm particle board raised floor + 105mm CLT + suspended PB ceiling on resilient clips	
④ 20mm particle board raised floor + 19mm plywood + timber I joists + 2xPB ceiling on resilient clips	
⑤ 19mm cement sheet + 10mm chopped rubber mat + 19mm plywood + timber I joists + 2xPB ceiling on resilient clips	

<table>
<tr><th>Test ID</th><th>Construction Details</th></tr>
<tr><td>⑥
19mm plywood + timber I joists + 2xPB ceiling on resilient clips</td><td>
</td></tr>
<tr><td>⑦
20mm plywood + timber joists + 2xPB ceiling on resilient clips</td><td>
</td></tr>
<tr><td>⑧
175mm concrete on 60mm profiled tray + suspended PB ceiling</td><td>
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5 ASSESSMENT CRITERIA AND METHODOLOGY

The various floors were each assessed against the airborne and impact sound insulation performance metrics found in the Building Code of Australia (BCA) and the New Zealand Building Code (NZBC). Additionally, assessing the low-frequency performance of these floors was of particular interest. Because the standard tapping machine impact tests described in the ISO and ASTM standards (refered to in the BCA and NZBC) are unsuitable for assessing very low-frequency floor impact performance, the “Japanese ball drop” heavy impact source method was used to give a simple, yet standardised, assessment procedure. This type of floor impact test is intended to be representative of heavy and soft impacts, such as jumping and the running around of children (JIS A 1418-2: 2000).

The assessment methods used were as follows:

- **$D_{nT,w}$ + C_{tr}**: Weighted standardised level difference with spectrum adaptation term determined according to ISO 717.1-1996 (BCA Part F5 2016 requirement)
- **FSTC**: Field Sound Transmission Class determined according to ASTM E 336 - 90 and ASTM E 413 - 87 (NZBC G6 1992 requirement)
- **$L_{nT,w}$**: Weighted standardised impact sound pressure level determined according to ISO 717.2-2004 (BCA Part F5 2016 requirement)
- **FIIC**: Field Impact Insulation Class determined according to ISO 140/VII-1978 and ASTM E 989 - 89 (NZBC G6 1992 requirement)
- **$L_{iA,Fmax}$**: Maximum A-weighted floor impact sound level (octave bands 31.5Hz to 500Hz) determined according to JIS A 1418-2: 2000 using the rubber ball drop method and JIS A 1419-2: 2000 Annex 2

The minimum Building Code on-site performance requirements for apartment floors are as follows:

- BCA airborne: Not less than $D_{nT,w}$ + C_{tr} 45dB
- BCA impact: Not greater than $L_{nT,w}$ 62dB
- NZBC airborne: Not less than FSTC 50
- NZBC impact: Not less than FIIC 50
- No $L_{iA,Fmax}$ criteria under either Building Code

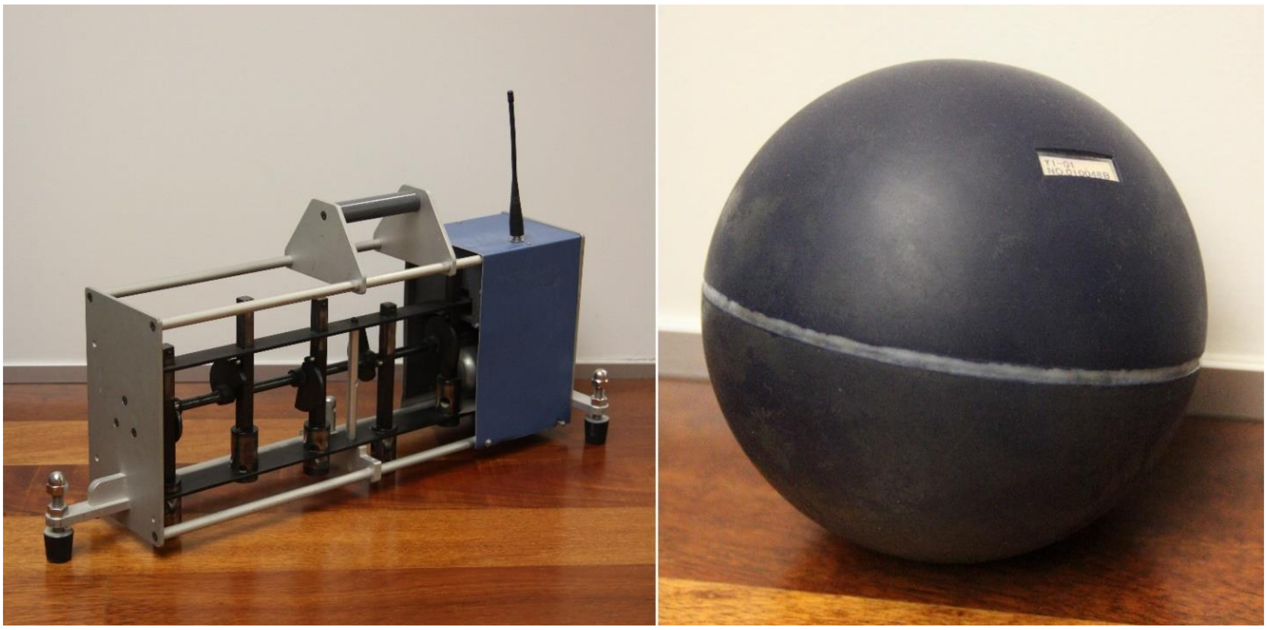

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Figure 1: Tapping machine (left) and standardised rubber ball (right) used during floor impact testing.

6 RESULTS

The graphs and tables below summarise the measured results. For conciseness in Figure 2 below, the apparent sound reduction index, R'_w, has been plotted in place of the BCA required $D_{nT,w}$. Similarly, in Figure 3 below, the normalised impact sound pressure level, $L'_{n,w}$, has been plotted in place of the BCA required $L_{nT,w}$. In both cases the graphed results still show the general trends in sound insulation performance relative to the reference contours. Note that the airborne sound insulation for floor Tests 6 and 7 was not measured.

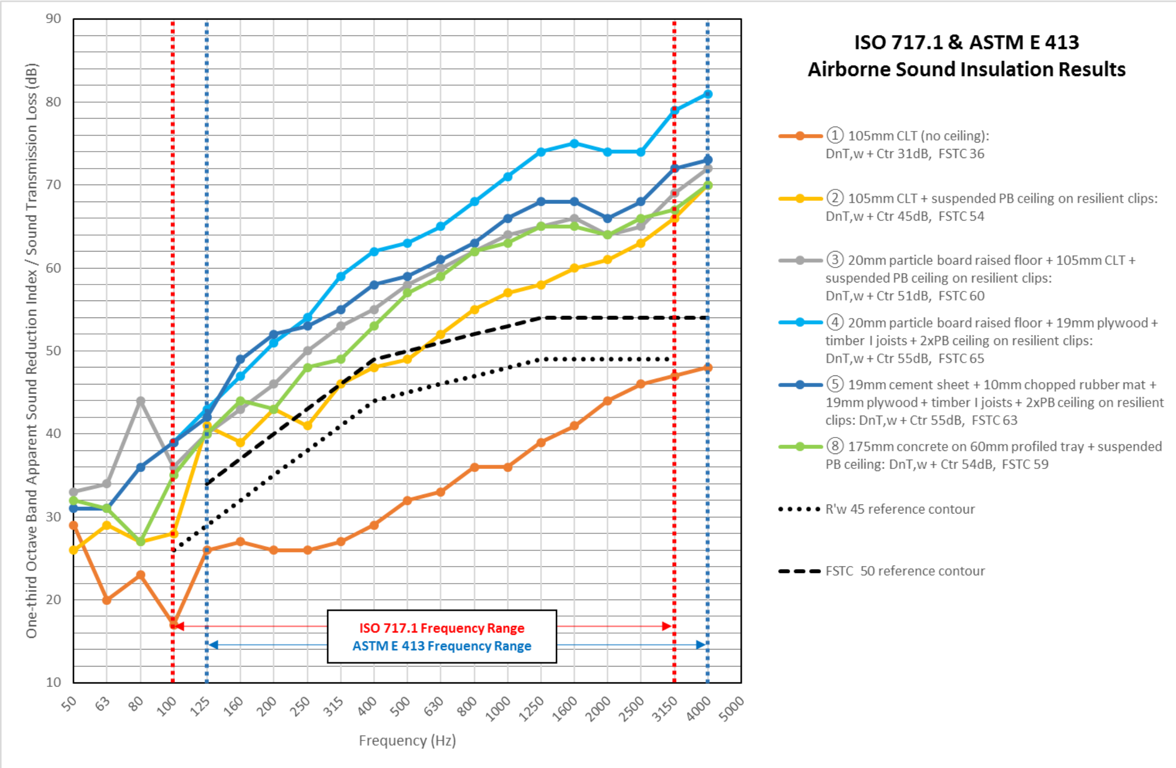

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Figure 2: Measured airborne sound insulation results for various floor constructions

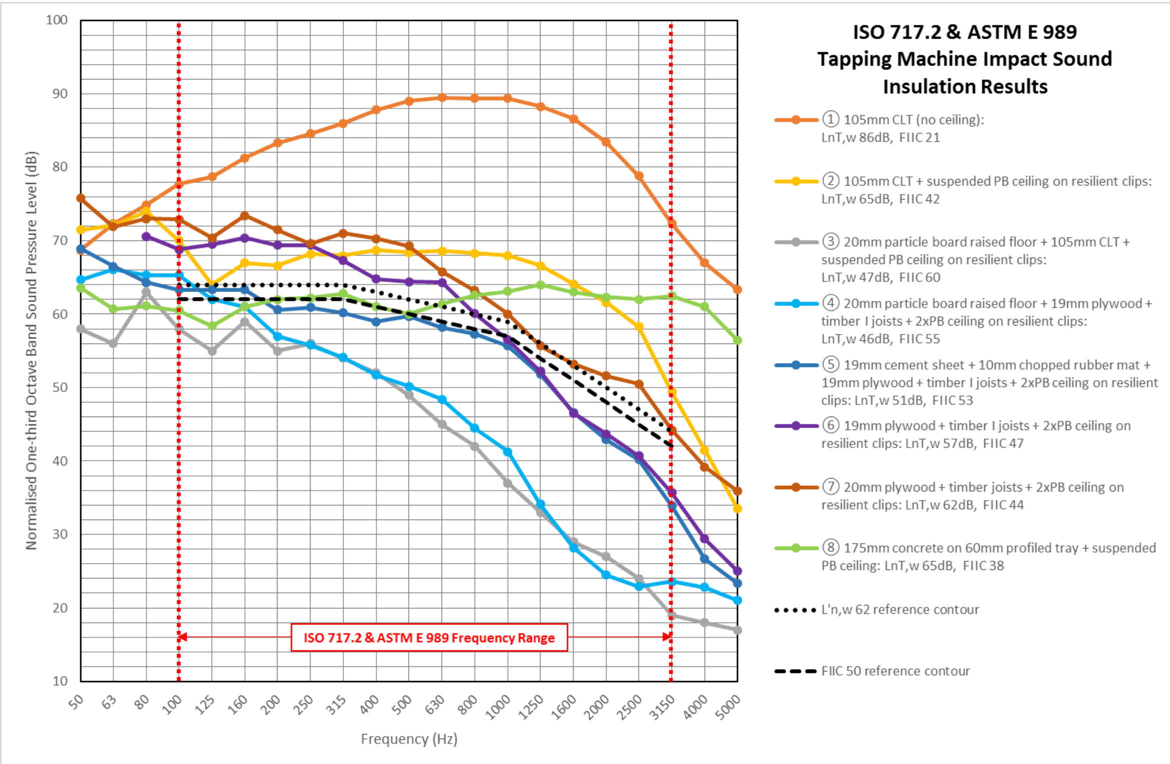

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Figure 3: Measured tapping machine impact sound insulation results for various floor constructions

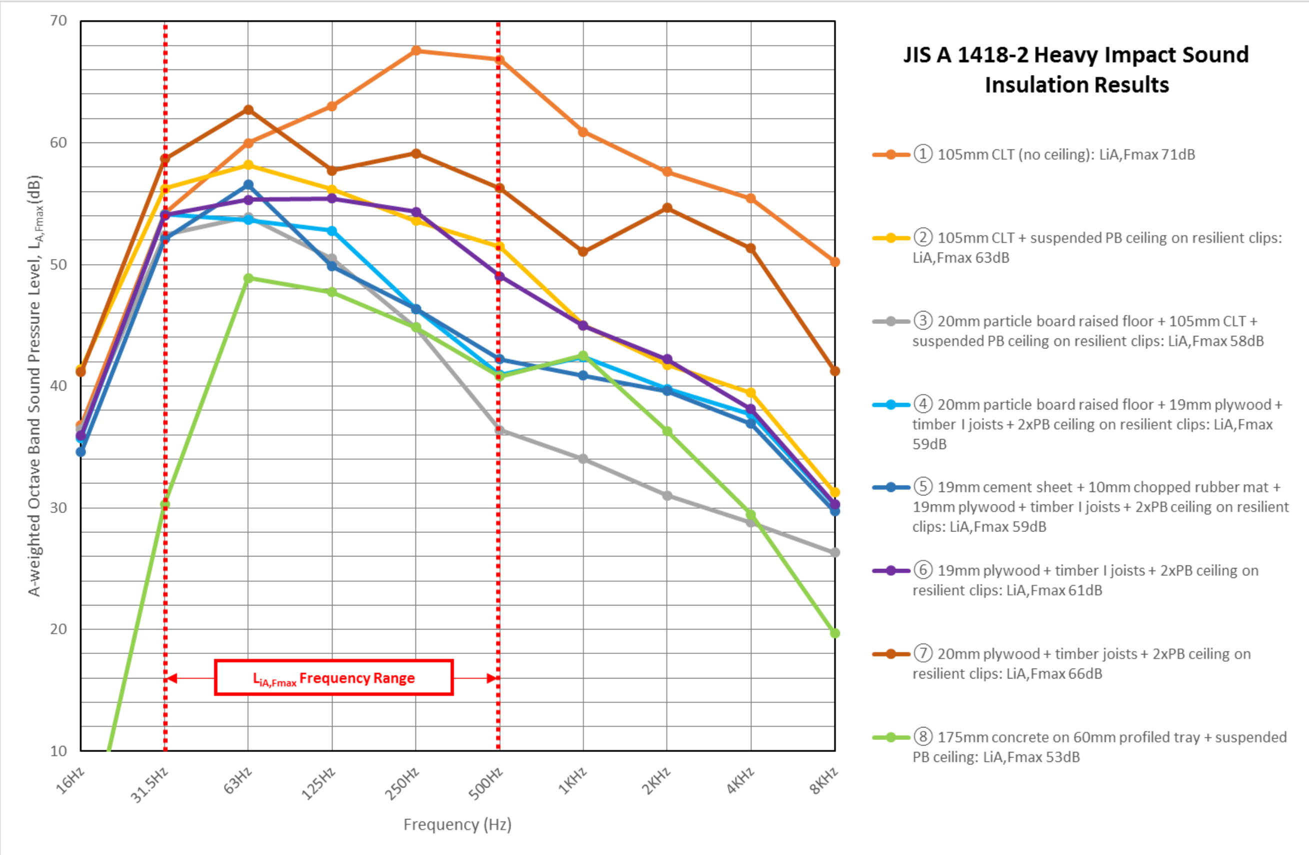

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Figure 4: Measured heavy impact sound insulation results for various floor constructions

Table 2: Summary of measured results

Test ID	Description	$D_{nT,w} + C_{tr}$	FSTC	$L_{nT,w}$	FIIC	$L_{iA,Fmax}$
①	105mm CLT (no ceiling)	31	36	86	21	71
②	105mm CLT + suspended PB ceiling on resilient clips	**45**	**54**	65	42	63
③	20mm particle board raised floor + 105mm CLT + suspended PB ceiling on resilient clips	**51**	**60**	**47**	**60**	58
④	20mm particle board raised floor + 19mm plywood + timber I joists + 2xPB ceiling on resilient clips	**55**	**65**	**46**	**55**	59
⑤	19mm cement sheet + 10mm chopped rubber mat + 19mm plywood + timber I joists + 2xPB ceiling on resilient clips	**55**	**63**	**51**	**53**	59
⑥	19mm plywood + timber I joists + 2xPB ceiling on resilient clips	-	-	**57**	47	61
⑦	20mm plywood + timber joists + 2xPB ceiling on resilient clips	-	-	**62**	44	66
⑧	175mm concrete on 60mm profiled tray + suspended PB ceiling	**54**	**59**	65	38	53

For clarity, in the $D_{nT,w} + C_{tr}$, FSTC and FIIC tests above, a higher value represents better sound insulation. Conversely, in the $L_{nT,w}$ and $L_{iA,Fmax}$ tests, a lower value represents better sound insulation. The results are colour coded from worst (red) to best (green) sound insulation. Values in bold are compliant with the relevant Building Codes.

7 DISCUSSION

7.1 Airborne sound insulation results ($D_{nT,w} + C_{tr}$ and FSTC)

Not surprisingly, the bare CLT with no ceiling (Test 1) provided the poorest airborne sound insulation performance due to it being a single, relatively lightweight panel (Figure 2). Adding an additional panel to this, i.e. the ceiling (Test 2), improved the performance to the point where Building Code compliance was just achieved. Adding a third panel, i.e. the raised or resiliently supported floors (Tests 3, 4 and 5), further improved the airborne insulation to a level which could be considered very good. The concrete floor with ceiling (Test 8) performed similarly to the three-panel floors (Tests 3, 4 and 5) simply due to the large mass of concrete.

Although not assessed, it is estimated that bare plywood-on-timber-joist floors (Tests 6 and 7) would achieve airborne sound insulation compliance for both the BCA and NZBC.

7.2 Tapping machine impact sound insulation results ($L_{nT,w}$ and FIIC)

Again, the bare CLT with no ceiling (Test 1) did not provide good impact insulation (Figure 3). Adding a ceiling beneath the CLT floor (Test 2) improved its performance, making it comparable with the concrete floor with ceiling (Test 8). However, the spectrum shape of these two results is quite different, as can be seen in Figure 3. The concrete floor exhibits a characteristic flat spectrum, and the single-number ratings ($L_{nT,w}$ and FIIC) are limited by the floor's poor high-frequency performance. As is common practice, resilient floor finishes or underlays are required to improve the high-frequency performance of the concrete floor's impact insulation. The CLT floor with ceiling (Test 2), however, exhibited its main deficiencies in the mid-frequencies, with comparatively good high-frequency performance. This is due to the timber providing a degree of cushioning (absorption) of the tapping machine hammer impacts. Neither Test 2 nor Test 8 were compliant with Building Code requirements, so further upgrades would be required if used as the floor between apartments.

The remaining CLT and timber joist floors (Tests 3, 4, 5, 6 and 7) were all compliant with BCA impact requirements, although, interestingly, only those floors with upgraded top surfaces (Tests 3, 4 and 5) were compliant with NZBC impact requirements. The floors with bare plywood as the topping (Tests 6 and 7) fell reasonably short of NZBC compliance, highlighting the more onerous requirements under the NZBC for floor impact insulation compared to the BCA. It is the authors' opinion that the timber joist floors in Tests 6 and 7 would be deemed subjectively unacceptable by a large proportion of apartment dwellers who might live beneath such an intertenancy floor.

Overall, the best performing floor in this group of tests was the CLT floor, upgraded with a suspended plasterboard ceiling, and a raised particle board floor on top (Test 3).

7.3 Heavy impact sound insulation results ($L_{iA,Fmax}$)

As expected, the concrete floor with ceiling (Test 8) performed the best under the heavy impact test; in fact, significantly better (at least $L_{iA,Fmax}$ 5dB better) than all of the CLT and timber joist floor constructions. This indicates that there is really no substitute for mass in a flooring system for protecting against low-frequency footfall thumps.

Of the lightweight floors, the upgraded CLT with suspended ceiling and raised floor on top (Test 3) performed slightly better than the other timber joist floors with upgrades above and below the base floor (Tests 4 and 5).

7.4 Acoustic advantages of CLT floors

As can deduced from the discussion above, CLT flooring, like almost all other floor systems, requires upgrades from the base floor to achieve a reasonable level of impact sound insulation, and ultimately Building Code compliance. These upgrades will most likely involve the introduction of a ceiling below and resiliently mounted floor finish on top of the CLT panel.

Acoustically, the main advantage of using CLT as the base floor, however, is that fewer upgrades are required to achieve compliance. This can largely be attributed to the higher surface mass of the CLT base floor panel (45kg/m^2) compared to the plywood (12kg/m^2) used in the other non-concrete floor systems. Comparing the three fully compliant lightweight floor systems (Tests 3, 4 and 5), the CLT floor (Test 3) utilised a ceiling of only a single layer of standard 13mm plasterboard (9kg/m^2), compared to the timber joist floors which required two layers of heavier plasterboard (26kg/m^2 total) to achieve similar impact insulation results.

The thickness of CLT in the tested samples (3-ply 105mm) is also likely to be the thinnest CLT found in apartment floors. If thicker CLT panels were used (perhaps for structural reasons), the greater surface mass would further improve the base floor performance, meaning that less ceiling or floating floor upgrades would be required.

8 CONCLUSIONS

All of the base floor systems (whether CLT, timber joist or concrete) required both ceiling and floor topping upgrades to achieve Building Code compliance, except for the bare plywood-on-timber-joist floors (Test 6 and 7) which achieved BCA impact, but not NZBC impact compliance. The BCA-only compliance of floor Tests 6 and 7 is a function of the somewhat lower impact insulation standard required for compliance in Australian apartment buildings.

Heavy impact assessments on each floor configuration showed that the concrete floor performed significantly better than all of the lightweight floor configurations. The CLT base floor, upgraded with a ceiling and floating floor on top (Test 3), performed marginally better than the upgraded timber joist floors (Tests 4 and 5). The ceiling of the upgraded CLT floor configuration was less than half the surface mass of the timber joist ceiling.

In conclusion, the upgraded CLT floor configurations assessed in this study performed comparably to other timber joist floors that had similar or slightly greater upgrades. The 105mm thick CLT floor in this study, however, was relatively thin compared to that likely to be found on many other CLT projects. Thicker CLT floors would require fewer upgrades to meet Building Code compliance, making CLT as a base flooring material, potentially more attractive than standard timber joist floors from a sound insulation perspective.

9 FURTHER RESEARCH

Of particular interest to the authors is how the low-frequency performance of lightweight floors should be assessed and whether such floors are subjectively acceptable to apartment dwellers. The inadequacy of the tapping machine test at assessing low-frequency performance is somewhat alarming, and a repeatable and standardised method of low-frequency assessment needs to be adopted within the Australian and New Zealand acoustic industry, with some haste, as the number of lightweight-floored apartments rapidly increases.

The authors recommend that more heavy impact ($L_{iA,Fmax}$ rubber ball drop) sound insulation data is gathered from within Australian and New Zealand apartments and correlated with occupants' subjective impressions of the floors, to assist in defining appropriate low-frequency impact criteria.

Regarding the low-frequency performance of CLT, it is also of interest to conduct further research into whether a thicker, and therefore stiffer, CLT floor panel would significantly improve the low-frequency impact insulation performance of this floor type towards that of a concrete floor.

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